Technische Universität Berlin

Quality & Usability Lab, Faculty IV

Impact of auditory modality on user experience during augmented outdoor tourism navigation and exploration tasks

Master thesis

Author: Zhirou Sun
Matrnr.: 0474362
Address: Thulestraße 25, 13189 Berlin
E-Mail: zhirou.sun@campus.tu-berlin.de

First Supervisor:
Prof. Sebastian Möller
sebastian.moeller@tu-berlin.de
Second Supervisor:
Prof. Jan Niklas Voigt Antons
Jan-Niklas.Voigt-Antons@hshl.de

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Declaration of Originality:

I hereby declare that the thesis submitted is my own, unaided work, completed without any unpermitted external help. Only the sources and resources listed were used.

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Abstract

The auditory sense of humans is important when it comes to outdoor tourism navigation and exploration, yet in the domain of Augmented Reality (AR), interactions have primarily focused on the visual modality. This thesis delves into the impact of auditory modality on user experience during augmented outdoor tourism navigation and exploration tasks. To explore this, a mobile AR prototype was developed based on design rationales derived from literature research and specific experiment requirements. The study involved 20 participants, comparing two navigation modalities and two types of AR objects to assess user experience and immersion levels. The findings underscore the significance of auditory modality in providing more exciting, interesting, motivating, and novel AR experiences. The integration of spatial audio cues in navigation tasks and interactive AR objects with contextually relevant information in exploration tasks contributes to the user engagement and engrossment more than the total immersion. The results offer valuable insights into designing auditory AR applications in outdoor tourism settings, contributing to the future of engaging and immersive AR tourism experiences.

Keywords: Augmented Reality, Outdoor Tourism, Auditory Modality, Navigation Experience, Exploration Experience, AR Interaction

Zusammenfassung

Der auditive Sinn des Menschen spielt eine wichtige Rolle bei der Navigation und Erkundung im Bereich des Outdoor-Tourismus. Dennoch haben sich die Interaktionen im Bereich der Augmented Reality (AR) hauptsächlich auf die visuelle Modalität konzentriert. Diese Arbeit untersucht die Auswirkungen der auditiven Modalität auf das Benutzererlebnis während augmentierter Outdoor-Tourismus-Navigations- und Erkundungsaufgaben. Um dies zu untersuchen, wurde ein mobiles AR-Prototyp entwickelt, der auf den Designprinzipien basiert, die aus der Literaturrecherche und den spezifischen Experimentanforderungen abgeleitet wurden. Die Studie umfasste 20 Teilnehmer und verglich zwei Navigationsmodalitäten und zwei Arten von AR-Objekten, um das Benutzererlebnis und das Immersionsniveau zu bewerten. Die Ergebnisse unterstreichen die Bedeutung der auditiven Modalität bei der Bereitstellung aufregenderer, interessanterer, motivierenderer und neuartigerer AR-Erfahrungen. Die Integration von räumlichen Audiohinweisen in Navigationsaufgaben und interaktiven AR-Objekten mit kontextuell relevanten Informationen in Erkundungsaufgaben trägt mehr zur Benutzerbindung und Vertiefung bei als zur Gesamtimmersion. Die Ergebnisse bieten wertvolle Erkenntnisse für das Design auditiver AR-Anwendungen in Outdoor-Tourismusumgebungen und tragen zur Zukunft von ansprechenden und immersiven AR-Tourismuserlebnissen bei.

Schlüsselwörter: Erweiterte Realität, Tourismus im Freien, Auditive Modalität, Navigationserfahrung, Erlebniserfahrung, Interaktion in der erweiterten Realität

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1 Introduction

In the age of ever-evolving technological advancements, the realm of augmented reality (AR) has emerged as a fascinating frontier, transforming the way we experience and interact with the world around us. As the early conceptualization, Milgram et al. (1994) proposed that AR technology can be situated on a reality-virtuality continuum. As depicted in Figure 1, both AR and virtual reality (VR) fall under the category of mixed reality (MR), wherein they incorporate virtual elements and enable user interactions with these virtual layers to varying extents. AR emphasizes the addition of information to the real world, while VR represents the opposite extreme, completely immersing users in a digitally crafted virtual environment. Unlike the comprehensive and immersive experience of VR, AR enhances the real physical space by superimposing virtual augmentations, allowing users to engage with these augmentations while maintaining their connection to the real world.

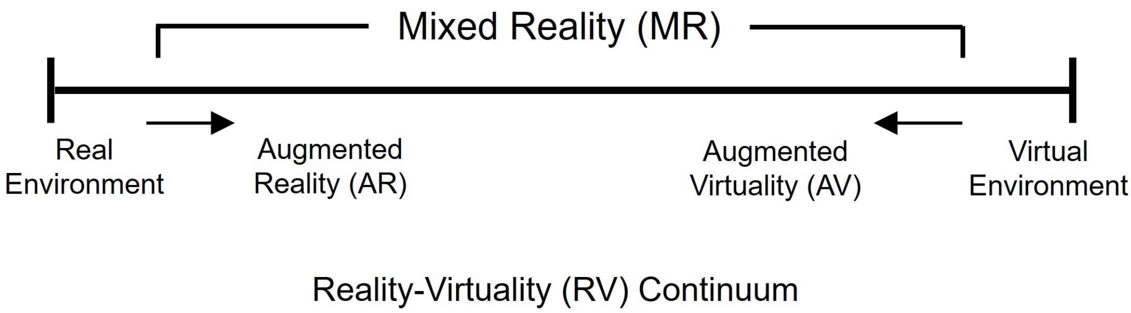


Figure 1: The mixed reality spectrum (Milgram et al., 1994)

Over the past few years, AR has witnessed remarkable progress, driven by significant advancements in hardware and software technologies, including powerful systems and sophisticated computer vision algorithms. The utilization of AR in mobile devices has opened up a plethora of possibilities, with numerous exemplary applications showcasing the technology's potential. Among the diverse applications of AR, its integration into outdoor navigation and exploration has garnered substantial attention. Applications such as Google Maps[1] integrate AR Navigation which overlays real-time visual information on a smartphone's camera feed, guiding users with digital directions directly in the real-world

[1]https://maps.google.com/

environment. The AR game Pokemon[2] superimposes virtual creatures and elements onto the real world through the smartphone camera, which encourages players to explore their surroundings actively.

Furthermore, state-of-the-art technologies in AR have transcended beyond simplistic visual overlays, incorporating diverse modalities to enhance user experiences. Advanced AR platforms, such as Microsoft's HoloLens[3] and Magic Leap One[4], offer mixed reality experiences by combining computer-generated elements with the physical world, enabling users to interact with digital content in a more immersive manner. These technologies leverage sophisticated spatial mapping, depth sensing, and gesture recognition to seamlessly blend virtual and real-world elements, opening up new possibilities for outdoor exploration.

1.1 Motivation

AR enables users to perceive and interact with virtual objects or information within their real-world surroundings, enriching their overall perceptual experiences. Azuma (1997) highlights three key characteristics of AR: the fusion of real and virtual elements, real-time interaction, and 3D registration, where virtual objects are aligned with physical locations in the 3D space. Consequently, AR has predominantly been perceived from a visual standpoint, with public perception and integration of AR technologies heavily emphasizing the visual experience.

However, human interactions are inherently multimodal, involving multiple senses beyond just vision. While the visual dimension has been the primary focus in AR applications, the role of auditory perception could be equally crucial, particularly in tasks involving navigation or exploration of both familiar and unfamiliar environments. Human reliance on the auditory sense becomes especially apparent when the visual view is obstructed, requiring complementary elements to enhance user experiences. Although sight is essential for AR interactions, augmenting the experience with auditory cues can significantly enrich the overall encounter, creating a more immersive and informative environment.

[2] https://pokemongolive.com/
[3] https://www.microsoft.com/en-us/hololens
[4] https://www.magicleap.com/

To explore the potential benefits of AR for outdoor tourism, the integration of auditory modality emerges as a promising avenue that may enhance user engagement and potentially reduce cognitive load during navigation and exploration tasks. By considering the incorporation of soundscapes and contextually relevant audio information, AR applications have the potential to offer tourists a more multi-sensory experience, potentially enhancing spatial awareness and fostering deeper connections with their surroundings. Investigating the impact of auditory modality on user engagement and satisfaction during outdoor tourism navigation and exploration tasks is important for optimizing AR applications and potentially shaping the future of immersive tourism experiences.

1.2 Thesis Structure

In the subsequent chapters of this thesis, this research delves into the impact of auditory modality on user experiences during augmented outdoor tourism navigation and exploration tasks. Following Chapter 1 of the introduction, Chapter 2 explores relevant literature on AR tourism, user experience, and auditory integration in AR to establish a theoretical foundation. Chapter 3 details the methodology, comes up with the research questions, and elaborates on design rationales, development, and evaluation methods. Chapter 4 presents results from the user evaluation, and analyzes the collected data statistically. Chapter 5 discusses and interprets the results and potential limitations and provides recommendations for future work. Chapter 6 answers the research questions, concludes the study, and emphasizes its contributions to the outdoor tourism industry and AR development.

2 Literature Review

One of the pioneering works that laid the foundation for exploring AR in the tourism field was conducted by Feiner et al. (1997). Their study introduced a touring machine, utilizing a head-tracked, see-through, and head-worn 3D display to present campus information, showcasing early approaches to outdoor navigation and information-seeking through AR technology. Since the 1990s, over the past two decades, AR has garnered significant research interest, leading to substantial developments in the field. In this chapter, three main research streams related to augmented outdoor tourism navigation and exploration with a focus on auditory modality's impact on user experience are examined. The review encompasses an analysis of state-of-the-art advancements in AR tourism, particularly in outdoor settings (Chapter 2.1). It also delves into user experience within AR environments, investigating various interaction modalities and evaluation methods (Chapter 2.2). Furthermore, the review explores the role of auditory modalities in AR applications for tourism and introduces pertinent design guidelines employed in related research (Chapter 2.3). By synthesizing and analyzing relevant literature from these diverse research streams, this literature review aims to provide a comprehensive overview of the current knowledge in the field, setting the stage for further exploration into the impact of auditory modality on AR-driven tourism activities.

2.1 AR in Tourism

2.1.1 State of the Art

Augmented Reality (AR) has emerged as a transformative technology in the realm of tourism, seamlessly combining the real world with virtual environments, revolutionizing tourists' experiences (Park and Stangl, 2020). As AR technology advances and research progresses, it opens up new markets and experimental applications across various sectors, including stores, hotels, restaurants, and tourism destinations (Loureiro et al., 2020). Presently, AR plays a crucial role in enhancing outdoor tourism experiences, allowing tourists to engage more interactively and immersively with natural and cultural heritage sites. Consequently, scholars have taken a keen interest in studying the success factors of virtual environments in tourism, driven both by the progress of AR technologies and the proliferation of AR research and commercial applications in the field.

The research on AR in tourism has been thriving, with an emerging body of studies exploring its potential to enhance tourists' experiences. Yung and Khoo-Lattimore (2019) conducted a systematic quantitative review, mapping the current state and emerging trends of VR and AR research in tourism. The research shows that AR was more dominant than VR among the categories of tourism and hospitality. Most of these AR-related studies explored how AR applications enhanced tourism experiences at physical locations, often serving as information dissemination tools in museums or location guides. However, the authors noted a need for more extensive research into the user experience aspect of AR applications in tourism. They identified key gaps and challenges in VR and AR research, including technology awareness, usability, the time required to learn, and the willingness to replace physical experiences with virtual ones.

In another comprehensive analysis, Loureiro et al. (2020) examined 56 articles on VR and AR in Tourism spanning the years 1995 to 2019. Their research delineated four key realms grounded in technological developments. These realms encompassed AR applications that focused on physical and sensory stimulations, provided enhanced longitudinal virtual experiences, contributed to well-being development, and employed artificial intelligence within virtual environments. This study's findings provide valuable insights into the future research directions and potential of AR in the tourism context, offering a strong reference for further advancements and innovations in the field.

Moreover, distinguishing itself from reviews combining AR and VR, the systematic review by Jingen Liang and Elliot (2021) focuses exclusively on AR research within the tourism literature. The review identifies five prominent research clusters, with user acceptance of AR being the predominant category, commonly employing the technology acceptance model. A meta-analysis of selected empirical studies shows that perceived ease of use significantly influences perceived usefulness. The review suggests future research directions, including advancing knowledge in gamification and AR, employing innovative methods to capture actual behavior, and investigating the potential negative consequences of AR application in tourism. Furthermore, the review encourages further exploration of factors influencing AR tourist users' behavior intentions.

In a recent practical study conducted by Ronaghi and Ronaghi (2022), the acceptance of AR technology among visitors to Persepolis was evaluated. The researchers employed a mixed and extended Unified Theory of Acceptance and Use of Technology (UTAUT) model, which incorporated innovation resistance and perceived fee for AR technology as additional factors alongside the traditional UTAUT components. The research involved a survey-based approach with the entire population of Persepolis tourists and visitors as the study sample. The results of the investigation demonstrated that social influence, effort expectancy, and enjoyment significantly influenced the perceived value of tourists, thereby affecting their adoption and use of AR technology. Interestingly, the perceived fee and innovation resistance did not exert negative effects on the perceived value and use of AR. Furthermore, the study revealed no significant differences in the usage of augmented reality technology among tourists visiting different sites. This contextually-oriented study offers valuable insights into the acceptance of AR technology in the tourism industry, illuminating the factors that influence tourists' perceptions and adoption of AR experiences at various tourism sites.

2.1.2 AR Tourism in Outdoors

Making AR systems that work outdoors is a natural step in the development of AR toward the ultimate goal of AR displays that can operate anywhere, in any environment (Azuma et al., 1999). Despite initial technical limitations, AR demonstrated its potential by registering virtual 3D objects with real-world elements, offering multimedia information within the spatial context of outdoor environments. Challenges, as proposed by Azuma et al. (1999), included ergonomic considerations, display contrast, and accurate outdoor tracking to minimize registration errors. To address these challenges, it was suggested to adopt hybrid tracking techniques as a feasible approach in the near term.

Notable among the earliest outdoor AR implementations was ARQuake, a first-person AR application developed by Thomas et al. (2000). ARQuake showcased the feasibility of outdoor AR, utilizing GPS, digital compass, and fiducial vision-based tracking. The system allowed users to view the physical world while displaying augmented information (e.g., monsters, weapons, objects of interest) through a head-mounted display (HMD) in spatial context with the real world. The successful implementation of ARQuake demonstrated that AR was achievable using cost-effective, off-the-shelf software. The development of mobile devices has promoted the application of AR in outdoor environments. In the context of mobile augmented reality (MAR) applications, Chatzopoulos et al. (2017) categorized various fields and presented representative examples of AR's application. These examples encompassed campus exploration, cultural and historical site tours, street navigation, and travel planning. AR technology supported these applications with features like GPS, object image detection, motion sensors, and overlays of additional information, integrating content from networks, communities, and open and government data.

In the domain of city exploration, CityViewAR by Lee et al. (2012) introduced a mobile outdoor AR application that provided geographical information about Christchurch through augmented visualizations on a city scale. The application presented geo-located content in 2D map views, AR visualizations of 3D building models on-site, immersive panorama photographs, and list views. Comparing user responses to AR and non-AR viewing, the study concluded that AR modalities in mobile applications enhanced user experiences and held potential for city-scale tourism and outdoor guiding. Additionally, AR's contribution to cross-time historical exploration was evident in Ramtohul and Khedo (2019) introduction of a Location-Based Mobile AR (LBMAR) system for a cultural heritage site. This LBMAR system employed the multi-sensing capabilities of smartphones to capture live images, calculate users' field of view, and rotation view. The design involved several sub-systems working in tandem to provide real-time augmented information to users, ultimately enhancing engagement levels and promoting cultural heritage sites among the public (Ramtohul and Khedo, 2019).

Collectively, these studies illustrate the progression of AR technology in outdoor tourism, showcasing its ability to enrich user experiences, guide tourists through historical sites, and seamlessly integrate virtual content with real-world environments. However, beyond the technology aspects lies a critical consideration of the user experience in AR tourism. To delve deeper into this crucial aspect, the next chapter will review the existing literature under the topic of user experience in AR tourism. This exploration will shed light on various interaction modalities, evaluation methods, and factors influencing users' perceptions, satisfaction, and engagement within AR-driven tourism scenarios.

2.2 User Experience in AR Tourism

User experience (UX) has been comprehensively defined as the outcome arising from a user's internal state, the attributes of the designed system, and the contextual environment in which the interaction takes place (Hassenzahl and Tractinsky, 2006). In the context of mobile AR and its applications in tourism, the user interface and experience assume paramount significance, as they directly influence user engagement and perception of AR content and interactivity (Chatzopoulos et al., 2017). Consequently, well-designed AR applications, aligning with tourists' behaviors, enhance their utility as travel information sources, underscoring the crucial significance of understanding user experiences (Park and Stangl, 2020). This chapter delves into the multifaceted realm of user experience in AR tourism, exploring three main subtopics: the state of the art in UX research within the AR tourism domain, various interaction modalities employed in AR tourism applications, and the evaluation methods that offer insights into users' perceptions, satisfaction, and engagement during AR-driven tourism experiences.

2.2.1 State of the Art

As user experience gains prominence, research in the field of tourism has increasingly focused on multidisciplinary theories to fully exploit the potential of AR technology in enhancing user experiences. Kounavis et al. (2012) propose a model for developing AR mobile applications in tourism, emphasizing the importance of personalized content and services tailored to individual tourists' specific needs, and the incorporation of diverse multimedia formats to deliver personalized, interactive, and enriched tourist experiences. Adopting a stakeholder approach, Cranmer (2019) offers a holistic understanding of effective AR tourism application design, deriving four design categories: visitor value, organizational value, stakeholder value, and economic value. The study underscores the significance of considering these categories in future AR projects. To comprehend travelers' AR experiences in obtaining travel information, Park and Stangl (2020) apply the concept of sensation-seeking and advocate for delivering personalized AR content through the classification of target user groups.

Additionally, the end-user perspective plays a crucial role in translating user experience theories into practice. The Dublin AR project (Han et al., 2013) aims to evoke an emotional experience of intangible heritage in Dublin by providing a platform to superimpose relevant tourism information and revive past stories. Interviews and thematic analysis conducted by the authors reveal key user requirements for the mobile AR application in the Urban Heritage Tourism context. The study highlights the significance of up-to-date information, social networking features, and user-friendly navigation in ensuring continuous utilization of the AR application. Dublin AR effectively implements AR in tourism, engaging users and providing an enhanced user experience.

Integrating both technology and user experience considerations, the TourMAR project by Ocampo (2019) introduces a design architecture that integrates tourism data based on tourists' needs into mobile AR applications, with the aim of enhancing user experiences. The architecture encompasses two main components: content management and design principles of MAR. For content management, tourism data is classified into four modalities: audio, 3D images, video, and images. The design principles proposed by TourMAR utilize context to provide content and optimize visual design to encourage a more interactive user experience. Moreover, technical aspects such as the compatibility of 3D interaction and accuracy of location-based services are taken into account.

As can be seen, the state-of-the-art research has shed light on the pivotal role of tourism content in shaping immersive and captivating AR applications, necessitating the incorporation of multiple interaction modalities. Building upon these crucial insights, the subsequent section will delve into a comprehensive exploration of the diverse interaction modalities employed in AR tourism applications.

2.2.2 Interaction Modalities

Interaction modalities in the context of AR have undergone reidentification and categorization in recent decades. To address this, Papadopoulos et al. (2021) aimed to organize existing interaction methods and establish a well-structured taxonomy that represents human-computer interaction within mixed and augmented reality environments. Through a comprehensive review of over 200 relevant papers and established theories, the authors proposed a complete classification, employing a modality-based interaction-oriented diagram. This diagram presents four primary modalities: visual-based, audio-based, haptic-based, and sensor-based modalities, with further in-depth classification extending to the context and method levels. The study contributes a holistic review of interaction modalities in the AR context, offering valuable insights into the diverse ways users interact with AR applications.

Perkis et al. (2020) introduced the concept of Immersive Media Experience (IMEx) with AR as one of the immersive media technologies. The immersive media experience was defined as a high-fidelity simulation provided and communicated to the user through multiple sensory and semiotic modalities. From the experiential perspective, the definition also highlights a user's sense of presence which can be achieved through an interwoven triad of immersivity, interactivity, and narrativity.

Furthermore, the convergence of AR related technologies contributes to an increasingly rich and multi-faceted immersive experience, paving the way for even more captivating and engaging user interactions in the AR domain. Head-mounted displays (HMDs) stand out as one of the most significant technologies, enabling immersive content distribution and delivering a sense of being fully immersed within the virtual scene. Alongside HMDs, the exploration of omni-directional video and audio has introduced omnidirectional media experiences and other three-dimensional representations. Notably, the emerging trend of mulsemedia incorporates new sensory effects, such as haptics or olfactory cues, alongside visual and audio information. Synchronized with multimedia content, these sensory enhancements offer novel levels of immersion, effectively heightening the sensation of presence and interaction for users. (Perkis et al., 2020)

However, as emphasized by Gander (1999), the mere incorporation of additional senses does not guarantee greater levels of immersion or superiority over other applications. To truly ascertain the effectiveness and impact of interaction modalities in AR Tourism, a rigorous evaluation of the user experience becomes indispensable. The current section has explored diverse interaction modalities employed in AR applications, shedding light on the diverse ways users engage with AR content. In the subsequent section focusing on User Experience Evaluation in AR Tourism, the critical process of systematically assessing and comprehending the impact of these interaction modalities on users' perceptions, immersion, and overall engagement will be examined.

2.2.3 User Experience Evaluation

Yovcheva et al. (2013) defines 11 the most significant determinants for augmented tourism experiences, including awareness, efficiency, empowerment, engagement, liveliness, meaningfulness, motivation, novelty, safety, surprise, tangibility, which set directions for subsequent research and evaluation metrics on AR experiences in the context of tourism.

Devling more into the evaluation metrics, Arifin et al. (2018) presents an in-depth investigation into the UX measurement in the context of AR applications, with a specific focus on the field of education. The authors conducted a thorough review of existing research and measurement standards to identify relevant UX metrics for AR applications. The study suggests that existing standard metrics, often used for usability measurement, can be adapted and combined to evaluate the quality of UX in AR applications. The identified metrics primarily encompass performance, self-reported, behavioral and psychological aspects of UX. Specifically, the pragmatic aspect focuses on task completion, while the hedonic aspect centers on user satisfaction during interactions with the applications.

Along the path of usability testing, Pranoto et al. (2017) addresses the crucial aspect of evaluating systems or software during their development to ensure high quality in functionality and non-functionality aspects. The study explores various evaluation methods applicable to AR applications, encompassing subjective measurements based on human perception, objective measures derived from observation, and expert evaluations employing techniques such as cognitive walkthroughs, heuristic evaluation, and questionnaires. The authors emphasize the significance of employing multiple evaluation methods to enhance the validity of the assessment results. The three primary methods of evaluating usability are testing, inspection, and inquiry, each comprising several sub-methods. For future usability evaluations, the paper suggests a comprehensive approach involving user perception measurement, objective observation or experimentation, and insights from experts, thereby advocating the integration of multiple evaluation methods to yield more comprehensive and insightful assessments of AR applications or systems.

Davidavičienė et al. (2021) further highlight the common practice among researchers of employing a mix of qualitative and quantitative research methods when analyzing the end-user experience of AR platforms. A variety of instruments are commonly utilized in scientific research, such as the System Usability Scale (SUS) (Brooke, 1996), Usefulness, Satisfaction, Easy to Use and to Learn (USE) metrics (Lund, 2001), Handheld Augmented Reality Usability Scale (HARUS) (Santos et al., 2014), usability questionnaire by the International Organization for Standardization (ISO) covering aspects of Usability, Effectiveness, and Efficiency, the Technology Acceptance Model (TAM), and the User Experience Questionnaire (UEQ) (Laugwitz et al., 2008).

Among the factors that shape the user experience, immersion has garnered significant interdisciplinary interest over the past few decades, playing a pivotal role in enhancing user experiences. Immersive media has emerged as a powerful tool, delivering prolific frameworks to enhance user interactions, promote enjoyment, engagement, and even facilitate learning. In the realm of AR tourism applications, measuring immersion becomes paramount, enabling researchers and designers to evaluate how effectively the application immerses users in the location-aware environment. The work of Georgiou and Kyza (2017) addresses this crucial need by introducing the ARI questionnaire, a meticulously validated instrument that serves as a valuable tool to measure immersion in location-based AR applications designed for learning or entertainment purposes. The questionnaire is a 21-item, seven-point Likert-type instrument with satisfactory construct validity, and includes Engagement, Engrossment and Total Immersion three factors. Through the comprehensive understanding of the level of immersion experienced by users, the further research of the construct of immersive AR experiences can be supported.

Having explored the existing literature in the field of tourism, encompassing the state of the art and user experiences within AR applications, the subsequent section delves into the realm of auditory modality in AR experiences, which places particular emphasis on its applications in the context of tourism, especially in the navigation scenarios and design guidelines aimed at enhancing navigation and exploration tasks.

2.3 Auditory AR

In the context of mobile usage, where users must maintain continuous awareness of their surroundings, such as in urban tourism scenarios, the role of audio augmented reality (AAR) becomes particularly critical. AAR should enable users to simultaneously perceive both the real environment and a virtual audio overlay (Boletsis and Chasanidou, 2018). Cohen et al. (1993) were among the first to provide a broad definition of AAR, describing it as an extension of visual AR, where computer-generated sounds are superimposed on directly acquired audio signals. An illustrative example they present is sound reinforcement in a public address system. While several works have explored guidelines and frameworks for effective AR engagement and enhanced user experiences, the majority of AR content is predominantly presented visually as additional information overlay. Even in the cultural heritage field, where AR has been employed to interact with historical sites (Kasapakis et al., 2016), audio is often used as an alternative feedback alongside visual indicators, rather than as the main modality influencing user experiences. However, the incorporation of contextual information through auditory inputs can significantly enhance the immersive experience, providing situational awareness and extending the boundaries beyond visual cues. As a result, audio-based interactions have the potential to create a more natural and reality-like experience for users (Papadopoulos et al., 2021). Consequently, it becomes essential to thoroughly examine how various audio AR system designs, specifications, and component technologies can impact user experiences (Huang et al., 2012).

2.3.1 AAR in Tourism

In the field of tourism, early prototype works demonstrated the application of AAR to enhance user experiences during exploration and navigation tasks. For instance, Bederson (1995) developed an automated tour guide that superimposed audio descriptions based on the user's location, enabling users to receive relevant information as they moved through different areas. This pioneering work laid the foundation for later studies in AAR for tourism contexts.

The characteristics of auditory modality in AR have been identified and investigated by researchers. Huang et al. (2012) highlighted four essential characteristics of AAR: spatial representation, flexible presentation, user tracking extent, and user mobility. Spatial representation refers to the various formats of virtual audio, which can be presented in mono, stereo, 2D, or 3D signals. Flexible presentation allows virtual audio to cater to individual users or collective group audiences. User tracking extent incorporates head-orientation tracking, enhancing the positioning of audio sources in relation to the user's movements. User mobility emphasizes the user's freedom to move around while still maintaining an effective tracking system. These characteristics have significantly contributed to the user experience in augmented reality applications.

Examples of AAR applications in tourism illustrate its potential to enrich outdoor experiences. Mantell et al. (2010) introduced Navinko, an audio augmented reality mobile application designed for cyclists in Tokyo. By utilizing locative sounds assigned to specific places, Navinko provided a spatial navigation experience that enhanced outdoor urban riding. Ren et al. (2018) conducted a study evaluating the effect of haptic and audio displays on mobile user experiences with tourism applications. The combination of both modalities was found to achieve the best performance, with audio display alone performing slightly better than haptic display alone. Vazquez-Alvarez et al. (2012) compared four different auditory displays in a mobile AR environment, finding that the combination of spatial audio and Earcons was the most effective auditory display, encouraging a more exploratory and playful response to the environment. The use of auditory cues in AR tourism applications not only complements visual cues but also guides users' attention to specific points of interest in the real environment, ultimately enhancing the immersive experience.

Overall, AAR in tourism holds promise for providing additional sensory cues, aiding users in navigating effectively and enriching their overall outdoor tourism experiences. By conveying critical information such as direction and distance of landmarks, objects, and points of interest through audio cues, AAR has the potential to contribute to more efficient and engaging navigation tours.

2.3.2 Spatial Auditory Navigation

In the case of navigation tasks, the implementation of spatial audio stands out, particularly in orientation and navigation scenarios, where it demonstrates superior performance compared to other modalities. Sundareswaran et al. (2003) were among the pioneers exploring spatial audio in AR experiences. They developed a wearable 3D audio system capable of delivering alerts and informational cues to mobile users from specific locations in their environment, effectively incorporating audio into AR experiences.

Studies like Russell et al. (2016) with their HearThere system, and Miyakoshi et al. (2021) with AudioMaze, further demonstrate the potential of spatial audio in seamless mixing of real-world and virtual sound sources. Rumiński (2015) conducted an experimental study of spatial sound usefulness in searching and navigating through augmented reality environments. The experiment showed that the participants of the spatial sound group performed faster and more efficiently than working in no-sound configuration. Martens and Cohen (2021) evaluated the performance of spatial navigation in multimodal AR systems, yielding insights into the effective utilization of the auditory component for supporting spatial navigation.

Spatial auditory navigation not only enhances efficiency in navigation tasks but also reduces cognitive load on users by providing a natural and intuitive way of interacting with the environment. Albrecht et al. (2016) explored the use of spatial music to guide pedestrians and cyclists, resulting in pleasant navigation experiences where users could follow sound cues without constant visual reliance. This capability allows users to focus on their surroundings and enjoy a more immersive experience.

Moreover, spatial audio contributes to the realism and immersion of the navigation experience. Zhou et al. (2007) quantitatively and qualitatively investigated the effectiveness of 3D sound in AR environments, showing that it effectively complements visual AR displays, aids task performance, and enhances depth perception. The combination of visual and auditory cues creates a more realistic and immersive environment, fostering a sense of presence within the AR experience.

In summary, spatial audio plays a crucial role in improving the efficiency and engagement of navigation tasks in AR environments. It enriches the user experience by providing contextualization, realism, and immersion. By offering additional sensory cues, reducing cognitive burden, and enabling more natural and intuitive interactions with the environment, spatial auditory significantly enhances the overall user experience during outdoor navigation activities.

2.3.3 Design Guidelines for AAR

The concept of context immersion introduced by Kim (2013) offers a valuable approach to mobile AR in ubiquitous and mobile computing. The framework comprises three dimensions: time and location-based context immersion, object-based context immersion, and user-based context immersion. By considering elements like involvement and motivation, this contextual design guideline aids in enhancing the user experience in mobile AR settings.

Several studies have contributed design guidelines for effective AAR experiences, providing insights for further research. Vazquez-Alvarez et al. (2015) explored multilevel auditory displays to enable eyes-free mobile interaction with indoor location-based information in non-guided audio-augmented environments. Their evaluation of four display designs revealed that spatial audio in an exocentric auditory display encouraged exploratory behavior, fostering positive user involvement during space navigation.

Paterson et al. (2010) presented the design, implementation, and evaluation process of a location-aware game called Viking Ghost Hunt (VGH), where audio impact on immersion and emotional engagement was assessed. A soundscape representative of the location environment and game atmosphere was developed, employing background sound, sound effects, dialogue, and user interface elements. The use of audio, triggered by GPS locations, provided a realistic 3D audio experience, and participants appreciated both the narrative and sound effects' roles in enhancing immersion and engagement.

Audio can also serve as an informative tourist narrative. Boletsis and Chasanidou (2018) investigated an audio AR system, AudioNear, designed to support tourists exploring outdoor urban environments by providing speech-based information about surrounding sights based on the user's location. The concept was well-received, indicating potential for audio AR to offer informative tourist services and engaging experiences.

Furthermore, Indans et al. (2019) emphasized that not only spatial properties but also the information content of audio can significantly influence the subjective perception of space. Utilizing storytelling, they created immersive geolocated narratives, developing a purpose-built interactive locative audio storytelling application for AR. This approach enriches audio's potential in AR applications.

While audio has been successfully used to create environmental atmospheres, provide a sense of presence and immersion, and deliver additional information through narratives, challenges remain in employing audio as the primary modality for both navigation and exploration contexts within a single platform. Addressing complexities like ambient noise, weather conditions, and outdoor limitations, along with understanding users' expectations regarding audio's role in both contexts, remains crucial for future advancements in AAR design.

3 Methodology

The above review of the literature in the field of AR tourism has provided inspiration and outlined the design guidelines for integrating auditory modality in navigation and exploration on AR platforms. This chapter begins by outlining the research questions that drive the investigation of the thesis topic. Subsequently, the chapter positions the system within the theoretical framework defined by relevant literature, providing a solid theoretical foundation for the study. The research design is then detailed, elaborating the design rationales that informed the user flow, interfaces, and other object designs of the AR prototype. The development process of the system is outlined, followed by a strategy for evaluating the user experience. By systematically presenting the methodology, this chapter aims to ensure a robust and coherent approach to addressing the research objectives.

3.1 Research Questions

The study aims to establish a comprehensive understanding of how auditory media can transform conventional sightseeing into awe-inspiring, multisensory AR journeys. Building upon existing literature, this study seeks to address identified limitations and gaps by exploring the impact of auditory modality on user experiences during augmented outdoor tourism navigation and exploration tasks. Specifically, the investigation delves into the performance of spatial auditory modality during navigation tasks, the interactive display of AR objects with auditory cues during exploration tasks, and the influence of auditory AR on overall immersion. To achieve these objectives and address the research problem effectively, this study will seek answers to the following three research questions:
In the context of augmented outdoor tourism,

- What is the impact of auditory modality on user experience during navigation tasks?
- What is the impact of auditory modality on user experience during exploration tasks?
- How does the auditory AR impact the factors of immersion during navigation and exploration tasks?

3.2 Positioning the System

In positioning the system, the objective is to align it with relevant concepts and theories discussed in the literature. To address the research questions, a mobile AR application was developed, tailored to meet the specific tourism needs of *Tiergarten, Berlin.* The application was designed to facilitate outdoor tourism activities, encompassing functionalities for routing, navigation, and exploration of the selected tourism sites. Implemented as a mobile AR platform, the application will be accessible through mobile phones, allowing users to seamlessly engage with the AR content.

The core modality of the system will be auditory, employing a location-aware approach to enhance users' experiences. By leveraging spatial audio cues, the system will provide contextually relevant information based on users' physical location, enriching their interactions with the environment. While the primary focus is on the auditory modality, the application will also support haptic-based interaction modes, including single-touch and multi-touch functionalities. These additional interaction modes, although not the primary emphasis of this research, aim to complement the auditory experience and contribute to a holistic and immersive user interface.

Table 1 below provides an overview of the AR application and maps the system into the theoretical framework.

Table 1: Position the system with literature

Aspect	**Taxonomy**	**Description**
Functionality	Routing and navigation	The possibility to obtain directions and navigation to a POI, once it is visualized in AR view and selected.(Pospischil et al., 2002)

Table 1: Position the system with literature

Aspect	**Taxonomy**	**Description**
Functionality	Exploration of visible surroundings	Apart from looking up information about a particular item, place, object and category, tourists may wish to explore available information about their surroundings without predefined criteria.(Ajanki et al., 2011)
Platform	Mobile Augmented Reality	MAR supplements the real world of a mobile user with computer generated virtual contents.(Chatzopoulos et al., 2017)
Auditory modality	Location-aware sound effects	Based on the user location, sound effects were triggered indicating the paranormal activity level, thus exploiting the location-aware sound effects method.(Papadopoulos et al., 2021)
Audio AR in navigation	Spatial audio AR (3D)	An important sub-group of Audio AR only uses 2D or 3D spatial characteristics, with full position and orientation tracking, denoted herein as Spatial Audio AR (SAAR).(Mariette, 2012)
Audio AR in exploration	Locative audio (2D)	Locative audio refers to electronic media that relate to the user's locational context, it only requires mono audio and rough user position information.(Mariette, 2012)

3.3 Research Design

To address the research questions outlined in the previous section, a mobile AR prototype was developed, with a keen focus on the design rationale and considerations of the tourism demands at Tiergarten. To ensure the feasibility and practicality of the testing process, an area within a 20-minute walking distance was chosen for evaluation purposes. Within this constrained space, three prominent tourist sites in Tiergarten, the *Goethe Monument*, *Beethoven Memorial*, and *Amazone zu Pferde* - were selected as the areas of focus for the AR prototype.

3.3.1 Design Rationales

To answer the 1st research question, *What is the impact of auditory modality on user experience during navigation tasks?*, two conditions were designed with navigation modality as the control variable to compare the effects of *Spatial Auditory Navigation* and *Augmented Visual Navigation*. In the *Spatial Auditory Navigation* condition, users are guided only by spatial music without direction and distance information shown. In the *Augmented Visual Navigation* condition, users are guided only by visual AR indicators which show the direction and distance information, and 2D music is played at the same time to reduce the influence of music itself.

To answer the 2nd research question, *What is the impact of auditory modality on user experience during exploration tasks?*, two types of interactive AR objects were designed with the modality of tourism information display as the control variable to compare the effects of *Auditory Information Display* and *Textual Information Display* on the visual AR objects. For the AR objects with *Auditory Information Display*, users can get the tourism information by auditory media that is shown with the AR object. For the AR objects with *Textual Information Display*, the information is presented in the way of texts on the AR object.

To answer the 3rd research question, *How does the auditory AR impact the factors of immersion during navigation and exploration tasks?*, an additional experimental navigation condition was introduced, and the overall immersion level with the application was evaluated. This additional condition involved the integration of spatial auditory navigation along with augmented visual objects as navigation aids to enhance users' experiential engagement. Subsequently, a user study was conducted to gather feedback on participants' overall AR application experience, specifically focusing on various factors to immersion level.

In crafting the design approach for the AR application, various factors were taken into account, including the specific conditions necessitated by the research questions. Drawing from the prior research and existing works on mobile and auditory AR guides, as well as established principles of human-computer interaction (HCI), the design process was tailored to suit the unique requirements of urban tourism. Within this framework, Table 2 lists four key design rationales that derived directly from relevant literature which were selected with a focus on interaction, interface, content delivery, and their reflection on the system design.

Table 2: Reflect design rationales on the system design

Design Rationale	**System Reflection**
In location aware gaming, sounds used are representative of both the location environment and game atmosphere. Design, implementation and evaluation of audio for a location aware augmented reality game.(Paterson et al., 2010)	The app should be able to provide context-based audio feedback, and the audio used in the app should be tailored to reflect the atmosphere of each tourism site. For example, if the Goethe Monument represents a literary theme, incorporate audio related to poems, books, writing, or classical music to create an appropriate atmosphere.
Story-based and playful elements are facilitating the engagement in exploratory and participative experiences.(Hutzler et al., 2017)	Craft engaging audio narratives about the statues to captivate users' interest and provide them with a richer understanding of the historical and cultural context. Develop concise and compelling scripts that can be played back as part of the 2D audio information.

Table 2: Reflect design rationales on the system design

Design Rationale	**System Reflection**
Designing with reality and beyond to provide usable and interactive experiences with the AR content, adaptative AR situate the content with relation to users position and change dynamically according to it. Designing mobile augmented reality.(Seichter et al., 2013)	• Realistic AR Content: The content provided by AR objects aligns with the real-world context of the Tiergarten statues. The 3D models, textures, and animations were designed to be visually accurate and realistic, enhancing the user's sense of immersion. • Interactive AR experience: The AR objects were created to be interactive that encourage user engagement. Users could tap on specific objects to trigger additional information, animations, or hidden surprises, fostering a sense of discovery and interactivity. • Contextual Guidance: When it comes to the visual navigation, contextual guidance was implemented to assist users in exploring the Tiergarten statues effectively. Visual cues, such as arrows and distance indicators were designed to guide users to the next point of interest or provide directions within the AR environment, enhancing usability and facilitating exploration.
Spatial audio in an exocentric auditory display can be used to encourage exploratory behavior. Co-locating information in the physical space of an object generates a positive user involvement while navigating the space as it results in a more personal serendipitous exploration.(Vazquez-Alvarez et al., 2015)	When it comes to the spatial auditory navigation condition, the audio was situated in the tourism space and perceived as if it was fixed to a location in the physical space. The user gets the feeling like the sound is emitted from a physical place, with the user getting closer to the sound source, the audio is perceived as louder.

3.3.2 User Flow and Interface Design

To translate the design rationales into tangible elements within the AR prototype, a user flow was developed which is shown in Figure 2, and explained the steps that the user can go through and actions to interact with the mobile AR system. The aim of the interface design was to foster an immersive experience that encourages users to remain engaged with their physical surroundings. To achieve this, the camera function was consistently activated, enabling users to view their real-world environment at all times. The mobile interfaces were presented by augmented overlays, which were seamlessly blended with the physical environment to enhance realism. The detailed design for each page is described as follows, some example pages can be seen in Figure 3.

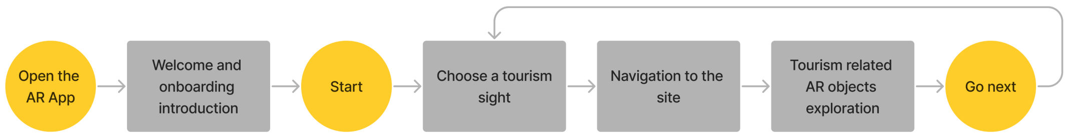


Figure 2: User flow of the AR prototype that shows the steps and actions the user can go through and interact with the system

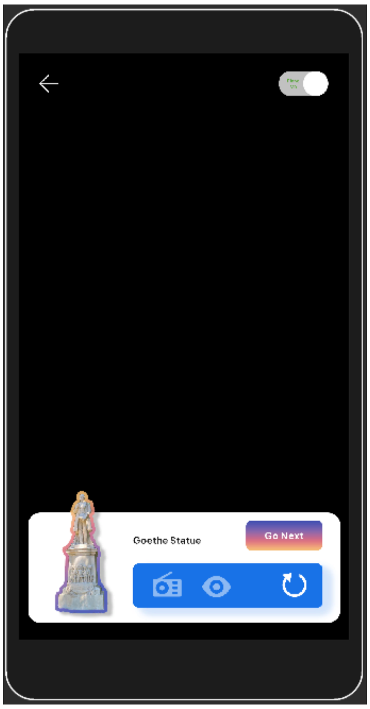
(a) The 1st page of the on-boarding interface

(b) The selection interface

(c) The Goethe Monument navigation interface

(d) The Beethoven Memorial navigation page

(e) Set a pin in the environment



(f) The Goethe Monument exploration page

Figure 3: Example designs of the AR prototype interface

Onboarding:

The onboarding interface features a carousel that allows users to navigate through a series of short introductions about the app and its environment. The presence of page indicators below the carousel serves two purposes: to indicate the use of swipe gestures for navigation and to provide visual cues about the user's current position within the carousel.

The Figure 3a shows 1st page of the onboarding interface. On the final page of the carousel, a prominently displayed "Start" button is provided. By selecting this button, users will be seamlessly directed to the selection page for further interaction.

Tourism site selection:

The selection interface (see Figure 3b) offers users the opportunity to choose from a selection of three statues. Through a swipe gesture, users can explore the different statues, with one being visually highlighted at a time through a dynamic 3D model. The surrounding text provides clear guidance to the user, encouraging them to make a choice. By clicking on the statue model, users are directed to the respective navigation page associated with their selected statue.

Goethe Monument navigation:

The Goethe Monument navigation section incorporates the spatial auditory navigation condition, allowing users to navigate toward the destination by following a guitar music piece presented in a 3D format. As shown in Figure 3c, upon entering the page, users are presented with a popup containing concise instructions and a "Go" button. Clicking the button dismisses the popup, enabling users to initiate the navigation towards the desired site. The interface intentionally avoids displaying any visual elements to ensure users can fully concentrate on the auditory cues during their journey.

Beethoven Memorial navigation:

The Beethoven Memorial navigation section integrates an augmented visual navigation feature. Similar to other navigation pages, an initial popup with instructions is presented and can be dismissed by the user. The augmented visual indicators encompass several elements, including a distance sign displaying the distance to the destination, a direct line rendering pointing toward the destination, a prominent floating arrow indicating the upcoming turning point, and a small arrow with a circle representing the distance board. The design of the visual cues aims to enhance the user's navigation experience in locating and reaching their desired destination (see Figure 3d).

Amazone zu Pferde navigation:

The Amazone zu Pferde navigation section combines spatial auditory navigation with an AR object. The navigation mechanism is similar to the Goethe Monument navigation section, providing users with spatial auditory cues for guidance. Additionally, this section offers the capability to place an AR pin at the current location, serving as a marker (see Figure 3e). Even if the user moves away from the pin and later returns, the virtual pin remains fixed in its original position, preventing it from getting lost in an unfamiliar environment.

Tourism site exploration:

As shown in Figure 3f, at the bottom of the interface, there is a card containing four distinct actions. The audio-related icon button enables users to place an audio AR object on the AR plane, which is represented by a 3D model and accompanied by audio playback. Three buttons positioned at the top allow users to pause, play, and stop the audio. The placed AR object can be moved by dragging it and scaled up or down using a two-finger pinch gesture. Tapping on the body of the object selects it, causing a highlighted transparent box to appear, enabling users to rotate the object. Pressing the clear button removes the currently placed object, allowing users to replace it with another object. Only one object can be present on the screen at a time. The button featuring an eye icon represents the text object, which introduces an AR 3D object with accompanying textual information on the plane. Tapping the info icon at the top of the 3D model hides the information. The gesture interaction mechanism remains consistent with the audio AR object.

Additionally, the card includes a "Go Next" button that enables users to return to the selection page. Positioned at the top right corner, there is a toggle button that allows users to toggle the visibility of the AR plane on or off.

3.3.3 AR Objects Design

The section presents a detailed account of the AR objects integrated into the prototype, encompassing both *Auditory Information Display* and *Textual Information Display*. Each AR object is tailored to cater to various exploration pages within the application. Table 3 provides an overview of these AR objects, accompanied by short descriptions.

Table 3: Overview of interactive AR Objects and descriptions

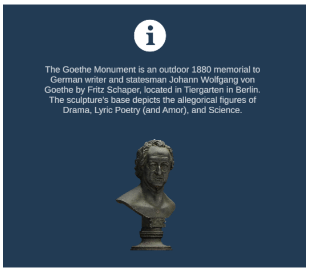
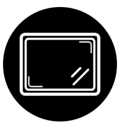
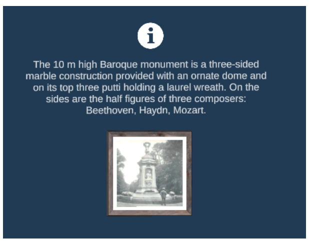
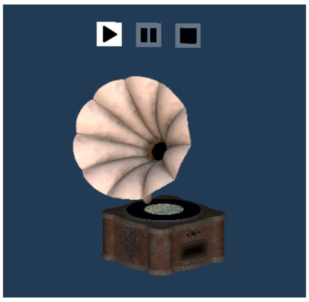
Tourism Site	**Interface Icon**	**AR Object**	**Description**
Goethe Monument			A 3D model of a radio box in the retro style, which plays an audio rendition of *Erlkönig*, a ballad written by *Johann Wolfgang von Goethe*.
			A 3D model of Goethe statue, with a brief introduction for the *Goethe Monument* on the top.
Beethoven Memorial			A 3D model of a piano in the retro style with wooden texture, which plays the piano of *Beethoven*'s work *Pastoral*.
			A 3D model of a retro frame with the picture of *Beethoven Memorial* in 1905, and a brief introduction is on the top.

Table 3: Overview of interactive AR Objects and descriptions

Tourism Site	Interface Icon	AR Object	Description
Amazone zu Pferde			A 3D model of a retro style of phonograph which plays the narrative of a short introduction for this statue.
			A 3D model of the statue with the brief introduction text on its top.

3.4 App Implementation

This section provides an overview of the software, external SDKs, and third-party assets utilized in the implementation of the AR prototype.

The prototype was developed in Unity[5] with an Android AR setup. For Android device implementation, ARCore[6] was integrated into the prototype. Leveraging Unity AR Foundation[7], the prototype was designed. Within the AR Foundation framework, various AR features, including device tracking, camera functionality, and plane detection, were selectively enabled by incorporating corresponding manager components into the scene.

[5]https://unity.com/
[6]https://developers.google.com/ar
[7]https://docs.unity3d.com/Packages/com.unity.xr.arfoundation@5.0/manual/index.html

3.4.1 Spatial Auditory Navigation

In the spatial auditory navigation condition, the Google ARCore Geospatial API[8] is utilized to remotely attach a sound source to the Goethe monument and continuously track the real-time user location. By obtaining latitude and longitude data for the statue in the real world, a 3D object containing the sound source is placed and anchored at the precise location. During system operation, the API leverages device sensors and GPS data to assess the device's environment and matches discernible environmental features to a localization model provided by Google's Visual Positioning System[9]. This process enables the accurate determination of the user's device location. The 3D sound experience is limited to an activation zone with a radius of 300 meters. Upon detecting a collision between the user's device and the destination, the system automatically transitions to the exploration page, providing clear confirmation of a successful arrival at the intended location.

The implementation of 3D sound involved integrating the FMOD plugin for Unity[10], which facilitated a straightforward setup process and adaptive audio capabilities. Following the plugin installation, the FMOD Studio Listener component was added to the AR camera within the navigation scene. This component ensured proper playback of 3D events through integration with the FMOD engine. Subsequently, the audio media was incorporated into the FMOD Event Browser and associated with a game object. Additionally, the reverb zone was activated to dynamically modify the overall sound quality based on the user's location. This feature allowed users to perceive direction and distance by perceiving variations in different sound attributes such as timing and volume. As mentioned before, the audio event is triggered only when the user is within the activation zone.

3.4.2 Augmented Visual Navigation

The augmented visual navigation was powered by[11], which can generate turn-by-turn directions based on the GPS data. With the Mapbox API, AR views of 3D Signs, arrows,

[8]https://developers.google.com/ar/develop/geospatial
[9]https://developers.google.com/ar/develop/unity-arf/geospatial/check-vps-availability
[10]https://www.fmod.com/unity
[11]https://docs.mapbox.com/help/glossary/directions-api/

and line renderings can be incorporated to guide the user throughout the route. The geographical positions defined by the latitude and longitude of the user device are detected in real-time. Similiar to the spatial auditory navigation scene, the page transition happens when the GPS position collision is detected.

3.4.3 AR Objects Interaction

For realizing the interaction with the AR objects, Unity XR Interaction Toolkit[12] was used, it provides a framework that makes 3D and UI interactions available from input events when creating AR experiences. The core of this system is a set of base *Interactor* and *Interactable* components, and an Interaction Manager that ties these two types of components together (Unity, 2023). With this package, the interaction tasks like hovering, selecting, and grabbing the AR objects are supported.

3.4.4 Content Materials

The visual and auditory assets utilized within the application were sourced from a combination of independent creations and free license repositories. The statues referenced in the system were initially photographed within Tiergarten and subsequently transformed into a 3D format. Interactive AR object models, such as the radio box and piano, were obtained from Sketchfab[13] and Unity Asset Store[14] and imported into the Unity development environment. Audio sources were acquired from online sources, while the narratives were generated using a freely available text-to-speech tool. Introduction texts for the statues were sourced from Wikipedia and modified to suit the appropriate length requirements for visualization purposes.

3.5 User Study

This section presents the design of the user study, encompassing the development of questionnaires, the flow of navigation and exploration tasks, and the evaluation methods.

[12]https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@2.1/manual/index.html
[13]https://sketchfab.com/
[14]https://assetstore.unity.com/

The starting point for the study was chosen based on considerations of traffic convenience. The Goethe Monument was designated as the destination for the spatial auditory navigation task, while the Beethoven Memorial served as the destination for the augmented visual navigation task. Lastly, the Amazone zu Pferde was designated for the experimental navigation condition. Each of these sites included tasks for the two types of AR object exploration. The layout of the user study sites can be seen in Figure 4.

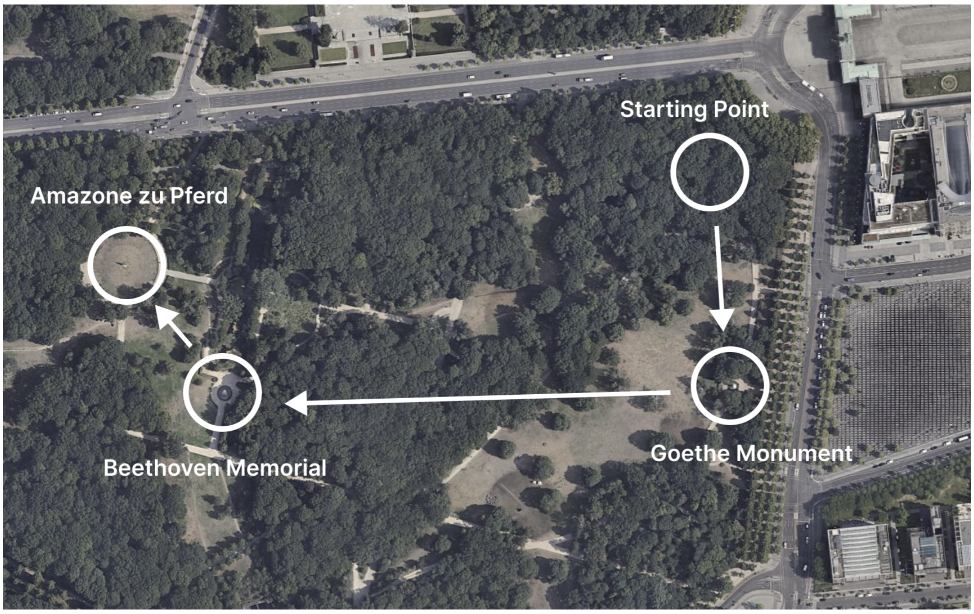


Figure 4: Layout of the user study sites

The experiment was in a within-subjects design and tasks-based assessment, allowing participants to partake in all conditions. A total of 20 participants were recruited to complete a standardized set of tasks (see Figure 5). Prior to the experiment, ethical approval was obtained from the Ethics Committee of Faculty IV of Technische Universität Berlin, and all participants provided informed consent by signing a consent form (see Appendix A). The experiment was conducted using an Android phone (*Oneplus 5*) and a headphone (*JBL 650*), both of which were provided to the participants for the duration of the experiment.

3.5.1 Questionnaire Design

Pre-session questionnaire

The pre-session questionnaires encompassed a demographic questionnaire and the Affinity

Figure 5: A participant is doing the user study task

for Technology Interaction (ATI) Scale questionnaire (Franke et al., 2018). The demographic questionnaire solicited information regarding participants' age, gender, employment status, nationality, and prior experience with mobile AR apps. This comprehensive understanding of participant characteristics aimed to provide an overview of the participant pool. The ATI questionnaire was specifically employed to gain deeper insights into participants' technological experiences, perceptions, and overall satisfaction with mobile AR systems.

Middle-session questionnaire

The middle-session questionnaire was administered during the experiment immediately after the completion of each relevant task section. Its design aimed to capture instant data and gather participants' immediate feedback on their specific AR experience. The questionnaire's length was kept as concise as possible to prevent participants from feeling overwhelmed. However, it was crucial to ensure that the data collected maintained high quality. To address these considerations, the Short Version of the User Experience Questionnaire (UEQ-S) (Schrepp et al., 2017) was selected to evaluate the navigation experience, while a customized version of the User Experience Questionnaire extension (UEQ+) (Schrepp and Thomaschewski, 2019) was employed to assess the exploration aspects of the task session. This combination of questionnaires allowed for efficient data collection while maintaining the integrity and depth of the feedback provided by participants.

In terms of the UEQ+ questionnaire for the evaluation of exploration experience with interactive AR objects, four scales were selected based on the suggestions from the UEQ+ handbook (Schrepp and Thomaschewski, 2019), as well as the specific requirements of the study. The scale items within these selected scales were carefully chosen to align with the research objectives and gather relevant insights on the participants' perception of the interactive AR object exploration.

Post-session questionnaire

The post-session questionnaire was specifically tailored and chosen to address the third research question, which examined the impact of the auditory modality on immersion factors during navigation and exploration tasks. Given the context of the location-based augmented reality setting and the emphasis on assessing immersion as a driver of enjoyment and engagement in a series of tasks, the ARI (Augmented Reality Immersion) questionnaire developed by Georgiou and Kyza (2017) was employed. This questionnaire served as a comprehensive tool for evaluating the overall level of immersion experienced by participants throughout the series of navigation and exploration tasks in the location-based AR environment and measures the immersion level regarding the factors of *Engagement (Interest, Usability)*, *Engrossment (Emotional attachment, Focus of attention)*, *Total Immersion (Presence, Flow)*.

3.5.2 Task Flow

As shown in the flow chart of the user study tasks (Figure 6), initially, participants were provided with a concise overview of the study objectives, followed by brief instructions on how to use the application and associated devices. Prior to commencing the tasks, participants were required to complete the pre-session questionnaire. Throughout the experiment, a moderator accompanied the participants, ensuring their presence did not disrupt the natural flow of the tasks. The moderator observed the participants' interactions with the application, ensuring adherence to the predefined task flows. To capture timely feedback, participants were interrupted immediately after completing each task section to fill in the middle session questionnaire under the guidance of the moderator. This approach facilitated the collection of detailed insights and reflections on the specific task section just completed, enhancing the overall data collection process.

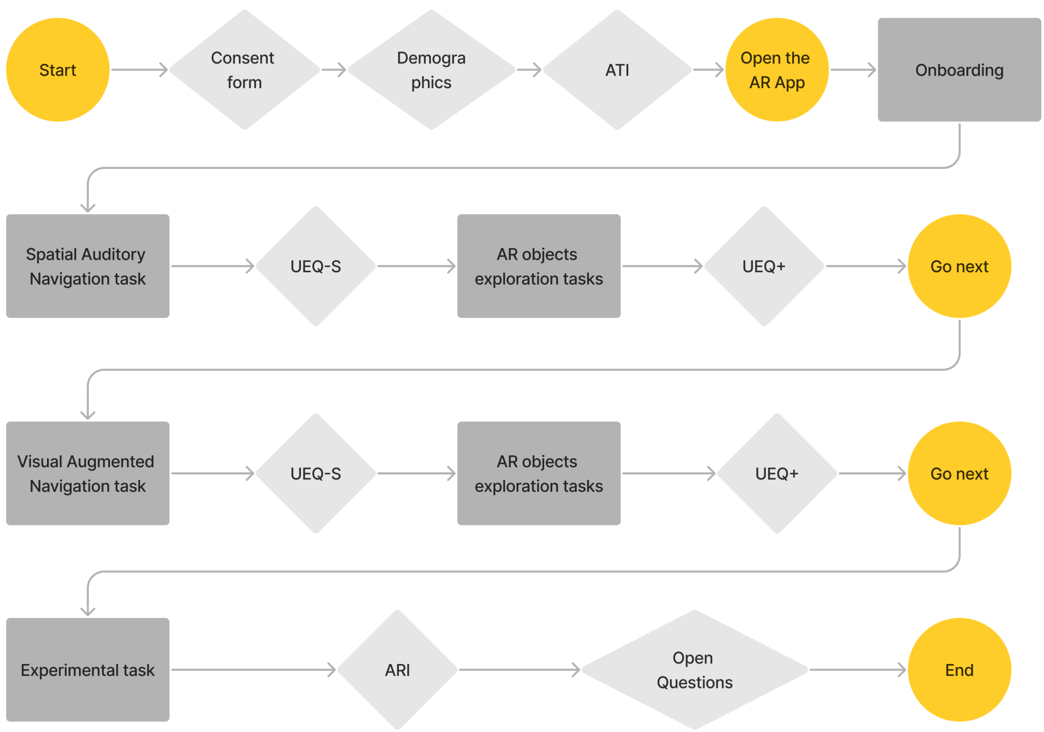


Figure 6: Task flow of the user study that shows the tasks a participant need to go through

Following the initial setup, participants proceeded to the formal task phase. The first task section instructed participants to open the app and follow the onboarding instructions. They were then prompted to select the "Goethe Monument" as their first destination, which facilitated spatial auditory navigation. Successful completion of this task required transitioning to the next page within the app, where the "Reach the site!" is shown.

The second task section focused on exploring the "Goethe Monument" site using the application's features. Participants were assigned specific subtasks related to tourist exploration, including placing and adjusting the size of an Audio AR object, controlling audio playback (pause, stop, play), clearing the plane canvas, placing and adjusting the size of a Text AR object, and toggling the visibility of the AR plane. Progression to the next task section was permitted once participants had completed all five subtasks.

In the third task section, participants were directed to navigate to the "Beethoven Memorial" destination, which relied on augmented visual navigation. Successful completion of this task required transitioning to the subsequent page within the app.

The fourth task section focused on exploring the Beethoven Memorial site with the application's features. Although detailed subtasks for AR object exploration were not explicitly described to reduce cognitive workload, participants were simply instructed to play with the two AR objects over the site and proceed to the next step once they had experimented with both objects.

The fifth task involved experimental navigation, where participants were instructed to proceed to the next destination, "Amazone zu Pferde" and set AR pins along the path. A successful transition to the next page indicated completion of the task. Upon arrival at the designated location, participants were provided with a three-minute period to explore the site using two types of AR objects, similar to previous tasks.

Middle-session questionnaires were interspersed throughout the experiment, immediately following each navigation and exploration task section, and the completion time of each task was counted. Upon completion of the experiment, participants were requested to fill out the post-session questionnaire. The holistic tasks and questionnaires can be seen in Appendix B. In addition to the structured questionnaire, participants were also asked some open-ended questions (see Appendix C), allowing them to provide qualitative feedback and share their insights on the overall AR experience.

3.5.3 Evaluation Design

Data from the user study was collected using Qualtrics XM[15], employing the aforementioned questionnaire and task design. The qualitative data analysis encompassed both the participants' responses to the questionnaires and the objective data of task completion time. Descriptive and inferential statistical analyses were conducted using the IBM SPSS[16] statistical software. For the data obtained from the UEQ-S and UEQ+ questionnaires, descriptive statistics such as mean values and standard deviations were calculated. Additionally, a paired-samples T-test was employed to examine statistically significant differences in Pragmatic Quality and Hedonic Quality of the user experience between the two navigation modalities and the two types of AR objects in exploration.

Regarding the data from the ARI questionnaire, descriptive statistics were computed to summarize the data. Furthermore, analysis of variance (ANOVA) was performed to compare the means of different factors (*Engagement*, *Engrossment*, *Total Immersion*) and determine whether any observed differences were statistically significant.

To evaluate the quantitative data obtained from the open-ended questions, a systematic approach was followed. The participants' answers were transcribed and carefully analyzed to identify recurring themes. These themes were subsequently categorized, allowing for a structured analysis of the data. Finally, the key findings were synthesized and summarized to provide a comprehensive understanding of the participants' qualitative responses. This systematic approach ensured the rigorous analysis and interpretation of the quantitative data derived from the open-ended questions, facilitating meaningful insights into the participants' perspectives and experiences.

[15]https://www.qualtrics.com/
[16]https://www.ibm.com/products/spss-statistics

4 Results

This section focuses on the evaluation and comparison of user experiences with two different modalities: *Spatial Auditory Navigation* and *Augmented Visual Navigation*, and the responses to the two types of interactive AR objects (*Auditory Goethe*, *Textual Goethe*, *Auditory Beethoven*, and *Textual Beethoven*) will be analyzed. Furthermore, the results obtained from the ARI questionnaire, which assesses the overall AR experience, are examined. Through a systematic analysis of these aspects, the research questions can be addressed, yielding valuable insights. Moreover, the trends observed in the quantitative data, along with the qualitative responses obtained from open-ended questions, can provide additional insights for discussion.

The research study included a sample of 20 participants, consisting of 9 males and 11 females. Regarding age distribution, there were 8 participants (40%) aged 35-44, 5 participants (25%) aged 18-24, 5 participants (25%) aged 25-34, and 2 participants (10%) aged 45-54. Among the participants, 12 were students. Geographically, 13 participants were from Germany, while the remaining 7 participants hailed from various countries originally, including China, Britain, Vietnam, Netherlands, Sweden, and Azerbaijan. In terms of familiarity with mobile AR apps, 9 participants reported no familiarity, 6 had slight familiarity, 4 had moderate familiarity, and only 1 participant claimed to be very familiar with such applications. The average Affinity for Technology Interaction (ATI) of the participants was 3.911 (SD = 0.543).

4.1 Quantitative Data

4.1.1 UEQ-S

As outlined in Chapter 3, the UEQ-S was administered in the study, utilizing a 7-point Likert scale with eight items assessing Pragmatic Quality and Hedonic Quality. Each item had a range from -3 to 3. Thus, -3 represents the most negative answer, 0 is a neutral answer, and +3 is the most positive answer. The results of the UEQ-S in two navigation modalities regarding the mean values for each item are shown in Figure 7.

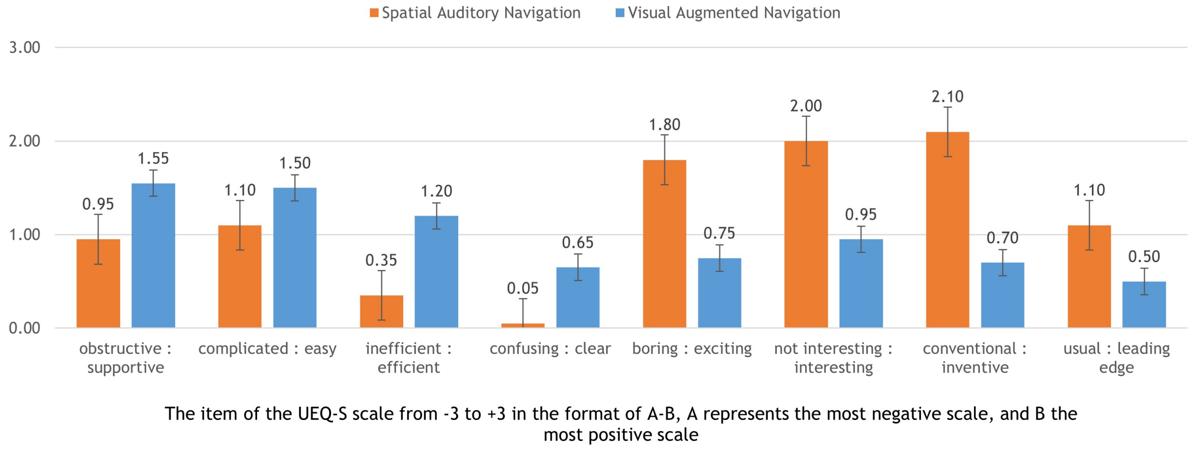


Figure 7: The mean value of each UEQ-S item for Spatial Auditory Navigation and Visual Augmented Navigation, with error bars representing a standard error

The data was calculated to get the results of mean values for Hedonic Quality, Pragmatic Quality, and UEQ Overall (see Figure 8). Then a paired-samples T-Test was conducted to determine statistically significant differences in these two scales between the two navigation modalities.

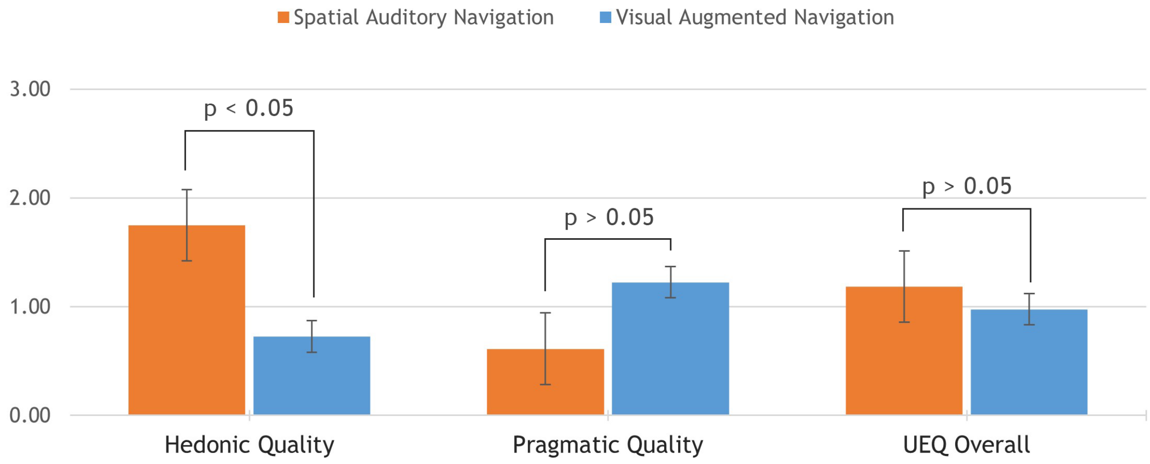


Figure 8: The mean value of Hedonic Quality, Pragmatic Quality, UEQ Overall in UEQ-S for Spatial Auditory Navigation and Visual Augmented Navigation with error bars representing a standard error, and p values indicating statistic difference

The results indicated a statistically significant difference in the Hedonic Quality scores between *Spatial Auditory Navigation* (M = 1.750; SD = 1.058) and *Augmented Visual Navigation* (M = 0.725; SD = 1.292) during the outdoor environment (t (19) = 2.983; p

= 0.008). *Spatial Auditory Navigation* was found to perform significantly better, demonstrating higher levels of excitement, engagement, and inventiveness. In terms of Pragmatic Quality, *Spatial Auditory Navigation* (M = 0.613; SD = 1.163) showed a lower score compared to *Augmented Visual Navigation* (M = 1.225; SD = 1.405), although the difference approached statistical significance (t (19) = 2.983; p = 0.089) but did not reach the threshold for significance. Regarding the UEQ Overall score, *Spatial Auditory Navigation* (M = 1.183; SD = 0.909) outperformed *Augmented Visual Navigation* (M = 0.976; SD = 1.122), although the difference was not statistically significant (t (19) = 0.801; p = 0.433). These findings suggest that while there are differences in user experience between the two navigation modalities, the effect on the overall user experience may not be substantial enough to be considered statistically significant.

4.1.2 UEQ+

The customized UEQ+ questionnaire includes four scales, Interesting, Motivating, Intuitive of Use, and Usefulness. Each item had a range from -3 to 3, -3 represents the most negative answer, 0 is a neutral answer, and +3 is the most positive answer.

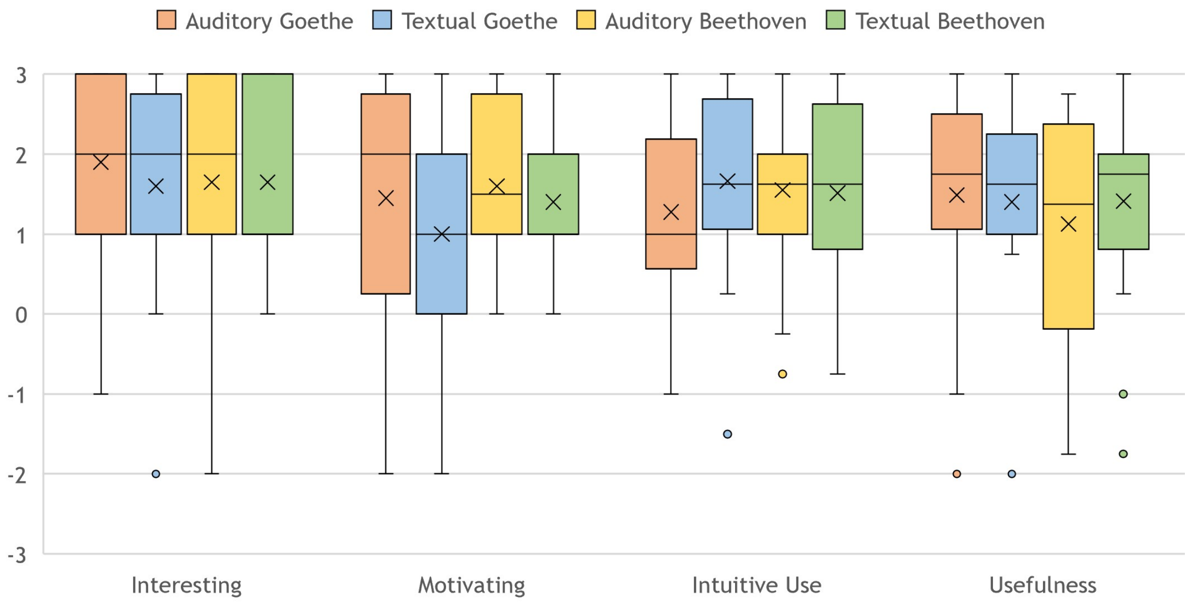


Figure 9: The data distribution of each UEQ+ scale for the AR objects Auditory Goethe, Textual Goethe, Auditory Beethoven, and Textual Beethoven with mean markers and outlier points

A set of boxplots (see in Figure 9) was generated to examine the distribution of responses. The visual representation indicates that the *Auditory Goethe* received higher scores for Interesting, Motivating, and Usefulness compared to the other scales. However, it obtained a relatively lower score for Intuitive Use. Similarly, the *Auditory Beethoven* achieved higher ratings for Motivating and Usefulness, particularly when compared with the *Textual Beethoven*. On the other hand, the *Textual Goethe* exhibited an advantage in terms of Intuitive Use when compared to the other AR objects, and the *Textual Beethoven* also demonstrated relatively high performance in this scale. Overall, the trends suggest that auditory AR objects tended to outperform textual AR objects in terms of Motivating, while Textual AR objects showed advantages in terms of Intuitive Use.

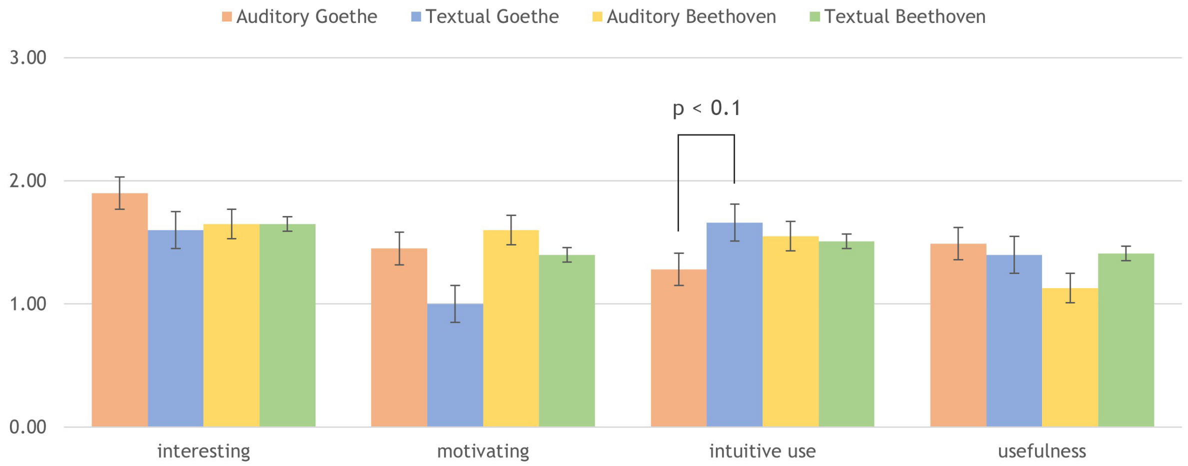


Figure 10: The mean value of each UEQ+ scale for the AR objects Auditory Goethe, Textual Goethe, Auditory Beethoven, Textual Beethoven with error bars representing a standard error

Figure 10 summarizes the responses in a series of bar charts regarding the mean value of each scale. In the evaluation of the two AR objects at Goethe Monument, participants reported the *Auditory Goethe* (M = 1.900; SD = 1.252) to be more interesting compared to the *Textual Goethe* (M = 1.600; SD = 1.273). However, at the Beethoven Memorial, the perceived interest in both the *Auditory Beethoven* (M = 1.650; SD = 1.268) and the *Textual Beethoven* (M = 1.650; SD = 0.988) was found to be comparable. The assessment of participants' perceived feelings of motivation at the two sights revealed a consistent trend. Specifically, the *Auditory Goethe* (M = 1.450; SD = 1.432) was reported to be more motivating compared to the *Textual Goethe* (M = 1.000; SD = 1.556). Similarly, at the Beethoven Memorial, participants found the *Auditory Beethoven* (M = 1.600; SD = 1.046) to be more motivating than the *Textual Beethoven* (M = 1.400; SD = 0.995).

These findings indicate a general preference for auditory AR objects over textual ones in terms of motivating the participants. In the aspects of Intuitive Use and Usefulness at the two sites, the results did not demonstrate a consistent trend. Specifically, participants perceived the *Auditory Goethe* (M = 1.275; SD = 1.022) to have lower intuitive use compared to the Textual Goethe (M = 1.400; SD = 1.324). On the other hand, for the Beethoven Memorial, participants assessed the *Auditory Beethoven* (M = 1.550; SD = 0.975) to have slightly higher intuitive use than the *Textual Beethoven* (M = 1.513; SD = 1.171).

Furthermore, in terms of usefulness, the participants rated the Auditory Goethe (M = 1.488; SD = 1.250) as more useful compared to the *Textual Goethe* (M = 1.400; SD = 1.324). However, for the Beethoven Memorial, the *Auditory Beethoven* (M = 1.125; SD = 1.346) was perceived to be less useful than the *Textual Beethoven* (M = 1.413; SD = 1.190).

A paired-samples T-Test was performed to evaluate whether there were statistically significant differences between the *Auditory Goethe* and *Textual Goethe*, as well as between the *Auditory Beethoven* and *Textual Beethoven*, across all the scales. The resulting p-values for each of the comparisons are presented in Table 4, indicating that no significant differences were found between the two types of AR objects. These findings suggest that, in terms of the evaluated scales (Interesting, Motivating, Intuitive Use, Usefulness), the participants did not perceive significant distinctions in performance between the auditory and textual versions of both the Goethe and Beethoven AR objects.

Table 4: T-Test results for two types of AR objects

Pair	Interesting	Motivating	Intuitive Use	Usefulness
Auditory Goethe - Textual Goethe	0.343	0.306	0.080	0.456
Auditory Beethoven - Textual Beethoven	1.000	0.408	0.817	0.368

4.1.3 ARI

In this section, the results from the ARI questionnaire about the overall immersive user experience regarding the three factors and their sub-factors, including Engagement (Interest, Usability), Engrossment (Emotional Attachment, Focus of Attention), Total Immersion (Presence, Flow) in the questionnaire are reviewed. The participants were asked to answer 21 questions for all the tasks they followed during the experiment. The answer to each question was a Likert-scale-based indication about the level of agreement to a statement where the number 1 represents strongly disagree and 5 strongly agree. Figure 11 shows the mean value of responses to all of the subfactors.

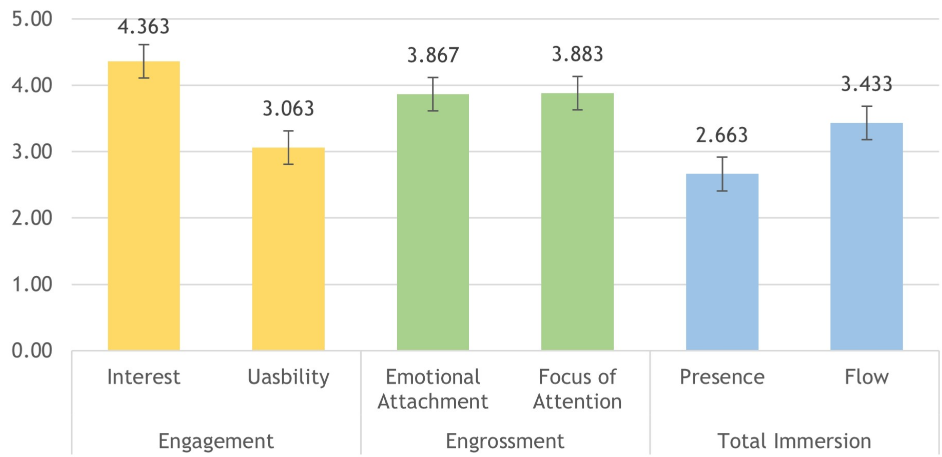


Figure 11: The mean value of each ARI sub-factor for the overall AR experience

The results indicate that Interest received the highest mean score (M = 4.363; SD = 0.705), suggesting that participants showed strong interest and enjoyment in the novel tasks and were willing to invest time in them. Emotional Attachment (M = 3.867; SD = 0.768) and Focus of Attention (M = 3.883; SD = 0.751) obtained relatively equal mean values, both marginally below the score of 4. This suggests that participants generally felt curious, excited, and engaged in the task progress, maintaining focused attention and a sense of involvement. Usability (M = 3.063; SD = 0.465) and Flow (M = 3.433; SD = 0.925) received mean values slightly above the neutral score of 3, indicating a more neutral perception regarding the ease of task completion with the AR application.

In contrast, Presence (M = 2.663; SD = 0.998) obtained a mean value below 3, indicating that participants generally did not perceive the interaction with the application as highly authentic. There seemed to be a perceptible gap between the augmented elements and the realistic experience, suggesting room for improvement in creating a more immersive and authentic augmented reality environment.

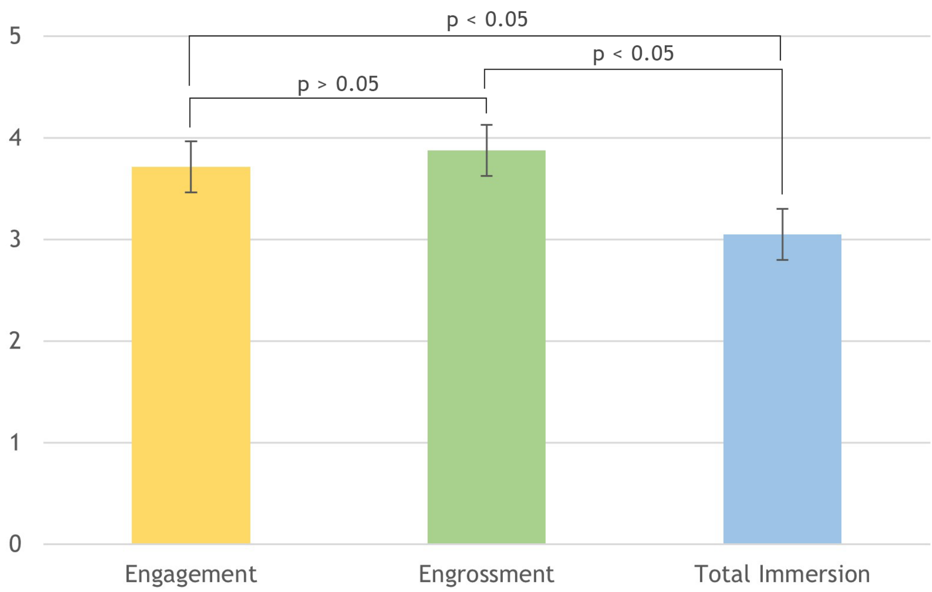


Figure 12: The mean value of each ARI factor for the overall AR experience with p values showing one-way ANOVA test results

A one-way ANOVA test was performed to compare the mean scores of three factors Engagement, Engrossment, and Total Immersion, based on responses from the 20 participants. Figure 12 shows the mean value of responses to all of the factors. The results indicated a statistically significant difference among the factors ($F(2,57) = 9.285$; $p < 0.001$). Subsequently, a Tukey post hoc test was conducted for multiple comparisons. The findings revealed that the mean score of Engagement ($M = 3.713$; $SD = 0.395$) was significantly higher than that of Total Immersion ($M = 3.875$; $SD = 0.646$), with an average difference of 0.665 ($p = 0.005$). Similarly, the mean score of Engrossment ($M = 3.048$; $SD = 0.817$) was significantly higher than that of Total Immersion, with an average difference of 0.827 ($p < 0.001$). However, no statistically significant difference was observed between Engagement and Engrossment ($p = 0.705$).

4.2 Qualitative Data

This section goes through the qualitative data including interview responses from the test participants made about the two navigation modalities, two types of AR objects and their overall experience with the tasks, and observation notes by the moderator. Based on the feedback, the results can be summarized in the following sections.

4.2.1 Navigation Tasks

Spatial Auditory Navigation

In the context of spatial auditory navigation, participants reported novel and exciting experiences, but also identified challenges related to navigation information regarding distance and direction. However, challenges arose concerning the lack of explicit navigation information, particularly regarding distance and direction. A participant mentioned, "*the direction is effective, but the distance is a bit confusing.*" The unstable technical implementation and external disturbances further complicated accurate spatial music-based navigation. A participant noted, "*when there were two directions, I just moved a tiny bit then it switched to the other ear which made me confused because I wasn't sure anymore if I go left or right*". Participants expressed expectations for clear paths during navigation, but the presentation of paths solely through spatial music proved challenging.

Furthermore, some participants reported auditory fatigue due to the repetition of spatial music during the navigation. As one participant mentioned, "*It was nice at the first minutes of the navigation, then after that it repeated that made me feel nervous.*" To improve the spatial auditory navigation, participants suggested incorporating more diverse audio content. Another participant suggested, "*On the way to the destination, an audio guide like a narrator telling a story on the site instead of just the music could be interesting.*"

Despite these limitations, spatial auditory navigation was praised for its ability to divert attention away from visual information, reducing cognitive workload and allowing participants to focus on the environment itself. One participant commented positively, stating that "*I don't have to look at the phone to find my way around, which makes the environment really stand out.*"

Augmented Visual Navigation

On the other hand, augmented visual navigation received favorable feedback for its provision of more intuitive and explicit distance and direction information. Participants emphasized the importance of orientation and navigation, especially in outdoor tourism settings. Being aware of orientation was deemed crucial for effective navigation. The visual navigation system was praised for its ability to display the distance to walk and the directions clearly, enhancing user experience.

4.2.2 Exploration Tasks

Perception of AR Objects

Participants appreciated both types of AR objects for providing additional information about the tourism sites. The level of information desired with the AR objects varied among participants. Some preferred concise and summarized information, with one participant stating, "*It was cool to get short information like a conclusion about the monuments.*" However, others expressed a desire for more comprehensive details and further links to additional information and suggestions about nearby attractions, one participant mentioned that some links to further information and suggestions about where to go next were missing. This variability highlights the importance of offering flexible content options in AR experiences to cater to diverse user preferences.

Content of AR Objects

Feedback regarding the content provided by the auditory AR objects indicated a desire for longer narrations with holistic information about the sites. Participants felt that solely presenting music or poems about the statues was insufficient. A participant suggested enhancing the experience by incorporating spatial auditory effects, where audio changes according to the movement of the AR object. This suggestion indicates the potential for more immersive and dynamic interactions with AR content, aligning with participants' interest in exploring AR objects in various ways.

Usability Considerations

Participants noted the benefits of augmented text display in providing additional insights beyond written text. However, some mentioned challenges with usability, particularly when white text overlapped with the snow-covered background, making it difficult to read. This feedback highlights the importance of considering environmental conditions and readability when designing AR content for outdoor settings.

Interaction Modalities

Notable observations were made concerning interaction modalities within the AR application. For instance, one participant attempted to interact with the AR object by stretching out a hand in front of the camera, into the air, expecting touchless manipulation. This feedback underscores the significance of exploring and refining intuitive and user-friendly interaction methods within AR applications.

5 Discussion

This chapter delves into a comprehensive analysis of the results obtained from both qualitative and quantitative data gathered during the user study. This chapter aims to explore and interpret the findings, providing insights into the participants' navigation and exploration experiences, as well as their perceived level of immersion in the AR application. The analysis highlights key observations, identifies possible reasons behind the results, and discusses any limitations encountered during the research. Additionally, recommendations and strategies to address these limitations and enhance the overall AR user experience are presented.

5.1 Navigation Experience

The spatial auditory navigation condition was shown to have a higher Hedonic Quality score than the augmented visual navigation one. This result is also related to some participants reporting that spatial auditory navigation was novel and exciting, letting them be more present and enjoy the environment more. However, it is important to acknowledge the potential for bias in these results, as individuals tend to be more intrigued by emerging technologies and modalities with fewer practical applications. The *Spatial Auditory Navigation* condition got a lower Pragmatic Quality score than the *Augmented Visual Navigation*. Despite not reaching a statistically significant difference, this outcome seems to come from users' perception of *Spatial Auditory Navigation* condition, which was reported as more inaccurate in providing precise distance, orientation, and direction information than the *Augmented Visual Navigation*. Therefore, *Augmented Visual Navigation* results in more efficiency in completing a navigation task.

The relatively lower Pragmatic score for *Spatial Auditory Navigation* might also be attributed to technical implementation issues. Firstly, The spatial auditory setting required participants to maintain the camera in the same direction they were facing to obtain relatively accurate orientation, which demanded additional attention from the participant. Moreover, some sensitivity issues were reported especially when the participant was relatively close to the destination, as one participant mentioned that the spatial audio did not perform accurately and sometimes jumped between left and right ears, even though it was an unintentionally tiny movement. Additionally, when participants were too far away from the destination, the volume change with distance was not as apparent, which is probably because the range of volume is limited, and is not enough to support the long-distance navigation. To fully exploit the potential of spatial audio, more sophisticated and advanced technical implementations are necessary.

Besides, an inherent limitation of *Spatial Auditory Navigation* is its difficulty in providing users with a clear and precise path with its 3D characteristics, which usually only indicate the direct line between the user and destination without additional guidance. Possible solutions may involve integrating narratives with exact path information into the spatial audio or combining both spatial audio and visual augmented cues simultaneously for more precise navigation. Further research is needed to explore and validate strategies for enhancing user experience concerning both Pragmatic and Hedonic quality in AR navigation tasks.

5.2 Exploration Experience

Despite the absence of significant differences between the two types of AR objects across all measured user experience scales, AR objects with *Auditory Information Display* showed a trend towards higher motivating experience compared to those with *Textual Information Display*. This finding suggests that the auditory modality has the potential to enhance user experience by infusing AR objects with more entertainment and interest, encouraging increased user interaction. However, the *Auditory Information Display* was not as intuitive as the *Textual Information Display*, indicating that users may require additional instructions to comprehend the intention of the auditory display and how to effectively interact with it.

In addition, the qualitative data revealed that the level of information provided by the AR objects varied among individuals, with some participants expecting more comprehensive tourism-related content, while others preferred summarized information and simple audio media without narrative inputs. The future optimization of the system can consider giving users access to customize the information level to their preference.

Regarding the exploration tasks, participant feedback focused more on the content delivered by the AR objects than on the information display modalities themselves. This finding implies that the impact of auditory modality on user experience may rely on the type and level of information conveyed. Therefore, further research is necessary to identify the tourism content-related factors that influence user experience when utilizing auditory modality in AR applications during exploration tasks.

Furthermore, it is essential to notice certain limitations in the research design that might influence the outcomes. As the *Auditory Information Display* and *Textual Information Display* were presented on distinct AR objects, potentially introducing confounding variables related to the design of these objects, which could overshadow the true impact of information display modalities on user experience. To enhance the validity of the findings and isolate the influence of auditory modality, future research should consider refining the research design by ensuring that any differences in user experience are genuinely attributed to the auditory modality rather than the characteristics of the AR objects themselves.

5.3 Immersion Factors

The present study conducted an evaluation of immersion in the AR experience, primarily focusing on the overall system rather than specifically isolating the impact of different modalities. Nevertheless, it is evident that the integration of auditory modality is essential in creating engaging and immersive user experiences.

Regarding the three factors of Immersion, the results indicated that both Engagement and Engrossment levels were higher than the Total Immersion level. This finding suggests that users demonstrated great interest in the tasks, perceived the app's usability favorably, and displayed strong emotional attachment and focused attention. However, the sense of presence, and the state of users' full absorption, were relatively weak in comparison to the other factors. And the levels of Engagement and Engrossment were found to be similar.

The comprehensive evaluation of the whole task experience indicated that the integration of auditory modality can contribute to the immersion level of the augmented outdoor tourism experience. In comparison to the levels of Engagement and Engrossment within the system, the aspects of Total Immersion, encompassing Presence and Flow, present a greater potential for improvement. Participants' feedback highlighted the need for a clearer sign to indicate successful arrival at the destination, as the transition from the navigation flow to the exploration flow was perceived as somewhat disruptive. By addressing such optimization, it would be possible to create a more authentic, realistic, and fully immersed user experience.

Another factor that could influence the immersion level of the experience was the outdoor environment condition. As the user testing was done in the winter season, the outside temperature was not friendly for the outdoor activities, especially for tasks requiring participants to expose their hands to hold the phone. It's still a challenge to address such external factors with the current mobile AR setup.

In this study, the ARI questionnaire was employed as an evaluation tool for measuring immersive user experiences. To advance this line of research, future work may focus on employing the ARI instrument with participants in location-aware AR settings as a variable in investigating several immersion-related issues. This approach can provide valuable insights to contribute to improved location-aware AR designs.

6 Conclusion

6.1 Answering Research Questions

Based on the data collected through user testing and the subsequent data analysis, this study addresses the research questions as follows.

For the first research question, *In the context of augmented outdoor tourism, what is the impact of auditory modality on user experience during navigation tasks?*, the findings indicate that spatial auditory modality enhances the Hedonic Quality of navigation tasks by offering a more exciting, interesting, and novel user experience.

Concerning the second research question, *In the context of augmented outdoor tourism, what is the impact of auditory modality on user experience during exploration tasks?*, this study reveals that AR objects with information displayed through auditory modality have the potential to attract users' interest and motivate interactivity, which can help to lead to an enhanced user experience during exploration tasks. Further exploration is needed concerning the content and level of information delivered through the auditory modality.

As for the third research question, *In the context of augmented outdoor tourism, how does the auditory AR impact the factors of immersion during navigation and exploration tasks?*, the study identifies that auditory AR design contributes significantly to the factors of Engagement and Engrossment, demonstrating potential for immersive user experiences. However, there is scope for improving the factor of total immersion through further design optimization.

6.2 Summary and Outlook

In this study, the impact of auditory modality on user experience during augmented outdoor tourism navigation and exploration tasks was investigated. An AR prototype was designed and developed based on design rationales derived from relevant literature research and specific experiment requirements. Through a comprehensive user evaluation, the research questions were answered, and the system's validation was achieved. By comparing two navigation modalities and two types of AR objects, the study highlighted the significance of auditory modality in providing more exciting, interesting, motivating, and novel AR experiences. The integration of spatial audio cues in navigation tasks and interactive AR objects with contextually relevant information in exploration tasks contributes to user engagement and engrossment more than the total immersion.

The limitations of the study were discussed. For instance, a larger pool of test participants could further enhance the robustness of the findings. Moreover, as the prototype serves as a proof-of-concept rather than a polished system, future work should focus on technical improvements, especially concerning precise position tracking.

Furthermore, the study revealed the potential impact of combining multiple modalities and the influence factors like information levels on user experience. Consequently, some research directions concerning auditory modality can be considered in the future:

- *Investigating the combination of auditory and visual modalities for improved user experience during augmented outdoor tourism navigation tasks.* Under this topic, the comparison could involve auditory modality as the primary mode with visual assistance, and vice versa, to explore the most effective combination.

- *Assessing the influence of auditory information levels on user experience during outdoor tourism exploration tasks.* In this scenario, the control variable would be the level of information delivered through auditory modality, providing valuable insights into how different information levels impact user experience.

By further exploring these research directions, the understanding of auditory modality's role in augmented outdoor tourism experiences can be expanded, leading to more informed and optimized design strategies in the future.

References

Ajanki, Antti; Billinghurst, Mark; Gamper, Hannes; Järvenpää, Toni; Kandemir, Melih; Kaski, Samuel; Koskela, Markus; Kurimo, Mikko; Laaksonen, Jorma; Puolamäki, Kai and others, . An augmented reality interface to contextual information. *Virtual reality*, 15:161–173, 2011.

Albrecht, Robert; Väänänen, Riitta and Lokki, Tapio. Guided by music: pedestrian and cyclist navigation with route and beacon guidance. *Personal and Ubiquitous Computing*, 20:121–145, 2016.

Arifin, Yulyani; Sastria, Thomas Galih and Barlian, Edo. User experience metric for augmented reality application: a review. *Procedia Computer Science*, 135:648–656, 2018.

Azuma, Ronald T and others, . The challenge of making augmented reality work outdoors. *Mixed reality: Merging real and virtual worlds*, 1:379–390, 1999.

Bederson, Benjamin B. Audio augmented reality: a prototype automated tour guide. In *Conference companion on Human factors in computing systems*, pages 210–211, 1995.

Boletsis, Costas and Chasanidou, Dimitra. Smart tourism in cities: Exploring urban destinations with audio augmented reality. In *Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference*, pages 515–521, 2018.

Brooke, John. Sus: a "quick and dirty'usability. *Usability evaluation in industry*, 189(3): 189–194, 1996.

Chatzopoulos, Dimitris; Bermejo, Carlos; Huang, Zhanpeng and Hui, Pan. Mobile augmented reality survey: From where we are to where we go. *Ieee Access*, 5:6917–6950, 2017.

Cohen, Michael; Aoki, Shigeaki and Koizumi, Nobuo. Augmented audio reality: Telepresence/vr hybrid acoustic environments. In *Proceedings of 1993 2nd IEEE International Workshop on Robot and Human Communication*, pages 361–364. IEEE, 1993.

Cranmer, Eleanor E. Designing valuable augmented reality tourism application experiences. *Augmented reality and virtual reality: The power of AR and VR for business*, pages 73–87, 2019.

Davidavičienė, Vida; Raudeliūnienė, Jurgita and Viršilaitė, Rima. Evaluation of user experience in augmented reality mobile applications. *Journal of business economics and management*, 22(2):467–481, 2021.

Feiner, Steven; MacIntyre, Blair; Höllerer, Tobias and Webster, Anthony. A touring machine: Prototyping 3d mobile augmented reality systems for exploring the urban environment. *Personal Technologies*, 1:208–217, 1997.

Franke, T; Attig, C and Wessel, D. Affinity for technology interaction (ati) scale. *Int. J. Human–Computer Interact*, 2018, 2018.

Gander, Pierre. *Two myths about immersion in new storytelling media*. Lund University, 1999.

Georgiou, Yiannis and Kyza, Eleni A. The development and validation of the ari questionnaire: An instrument for measuring immersion in location-based augmented reality settings. *International Journal of Human-Computer Studies*, 98:24–37, 2017.

Han, Dai-In; Jung, Timothy and Gibson, Alex. Dublin ar: implementing augmented reality in tourism. In *Information and Communication Technologies in Tourism 2014: Proceedings of the International Conference in Dublin, Ireland, January 21-24, 2014*, pages 511–523. Springer, 2013.

Hassenzahl, Marc and Tractinsky, Noam. User experience-a research agenda. *Behaviour & information technology*, 25(2):91–97, 2006.

Huang, Weidong; Alem, Leila and Livingston, Mark A. *Human factors in augmented reality environments*. Springer Science & Business Media, 2012.

Hutzler, Armin; Wagner, Rudolf; Pirker, Johanna and Gütl, Christian. Mythhunter: gamification in an educational location-based scavenger hunt. In *Immersive Learning Research Network: Third International Conference, iLRN 2017, Coimbra, Portugal, June 26–29, 2017. Proceedings 3*, pages 155–169. Springer, 2017.

Indans, Reinis; Hauthal, Eva and Burghardt, Dirk. Towards an audio-locative mobile application for immersive storytelling. *KN-Journal of Cartography and Geographic Information*, 69:41–50, 2019.

Jingen Liang, Lena and Elliot, Statia. A systematic review of augmented reality tourism research: What is now and what is next? *Tourism and Hospitality Research*, 21(1): 15–30, 2021.

Kasapakis, Vlasios; Gavalas, Damianos and Galatis, Panagiotis. Augmented reality in cultural heritage: Field of view awareness in an archaeological site mobile guide. *Journal of Ambient Intelligence and Smart Environments*, 8(5):501–514, 2016.

Kim, Mi Jeong. A framework for context immersion in mobile augmented reality. *Automation in construction*, 33:79–85, 2013.

Kounavis, Chris D; Kasimati, Anna E and Zamani, Efpraxia D. Enhancing the tourism experience through mobile augmented reality: Challenges and prospects. *International Journal of Engineering Business Management*, 4:10, 2012.

Laugwitz, Bettina; Held, Theo and Schrepp, Martin. Construction and evaluation of a user experience questionnaire. In *HCI and Usability for Education and Work: 4th Symposium of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer Society, USAB 2008, Graz, Austria, November 20-21, 2008. Proceedings 4*, pages 63–76. Springer, 2008.

Lee, Gun A; Dünser, Andreas; Kim, Seungwon and Billinghurst, Mark. Cityviewar: A mobile outdoor ar application for city visualization. In *2012 IEEE international symposium on mixed and augmented reality-arts, media, and humanities (ISMAR-AMH)*, pages 57–64. IEEE, 2012.

Loureiro, Sandra Maria Correia; Guerreiro, João and Ali, Faizan. 20 years of research on virtual reality and augmented reality in tourism context: A text-mining approach. *Tourism management*, 77:104028, 2020.

Lund, Arnold M. Measuring usability with the use questionnaire12. *Usability interface*, 8(2):3–6, 2001.

Mantell, Jessica; Rod, Jan; Kage, Yuichiro; Delmotte, Fabien and Leu, Johnson. Navinko: Audio augmented reality-enabled social navigation for city cyclists. In *Proceedings of the Programme, Workshop Pervasive*, 2010.

Mariette, Nicholas. Human factors research in audio augmented reality. In *Human factors in augmented reality environments*, pages 11–32. Springer, 2012.

Martens, William L and Cohen, Michael. Spatial navigation by seated users of multimodal augmented reality systems. In *SHS Web of Conferences*, volume 102, page 04022. EDP Sciences, 2021.

Milgram, Paul; Takemura, Haruo; Utsumi, Akira and Kishino, Fumio. Augmented reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, 2351, 01 1994. doi: 10.1117/12.197321.

Miyakoshi, Makoto; Gehrke, Lukas; Gramann, Klaus; Makeig, Scott and Iversen, John. The audiomaze: An eeg and motion capture study of human spatial navigation in sparse augmented reality. *European Journal of Neuroscience*, 54(12):8283–8307, 2021.

Ocampo, Ardee Joy T. Tourmar: designing tourism mobile augmented reality architecture with data integration to improve user experience. In *Proceedings of the 2019 4th International Conference on Multimedia Systems and Signal Processing*, pages 79–83, 2019.

Papadopoulos, Theofilos; Evangelidis, Konstantinos; Kaskalis, Theodore H; Evangelidis, Georgios and Sylaiou, Stella. Interactions in augmented and mixed reality: An overview. *Applied Sciences*, 11(18):8752, 2021.

Park, Sangwon and Stangl, Brigitte. Augmented reality experiences and sensation seeking. *Tourism Management*, 77:104023, 2020.

Paterson, Natasa; Naliuka, Katsiaryna; Jensen, Soren Kristian; Carrigy, Tara; Haahr, Mads and Conway, Fionnuala. Design, implementation and evaluation of audio for a location aware augmented reality game. page 149–156. Association for Computing Machinery, 2010.

Perkis, Andrew; Timmerer, Christian; Baraković, Sabina; Husić, Jasmina Baraković; Bech, Søren; Bosse, Sebastian; Botev, Jean; Brunnström, Kjell; Cruz, Luis; De Moor, Katrien and others, . Qualinet white paper on definitions of immersive media experience (imex). *arXiv preprint arXiv:2007.07032*, 2020.

Pospischil, Günther; Umlauft, Martina and Michlmayr, Elke. Designing lol@, a mobile tourist guide for umts. In *Human Computer Interaction with Mobile Devices: 4th International Symposium, Mobile HCI 2002 Pisa, Italy, September 18–20, 2002 Proceedings 4*, pages 140–154. Springer, 2002.

Pranoto, Hady; Tho, Cuk; Warnars, Harco Leslie Hendric Spits; Abdurachman, Edi; Gaol, Ford Lumban and Soewito, Benfano. Usability testing method in augmented reality application. In *2017 International Conference on Information Management and Technology (ICIMTech)*, pages 181–186. IEEE, 2017.

Ramtohul, Arvind and Khedo, Kavi Kumar. A prototype mobile augmented reality systems for cultural heritage sites. In *Information Systems Design and Intelligent Applications: Proceedings of Fifth International Conference INDIA 2018 Volume 2*, pages 175–185. Springer, 2019.

Ren, Gang; Wei, Side; O'Neill, Eamonn and Chen, Fenfang. Towards the design of effective haptic and audio displays for augmented reality and mixed reality applications. *Advances in Multimedia*, 2018, 2018.

Ronaghi, Mohammad Hossein and Ronaghi, Marzieh. A contextualized study of the usage of the augmented reality technology in the tourism industry. *Decision Analytics Journal*, 5:100136, 2022.

Rumiński, Dariusz. An experimental study of spatial sound usefulness in searching and navigating through ar environments. *Virtual Reality*, 19(3-4):223–233, 2015.

Russell, Spencer; Dublon, Gershon and Paradiso, Joseph A. Hearthere: Networked sensory prosthetics through auditory augmented reality. In *Proceedings of the 7th Augmented Human International Conference 2016*, pages 1–8, 2016.

Santos, Marc Ericson C; Taketomi, Takafumi; Sandor, Christian; Polvi, Jarkko; Yamamoto, Goshiro and Kato, Hirokazu. A usability scale for handheld augmented reality. In *Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology*, pages 167–176, 2014.

Schrepp, Martin and Thomaschewski, Jörg. Handbook for the modular extension of the user experience questionnaire. In *Mensch & Computer*, pages 1–19, 2019.

Schrepp, Martin; Hinderks, Andreas and Thomaschewski, Jörg. Design and evaluation of a short version of the user experience questionnaire (ueq-s). *International Journal of Interactive Multimedia and Artificial Intelligence, 4 (6), 103-108.*, 2017.

Seichter, Hartmut; Grubert, Jens and Langlotz, Tobias. Designing mobile augmented reality. In *Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services*, pages 616–621, 2013.

Sundareswaran, Venkataraman; Wang, Kenneth; Chen, Steven; Behringer, Reinhold; McGee, Joshua; Tam, Clement and Zahorik, Pavel. 3d audio augmented reality: implementation and experiments. In *The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings.*, pages 296–297. IEEE, 2003.

Thomas, Bruce; Close, Benjamin; Donoghue, John; Squires, John; De Bondi, Phillip; Morris, Michael and Piekarski, Wayne. Arquake: An outdoor/indoor augmented reality first person application. In *Digest of Papers. Fourth International Symposium on Wearable Computers*, pages 139–146. IEEE, 2000.

Unity, . Unity. `https://unity.com/`, 2023.

Vazquez-Alvarez, Yolanda; Oakley, Ian and Brewster, Stephen A. Auditory display design for exploration in mobile audio-augmented reality. *Personal and Ubiquitous computing*, 16:987–999, 2012.

Vazquez-Alvarez, Yolanda; Aylett, Matthew P; Brewster, Stephen A; Jungenfeld, Rocio Von and Virolainen, Antti. Designing interactions with multilevel auditory displays in mobile audio-augmented reality. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 23(1):1–30, 2015.

Yovcheva, Zornitza; Buhalis, Dimitrios and Gatzidis, Christos. Engineering augmented tourism experiences. In *Information and Communication Technologies in Tourism 2013: Proceedings of the International Conference in Innsbruck, Austria, January 22-25, 2013*, pages 24–35. Springer, 2013.

Yung, Ryan and Khoo-Lattimore, Catheryn. New realities: a systematic literature review on virtual reality and augmented reality in tourism research. *Current issues in tourism*, 22(17):2056–2081, 2019.

Zhou, ZhiYing; Cheok, Adrian David; Qiu, Yan and Yang, Xubo. The role of 3-d sound in human reaction and performance in augmented reality environments. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, 37(2):262–272, 2007.

Appendices

A Declaration of Consent

The study aims to investigate the influence of audio on tourism navigation and exploration in an outdoor AR environment. You will be asked to start the experiment at a specific starting point in the park, and to use the mobile App to finish a list of tasks. During the process, a few questionnaires will be asked to finish at some points. The equipment for the experiment, like mobile phone and headphones, will be provided.

The study consists of:

- Pre-session questionnaire. (5 mins around)
- A list of tasks. (20 mins around)
- Mid-session questionnaires. (10 mins around)
- A post-session questionnaire. (5 mins around)
- Open-questions. (5 mins around)

By signing the form, you consent:

- I agree that the data collected through questionnaires, observation and interview stored in anonymous form and for scientific purposes (cf. Art. 89 GDPR), can be evaluated. I am aware that my participation primarily serves science and may not bring me a direct personal advantage.
- Personal data, such as this declaration of consent, will be kept strictly confidential and stored separately from each other. The transfer of personal data to third parties is excluded.
- My participation in the study is voluntary, so I can refuse to answer questions and I can cancel the study at any time without giving reasons.

- The declaration of consent is voluntary. I can revoke this declaration at any time. In the event of rejection or withdrawal, there are no costs or other disadvantages for me.
- I have been informed that my participation will only take place if I have signed this declaration of consent. I was given enough time for this and I was able to express my concerns and decide for or against participating in the study.
- I have read and understood the participant information in full. I also had the opportunity to ask questions and they were answered to my satisfaction. A copy of this declaration of consent will be given to me.
- I agree to be audio recorded in the open question session.
- I agree to be observed on intention by the test director.
- I agree that my time spent on the tasks can be recorded.
- I give permission for the questionnaire and audio data that I provide to be archived so it can be used for future research and learning. The information shared with other researchers will not include any information that can directly identify me. Researchers will not contact me for additional permission to use this information.
- I understand that information I provide will be used for the MSc thesis of the researcher and any subsequent study output. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact Zhirou Sun, at +31634299814, or email zhirou.sun@campus.tu-berlin.de.

Place, date and signature of participant:

....

B User Study Task Flow and Questionnaires

Introduction

Welcome to Tiergarten, Berlin! Tiergarten is Berlin's largest and most frequented inner-city park, you are now at the heart of Berlin life. Do you know there are many statues standing in the park? Do you expect to explore these statues with a novel AR experience? Do you want to hear the sound of the music in the park?

Here it is! "AR Tiergarten" is the mobile AR app that can navigate you to different statues in the park, and also let you learn the statues with music and AR objects. Please understand that the current App is still a prototype, which means technical issues could occur, but feel free to ask the test director whenever you have doubts.

Now it's time to check it out!

Please create your user ID in the format of "nickname_dd.mm.yyyy" (e.g. fishtank_23.10.2022).

....

Demographics

Please fill out the following questionnaire:

1. How old are you?
   O Under 18 O 18-24 years old O 25-34 years old O 35-44 years old O 45-54 years old O 55-64 years old O 45-54 years old

2. How do you describe yourself?
   O Male O Female O Non-binary / third gender
   O Prefer to self-describe ....
   O Prefer not to say

3. What best describes your employment status over the last three months?
   O Working full-time O Working part-time O Unemployed and looking for work O

A homemaker or stay-at-home parent O Student O Retired O Other

4. Which country do you come from?

   ....

5. How much prior experience do you have with mobile AR app?
   O Not familiar at all O Moderately familiar O Slightly familiar O Very familiar O Extremely familiar

ATI

Please indicate the degree to which you agree/disagree with the following statements:

Statement	Completely Disagree	Largely Disagree	Slightly Disagree	Slightly Agree	Largely Agree	Completely Agree
I like to occupy myself in greater detail with technical systems.	O	O	O	O	O	O
I like testing the functions of new technical systems.	O	O	O	O	O	O
I predominantly deal with technical systems because I have to.	O	O	O	O	O	O
When I have a new technical system in front of me, I try it out intensively.	O	O	O	O	O	O
I enjoy spending time becoming acquainted with a new technical system.	O	O	O	O	O	O
It is enough for me that a technical system works; I don't care how or why.	O	O	O	O	O	O
I try to understand how a technical system exactly works.	O	O	O	O	O	O
It is enough for me to know the basic functions of a technical system.	O	O	O	O	O	O
I try to make full use of the capabilities of a technical system.	O	O	O	O	O	O

Task Section 1

Please finish the following tasks:

1. Open the app and follow the onboarding instruction to start your journey.
2. Choose to visit "Goethe Monument".
3. Go to "Goethe Monument" with the 3D sound navigation.

You can go to the next step when you see the message "Reach the sight!" pops up.

Middle-session Questionnaire

Please fill out the following questionnaire:

How do you evaluate your experience with the 3D sound navigation?

obstructive	O	O	O	O	O	O	O	supportive
complicated	O	O	O	O	O	O	O	easy
inefficient	O	O	O	O	O	O	O	efficient
confusing	O	O	O	O	O	O	O	clear
boring	O	O	O	O	O	O	O	exciting
not interesting	O	O	O	O	O	O	O	interesting
conventional	O	O	O	O	O	O	O	inventive
usual	O	O	O	O	O	O	O	leading age

Task Section 2

Great! You just arrived your first sight, please continue to finish the following tasks:

1. Place an Audio AR object, adjust the size and move it around.
2. Pause, stop and play the audio.
3. Clear the plane canvas.
4. Place an Text AR object, adjust the size and move it around.
5. Turn off the plane.

You can go to the next step when you think you are done with all the tasks above.

Middle-session Questionnaire

Please fill out the following questionnaire:

In my opinion, handling and working with the AR object  are:

not interesting	O	O	O	O	O	O	O	interesting
demotivating	O	O	O	O	O	O	O	motivating
doesn't meet expectations	O	O	O	O	O	O	O	meet expectations
difficult	O	O	O	O	O	O	O	easy
illogical	O	O	O	O	O	O	O	logical
not plausible	O	O	O	O	O	O	O	plausible
inconclusive	O	O	O	O	O	O	O	conclusive
useless	O	O	O	O	O	O	O	useful
not helpful	O	O	O	O	O	O	O	helpful
not beneficial	O	O	O	O	O	O	O	beneficial
not rewarding	O	O	O	O	O	O	O	rewarding

In my opinion, handling and working with the AR object  are:

not interesting	O	O	O	O	O	O	O	interesting
demotivating	O	O	O	O	O	O	O	motivating
doesn't meet expectations	O	O	O	O	O	O	O	meet expectations
difficult	O	O	O	O	O	O	O	easy
illogical	O	O	O	O	O	O	O	logical
not plausible	O	O	O	O	O	O	O	plausible
inconclusive	O	O	O	O	O	O	O	conclusive
useless	O	O	O	O	O	O	O	useful
not helpful	O	O	O	O	O	O	O	helpful
not beneficial	O	O	O	O	O	O	O	beneficial
not rewarding	O	O	O	O	O	O	O	rewarding

Task Section 3

Please continue on the following tasks:

1. Go next and choose to visit "Beethoven Memorial".

2. Go to find the statue with visual AR navigation.

You can go to the next step when you think you are done with all the tasks above.

Please fill out the following questionnaire:

How do you evaluate your experience with the visual AR navigation?

obstructive	O	O	O	O	O	O	O	supportive
complicated	O	O	O	O	O	O	O	easy
inefficient	O	O	O	O	O	O	O	efficient
confusing	O	O	O	O	O	O	O	clear
boring	O	O	O	O	O	O	O	exciting
not interesting	O	O	O	O	O	O	O	interesting
conventional	O	O	O	O	O	O	O	inventive
usual	O	O	O	O	O	O	O	leading age

Task Section 4

Please play with the two AR objects over the site.

You can go to the next step when you tried the two objects out.

Middle-session Questionnaire

Please fill out the following questionnaire:

In my opinion, handling and working with the AR object  are:

not interesting	O	O	O	O	O	O	O	interesting
demotivating	O	O	O	O	O	O	O	motivating
doesn't meet expectations	O	O	O	O	O	O	O	meet expectations
difficult	O	O	O	O	O	O	O	easy
illogical	O	O	O	O	O	O	O	logical
not plausible	O	O	O	O	O	O	O	plausible
inconclusive	O	O	O	O	O	O	O	conclusive
useless	O	O	O	O	O	O	O	useful
not helpful	O	O	O	O	O	O	O	helpful
not beneficial	O	O	O	O	O	O	O	beneficial
not rewarding	O	O	O	O	O	O	O	rewarding

In my opinion, handling and working with the AR object  are:

not interesting	O	O	O	O	O	O	O	interesting
demotivating	O	O	O	O	O	O	O	motivating
doesn't meet expectations	O	O	O	O	O	O	O	meet expectations
difficult	O	O	O	O	O	O	O	easy
illogical	O	O	O	O	O	O	O	logical
not plausible	O	O	O	O	O	O	O	plausible
inconclusive	O	O	O	O	O	O	O	conclusive
useless	O	O	O	O	O	O	O	useful
not helpful	O	O	O	O	O	O	O	helpful
not beneficial	O	O	O	O	O	O	O	beneficial
not rewarding	O	O	O	O	O	O	O	rewarding

Task Section 5

Please continue on the following tasks:

1. Go next and choose to visit "Amazone zu Pferde".

2. Try the "set pins" along your path.

ARI

Thinking about your whole experience with the app, how much would you agree or disagree with the statements below?

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
I liked the activity because it was novel.	O	O	O	O	O
I liked the type of the activity.	O	O	O	O	O
I wanted to spend the time to complete the activity successfully.	O	O	O	O	O
I wanted to spend time to participate in the activity.	O	O	O	O	O
It was easy for me to use the AR application.	O	O	O	O	O

I found the AR application confusing.	O	O	O	O	O
The AR application was unnecessarily complex.	O	O	O	O	O
I did not have difficulties in controlling the AR application.	O	O	O	O	O
I was curious about how the activity would progress.	O	O	O	O	O
I was often excited since I felt as being part of the activity.	O	O	O	O	O
I often felt suspense by the activity.	O	O	O	O	O
If interrupted, I looked forward to returning to the activity.	O	O	O	O	O
Everyday thoughts and concerns faded out during the activity.	O	O	O	O	O
I was more focused on the activity rather on any external distraction.	O	O	O	O	O
The activity felt so authentic that it made me think that the virtual characters/objects existed for real.	O	O	O	O	O
I felt that what I was experiencing was something real, instead of a fictional activity.	O	O	O	O	O
I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/ objects directly.	O	O	O	O	O
I was so involved, that I felt that my actions could affect the activity.	O	O	O	O	O

I didn't have any irrelevant thoughts or external distractions during the activity	O	O	O	O	O
The activity became the unique and only thought occupying my mind	O	O	O	O	O
I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity.	O	O	O	O	O

C User Study Open Questions

1. How would you describe your overall experience?
2. How did you feel about the navigation with spatial music? How effective is it? Is it clear to you that how did the spatial music work?
3. How did you feel about the navigation experience with visual AR indication? How effective is it?
4. How satisfied or dissatisfied are you with the audio in the AR app?
5. What would you expect to happen when you reach a site?
6. How did you feel about the pins? How useful is it?
7. Which features did you like the best about the app?
8. What's most confusing or annoying in your experience?
9. What are you missing on the app?
10. What is the most important feature for you in an AR tourism app?