Understanding VR Accessibility Practices of VR Professionals

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ABSTRACT

Accessibility is a crucial concept in Virtual Reality (VR), pivotal for meeting the needs of users, including those with disabilities. In recent years, there is an increasing focus of VR products on enhancing the accessibility of a diverse range of digital content. Despite this growing attention from the VR community, there is a serious lack of empirical research on how VR practitioners consider VR accessibility. This includes their understanding of and insights into VR accessibility challenges and practices in the VR software development life cycle. In this paper, we aim to address these gaps using a mixed-methods approach. Specifically, we conducted interviews with 21 VR practitioners (incl. 3D modelers, developers, technical directors, and product managers), and surveyed 202 respondents from VR related industries. Our findings outline their insights and challenges they face concerning VR accessibility practices in the software development life cycle. Furthermore, our findings shed light on the challenges faced by practitioners concerning VR accessibility and the reasons why it often goes unconsidered. As far as we know, this is the first comprehensive report about the understanding of accessibility for VR software from the practitioner's perspective. We hope this paper will help VR professionals to better understand the issues and challenges in VR accessibility, and the potential solutions.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility**; **Empirical studies in accessibility**; • **Software and its engineering**;

KEYWORDS

Virtual Reality, Requirements, Accessibility, Survey, Interview, Empirical Research.

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1 INTRODUCTION

Accessibility is a key software quality factor that significantly influences end-user acceptance in large software markets [9, 47, 96]. Accessibility refers to the ease with which end-users including those with disabilities can interact with software products [15, 52, 68]. This includes performing basic tasks such as reading the text, using the keyboard for typing, and perceiving sounds [9, 10, 21]. There are existing standards for traditional software products. For example, the *Web Content Accessibility Guidelines* were recognized by the ISO in 2012 [113]. In recent years, the World Wide Web Consortium (W3C) released the initial *Extended Reality (XR) Accessibility User Requirements* (XAUR) guidelines in 2020 [40]. This guide includes a series of suggestions addressing user needs and requirements, such as immersive personalization [89], voice commands [33], interaction [104], color changes [105] and so on.

In recent years, due to the rapid growth of immersive technologies, VR has emerged as an important medium for the dissemination of digital content [32, 80]. Its influence has permeated various facets of daily life, facilitating communication [103], learning [43], entertainment [56], social interactions [8], and working [91]. However, VR accessibility issues have become significant challenges affecting the inclusiveness of VR products, particularly for users with disabilities. To address these issues, it is crucial to understand the perspectives of VR practitioners. However, the existing literature lacks comprehensive studies on VR practitioners' understanding of VR accessibility, their attitudes towards the software development life cycle, the reasons for not considering VR accessibility, and the challenges they faced.

In this study, we shed light on the insights and challenges concerning VR accessibility within the VR software development life cycle. The software development life cycle typically includes software requirements, software design and development, and software testing and evaluation. However, VR has rarely been considered in the software development life cycle. Traditional software development life cycle (e.g., websites and mobile applications) faced many accessibility challenges, [9, 28], and accessibility practices for VR may face even more unknown challenges and limitation [40]. To fill this gap, we conducted interviews and surveys with

VR practitioners, aiming to gain deeper insights into their attitudes toward VR accessibility within the VR software development life cycle. Our goal is to achieve a comprehensive understanding of these perspectives. The research questions (RQs) are:

- **RQ1:** What insights do VR practitioners have about integrating accessibility within the VR software development life cycle?
- **RQ2:** What are the reasons that lead VR practitioners to not consider accessibility during VR software development life cycle?
- **RQ3:** What challenges do practitioners face when addressing accessibility throughout the VR software development life cycle?

We employed a mixed-method in our study. We interviewed 21 VR practitioners and surveyed 202 VR practitioners to analyze their insights regarding VR accessibility in the software development life cycle. Additionally, we investigated the challenges they faced and the reasons why some may not prioritize VR accessibility.

Our findings indicated that VR practitioners from various professional backgrounds have significant differences in their understanding of VR accessibility. For example, VR practitioners with experience in traditional software development had a better understanding of VR accessibility. Throughout the software development life cycle, VR practitioners shared insights into VR accessibility, particularly during the requirements, design, development, testing, and evaluation phases. Nevertheless, our findings highlighted significant gaps in the implementation of VR accessibility practices within the software development life cycle. Furthermore, many VR practitioners did not prioritize VR accessibility, including a variety of reasons, such as human factors and experience, regional aspects, cost markets and teams, and hardware issues. Additionally, respondents specified particular reasons for not considering VR accessibility requirements. Challenges related to VR accessibility identified by VR practitioners included hardware features, insufficient professional knowledge, and difficulties encountered across various phases of the software development life cycle, such as requirements, design, development, testing, and evaluation. Finally, based on our findings, we discussed VR accessibility and proposed a series of future research directions. This study represents the first empirical investigation to explore insights and challenges of VR accessibility from the perspective of VR practitioners. It also stands as the first comprehensive investigation of VR accessibility practices from the perspectives of software engineering (SE) and VR. Therefore, our firsthand insights have the potential to significantly contribute to the advancement of VR accessibility within the software development life cycle.

2 RELATED WORK

2.1 Inclusive and Accessible VR

Unlike traditional software applications, VR applications are distinguished by their emphasis on immersive experiences. This immersive quality depends on the high-quality user experience, including aspects such as visual [51], sound [65], interface design [101], interaction mechanics [71], and user comfort [7]. For users with disabilities in VR, a high-quality user experience is crucial to address potential VR accessibility issues. XAUR has listed 19 XR requirements for users with disabilities, including visual, auditory, cognitive, neurological, physical, and speech disabilities. Such disabilities often interact with various human factors, such as age, gender, culture, and education [40]. Hidellaarachchi et al. [49] suggested that researchers should integrate various human factors to ensure that software applications (mobile applications and websites) are inclusive and accessible. However, the VR accessibility differs significantly from that of mobile applications and websites. Although mobile applications and websites have established mature accessibility standards, the XAUR standards are still under development. VR relies on various input devices, such as head-mounted displays, motion controllers, and gesture trackers. In contrast, mobile applications and websites depend on touchscreens, mice, keyboards, and voice input. Therefore, the interaction methods in VR differ significantly from those in mobile apps and websites. Moreover, VR accessibility depends on navigation, feedback, and the description and recognition of objects in virtual environments, whereas mobile apps and websites involve browsing information on a fixed screen, without the need for spatial movement.

In recent years, there have been increasing studies focusing on designing accessible VR systems for users with various types of disabilities. For example, Pladere et al. [84] suggested that VR systems should adapt digital content for users with visual disabilities, offering features like color blindness simulations, and text magnification. Collins et al. [18] proposed a framework that allows sighted guides to assist blind or low vision (BLV) users by navigating virtual environments and providing visual interpretation in social VR. Jung et al. [57] proposed accessible nonverbal cues that can represent non-verbal behaviors (nodding, shaking the head, and eye contact) through tactile and audio feedback. These cues assist BLV users in accurately and confidently grasping key information in social VR conversations. Allman et al. [2] re-developed a feature based on the computer game (Rock Band®) that converts visual information into tactile and audio feedback for users with limited vision. Wedoff et al. [118] designed verbal scaffolds and verbal/vibration scaffolds to help visually impaired teenagers experience VR games. The results showed that the performance of the verbal scaffolds was better than that of the verbal/vibration scaffolds. Andrade et al. [3] proposed an echolocation technology as a novel approach for users with visual impairments to explore virtual environments. Zhao et al. [124] proposed a toolkit named "SeeingVR", designed to make VR accessible to users with low vision. Similarly, Wang et al. [115, 116] proposed a novel approach using VR color blindness simulation to elicit special user needs during the requirements elicitation phase. For users with auditory impairments, Li et al. [65] presented a 'SoundVizVR' method, aimed at enhancing sound accessibility in VR for DHH (deaf or hard-of-hearing) users. For users with cognitive disabilities, Gerling et al. [38] recommended that VR systems automatically adapt interaction within VR environments for wheelchair users. They emphasized the importance of personalizing interaction based on the diverse abilities of the users. Vargas et al. [111] developed a VR-based application that incorporates music to aid therapy for users with cognitive disability therapy. The results showed that patients with cognitive impairments greatly enjoyed interacting with music within the virtual environments. For users with neurological disabilities, some studies found that people with neurological diseases can achieve active participation and immersion through game-based incentives [37, 94]. Lecavaliera et al. [19] demonstrated the feasibility of using VR for memory tasks among older adults. For users with speech disabilities, Atiyeh et al. [110] highlighted the potential of VR technology in assisting speech pathologists. They posited that VR-simulated social communication with personalized safe environments can be beneficial in treating people with speech impairments. Some studies also have explored the interaction of scents to enhance the overall VR experience [54]. Furthermore, Gualano et al. [42] found that social VR avatars can represent the diversity of disabled identities and resonate within specific communities. Conversely, these avatars may also lead to social biases. Therefore, is recommended that social VR applications allow users to flexibly adjust privacy settings according to different contexts, particularly to accommodate users with disabilities.

2.2 Challenges of VR Accessibility Practices

The importance of accessibility increased significantly towards the end of the 20th century [50, 62, 78]. Consequently, many large technology companies established dedicated accessibility programs, documents, and teams, such as Google, Apple, IBM, and Microsoft [78]. Governments in some regions also have established laws to guide IT companies in eliminating software usage barriers for people with disabilities [41]. Further, accessibility primarily focuses on the design and development of accessible software applications for users with disabilities. While the accessibility of traditional software applications is more established than emerging digital technologies (e.g., VR, AR, and MR), the software market still contains many applications with accessibility issues [9, 15]. Chen et al. [15] found that 89% of both open-source and close-source software applications have significant accessibility issues, with an average of 6.5 accessibility issues on each application page. In the last versions, 96% of the accessibility issues still have not been fixed. Furthermore, some software practitioners consider software accessibility as a non-priority. They believed that incorporating accessibility throughout the software life cycle might lead to extra costs, potentially affect software project timelines, and even unnecessary legal and regulatory issues [9].

While there has been increased attention to accessibility issues in domains such as the Web and software applications [16, 63, 85], digital technologies like Virtual Reality (VR) have received comparatively less attention. Mack et al. [68] reported that VR is among the top 20 keyword groups in the last 10 years, representing recent trends in VR technology with respect to accessibility and human-computer interaction (HCI). Currently, there are approximately 171 million VR users in the world [125], among which are people with disabilities. A survey by the Disability Visibility Project [106] reported that people with visual impairment or autism are not well supported with VR technology. They also found that people with mobility impairment might have challenges with actions like crouching or moving during VR gameplay. Kelly et al. [59] noted that cybersickness is a prevalent issue among VR HMD (head-mounted display) owners, with various types of displays leading to different symptoms. Thus, there is an urgent need to improve the accessibility of VR products, enabling VR practitioners to better meet users with disabilities. Furthermore, most VR manufacturing companies have released accessibility guidelines for their VR headsets such as Meta Quest [88], and HTC VIVE [112]. Heilemann et al. [46] found that the EN301549 accessibility standard (the harmonized European standard for ICT accessibility) is not actively adopted by VR game developers [30]. As a result, they proposed specific guidelines to enhance the accessibility of VR gaming.

In recent years, W3C released the XR Accessibility User Requirements (XAUR), providing user needs and requirements for users with disabilities when using VR. Meanwhile, the implementation of VR accessibility can be influenced by various factors, such as human factors, the size of an organization, and the complexity of VR products [20, 55, 60, 64]. Besides this, some methods can improve the evaluation of VR accessibility, including the XR access audit tool, surveys, interviews, and user testing from user feedback and conducting accessibility self-assessment [1, 27, 36]. However, there still remains a limited understanding of how VR practitioners reference VR accessibility standards.

With rapid progress in Metaverse, computer graphics, and hardware, there will be a consistent growth in the number of end users and products of VR [17, 26, 59, 100]. Yet, most VR practitioners still lack an understanding of VR accessibility in the software development life cycle. Furthermore, there is no comprehensive study that investigates VR practitioners' insights and challenges regarding VR accessibility. In this study, we aim to obtain firsthand qualitative insights into the practices and understanding of VR accessibility within the software development life cycle through in-depth interviews and surveys.

3 RESEARCH METHOD

To answer our research questions (RQs), we first conducted semi-structured interviews, and then designed an online survey informed by the key findings from our interview data analysis. This mixed-method approach not only provides deeper insights and identifies the challenges, and reasons for not considering VR accessibility in the software development life cycle (RQ1, RQ2 & RQ3), but also enhances the survey's reliability and validity. Figure 1 shows a summary of our study processes. The Research Ethics Committee at our university reviewed and approved our study. The materials used for conducting interviews and surveys are publicly available [122].

3.1 Interview with VR Practitioners

3.1.1 VR Practitioner Recruitment. The first author and two co-authors conducted one-on-one semi-structured interviews with professional VR practitioners. We advertised our study to VR-related social media groups on LinkedIn [66], Twitter [108], Discord VR community [25], Facebook [31], WeChat [117], and GitHub community [39]. We collected the email addresses of VR practitioners from GitHub using keyword searches (e.g., 'VR' and 'Virtual Reality') and sent them invitation emails. We also found some professional VR engineers through our professional networks. Among VR practitioners, some have extensive experience in the VR industry, covering a range of job roles including 3D modeling, VR development, VR engineering, UI/UX design, and IT project management. All these approaches and platforms have been used in the literature to recruit software practitioners [9, 11, 12, 67, 98, 99].

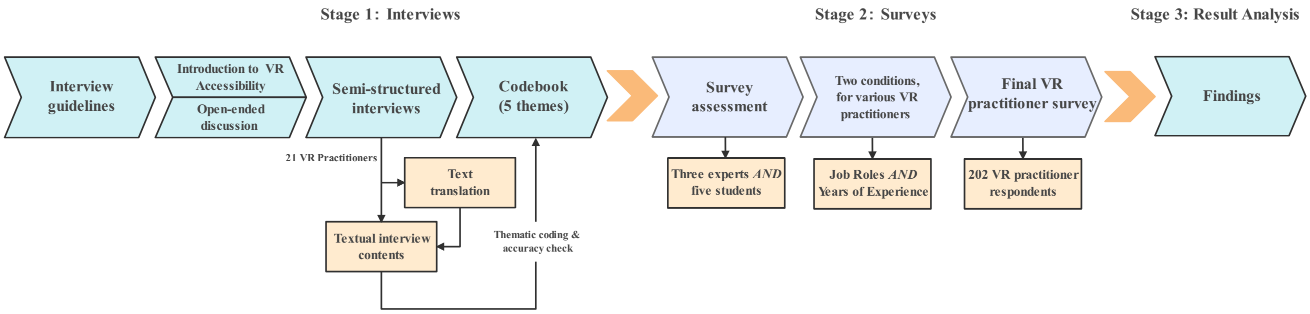

Figure 1: Sequential mixed-methods approach: an overview of the semi-structured interview and survey processes.

To ensure that all VR practitioners had a background in VR projects, we emphasized the inclusion criteria for all interested candidates in recruitment advertising. Interested candidates who met the criteria were able to send or respond to our emails indicating their willingness to participate in the interview study. We then scheduled an interview time with the interested candidates. Before the formal interviews began, we asked our VR practitioners for their understanding of VR accessibility based on our inclusion criteria. Initially, we first asked the practitioners if they were familiar with VR accessibility. For those who did not understand the concept, we provided an explanation. Then, we asked whether they had considered VR accessibility in their projects. VR practitioners who were unfamiliar with the concept of VR accessibility but had considered or somewhat considered it in their VR projects met our inclusion criteria. Those who were familiar with the concept of VR accessibility and had actively considered it in their VR projects also met our inclusion criteria. Conversely, VR practitioners who understood the concept of VR accessibility but did not consider it in their VR projects, as well as those who neither understood nor considered VR accessibility, were excluded from our study. We withdrew our interview study for some VR practitioners and did not provide a reward. Among these were 10 participants who did not attend our interview study. One participant was excluded due to a lack of VR development experience, despite having experience in 3D modeling. Finally, we recruited 21 VR practitioners. We also provided each interviewee with a choice of a 20 USD or 30 AUD e-gift card and a 150 RMB red envelope on WeChat [120].

3.1.2 VR Practitioner Demographics. In total, we interviewed 21 VR practitioners via online meetings. Each of the VR practitioners had more than three years of VR experience in the industry. They had seven years of experience on average (SD=4) in the VR industry. The age distribution of the participants was as follows: 11 were between 25-34 years old, nine were between 35-44 years old, and only one was between 18-24 years old. Only one participant identified as female, while the rest identified as male. 14 participants were affiliated with mid-size IT companies, three with startups, two with large IT companies, and two with universities. Nine participants had more than a year of prior work experience in large VR companies. All VR practitioner participants had experience in VR projects. Among them, eight participants previously held different roles in industries, three participants had traditional software design and development experiences (e.g., web and mobile application design and development). Two participants were from universities; one had three years of VR development experience in industries; while the other studied VR artifacts restoration and tourism at a university research institute. In addition, participants participated in the development of various types of VR products, including education, gaming and entertainment, training and simulation, architecture, healthcare, tourism, shopping, and industrial design. Table 1 summarizes VR practitioner participants' demographics. In Table 1, 'PF' represents VR practitioners who specialize in VR accessibility and possess a comprehensive understanding of it. 'PA' represents VR practitioners who are familiar of VR accessibility but have limited practical experience. 'PU' represents VR practitioners who are unfamiliar with the concept of VR accessibility but also have limited practical experience.

3.1.3 Study Procedure. We sent the plain language statement and consent form, which included additional information about our interview study (e.g., inclusion criteria), to VR practitioners ahead of the interviews. After screening out participants who did not meet the inclusion criteria, we then briefly introduced our study based on our interview guidelines. We asked participants if they were unfamiliar with the concept of accessibility. For those who were, we provided an introduction to the concept of accessibility. We then engaged in an open-ended discussion with VR practitioners for around five minutes.

Once the formal interview began, we first collected participants' demographic information to ensure they were qualified to answer the subsequent questions. We then asked the participants about the eight main questions and nine sub-questions that we had designed. These covered a series of topics on VR accessibility in the software development life cycle. Specifically, (1) We asked about the details of the VR accessibility practices in the software development life cycle (incl. requirements, design, development, testing, and evaluation phases). We also asked if there were internal company standards or industry requirements. Furthermore, we discussed the differences between traditional software development and VR software development and asked whether traditional software accessibility standards are suitable for VR accessibility requirements. (2) We discussed with VR participants the strategies they used to improve inclusion in VR products. We presented them with a series of accessibility issues in VR, such as operational, visual, auditory, cognitive, olfactory, and social challenges, taken from [1, 40, 65, 79, 124]. We then asked participants whether accessibility issues were considered or potentially considered in VR development and again asked about the approaches to overcome VR accessibility issues in the software development life cycle. (3) We discussed the challenges, and reasons for not considering VR accessibility in the software development life cycle. We asked about technical solutions and attitudes towards VR accessibility. We also asked about their familiarity with VR accessibility standards, such as XAUR or Virtual Reality Checks (VRC), technical challenges and open sources on VR accessibility toolkits, taken from a series of literature [1, 40, 75, 79, 124].

The interviews lasted between 22 and 60 minutes, on average 30 minutes (SD=12), and were conducted in English and Chinese. After the first few rounds of interviews, we revised the interview script to ask more precise and new questions that provided a deeper and clearer understanding of our interview questions. Once we reached theoretical saturation within our data, we stopped our interview study. The number of 21 VR practitioners has sufficed for a comprehensive interview study, and the responses have reached saturation [9, 82, 114].

3.1.4 Data Collection and Analysis. All interviews were audio-recorded via Zoom [126] and Voov [72], and transcribed using iFLYTEK's professional automated transcription services [53]. Four graduate students and one PhD student translated the Chinese transcripts into English and checked for data accuracy. They were proficient in both Chinese and English. They also performed an initial accuracy check on the auto-transcriptions. Two authors then performed a second round of rigorous quality checks on the transcriptions. This quality check aimed to rectify errors emerging from the automated transcription and translation process (e.g., translation of proper nouns) and to organize the structure of the transcriptions.

We analyzed the interview transcriptions using the MAXQDA [70]. The first author, in collaboration with two co-authors, inductively conducted "segment-by-segment" coding the 21 transcriptions using thematic analysis [14, 44]. We then conducted open-coding on the transcribed data, avoiding any influence from preconceived notions, presupposed codes, or theoretical assumptions. We finalized our code through multiple iterations and discussions, merging the overlapping codes, and discarding the duplicate ones. To establish validity and minimize bias in our coding process, all authors participated in a coding effort that spanned multiple weeks. Major disagreements were resolved through multiple iterations and discussions [22]. As a result, our codebook included three themes, **VR Accessibility in the Software Life Cycle**, **Unconsidered VR Accessibility**, and **Challenges in VR Accessibility**. These themes included a total of 126 final codes.

3.2 Survey with VR Practitioners

3.2.1 VR Practitioner. We designed an online survey: VR Practitioner Survey. We posted the VR Practitioner Survey to VR-related social media groups on platforms like LinkedIn, Facebook, Twitter, Discord, WeChat, GitHub and Prolifc [86]. We also emailed our **VR Practitioner Survey** to VR practitioners using addresses we previously collected from GitHub. We sent our online survey to our personal connections in the U.S., the U.K., Australia, and China-based VR technology companies and asked them to pass along the VR practitioner survey to VR departments within their organization. Our intention was to use snowball sampling to increase reach beyond the areas where we were advertising [45]. Additionally, 21 interviewees were asked to complete an online survey.

To ensure the quality of our survey, we invited two professionals in software engineering and one in VR to review the survey's design. We then conducted a pilot test with five students (three bachelor and two master students in IT) filling out the survey to verify its functionality. On the survey homepage, we specified the inclusion criteria for VR respondents: (1). Respondents must be in full-time employment, excluding those in internships or part-time positions. (2). VR respondents must be involved in VR-related work, which including roles VR UI/UX designers, VR software developers, VR software engineers, 3D modelers, audio and visual designers, VR project managers, VR testers, VR trainers, VR business analysts. (3). VR respondents must know VR accessibility or have considered the accessibility need of users with disabilities in their VR projects. To ensure data accuracy, we first enabled automatic detection of invalid responses on the survey platform and collected a total of 261 responses. Automatic detection identified 40 low-quality responses. We then manually reviewed the survey for response time, duplication rate, and completeness of response, excluding 19 responses. We offered each participant the choice of an Amazon e-gift card of 3 USD or 5 AUD and a red envelope of 20 RMB via WeChat (excl. Prolifc). We began recruiting in late December 2023 and accepted our last response in late January 2024. In total, we collected 202 responses.

3.2.2 VR Practitioner Demographics. Among VR practitioners, 24% respondents had less than 1 year of experience, followed by 1-4 years (40%), 5-9 years (22%), 10-14 years (8%), and more than 15 years (5%) in the VR-related industry (see Table 2 for details). In terms of gender, 50% self-identified as male, 40% as female, and 20 (10%) as prefer not to say.

3.2.3 Study Procedure. The VR Practitioner Survey consisted of all closed-ended questions inspired by our interview study. The VR Practitioner Survey explored VR practitioners' understanding and insights into VR accessibility, and its practices throughout the software development life cycle, including a series of phases such as requirements, design, development, testing, and evaluation. The survey also explored the challenges they faced. We activated AI detection of response quality on our survey platform. According to previous studies, more than 200 qualified VR respondents has sufficed for a comprehensive survey study [9, 114].

3.2.4 Data Collection and Analysis. We collected data using Wenjuanxing in Chinese [119] and Qualtrics in English [87]. We used a descriptive analysis of responses to all closed-ended questions (single-choice, multiple-choice, 5-point Likert & 5-point matrix rating scale questions) using RStudio [90].

4 FINDINGS

We present our findings based on analysis of interview and survey data. In each subsection, we outline the results from our interview

Table 1: A Summary of VR Practitioner Demographics.

ID	Age	Gender	Company Type	Job Roles (within five years)	VR Products	Exp. (Years)
PF1	24-30	Male	Mid SW Comp.	Project Manager & Technical Director	Training and Simulation	6
PU2	35-44	Male	Mid VR Comp.	VR Developer	Gaming and Entertainment	3
PU3	35-44	Male	Mid SW Comp.	Technical Director	Training and Simulation	6
PU4	35-44	Male	Mid SW Comp.	Technical Director	Training and Simulation	7
PU5	24-30	Male	Mid SW Comp.	VR Developer	Training and Simulation	4
PU6	24-30	Female	Mid SW Comp.	VR Developer & Web Developer	Education	3
PA7	24-30	Male	Mid SW Comp.	VR Developer	Education & Healthcare	6
PA8	35-44	Male	Startup	VR Developer	Gaming and Entertainment	7
PU9	35-44	Male	Large SW Comp.	VR Developer	Gaming and Entertainment & Education	12
PU10	25-34	Male	Mid SW Comp.	Senior Engineer	Gaming and Entertainment	14
PA11	25-34	Male	University	Senior Engineer	Training and Simulation & Education	5
PU12	35-44	Male	Mid SW Comp.	Project Manager & VR Developer	Education & Culture and Tourism	5
PA13	35-44	Male	University	UI/UX Designer & 3D Modeler & VR Developer	Culture and Tourism & Education	17
PA14	35-44	Male	Large SW Comp.	Senior Engineer	Architecture & Education	15
PF15	25-34	Male	Mid SW Comp.	VR Developer & 3D Modeler & UI/UX Designer	Education & Culture and Tourism	7
PA16	25-34	Male	Startup	Senior Engineer & Founder	Culture and Tourism	10
PU17	35-44	Male	Mid SW Comp.	Senior Engineer (Founder)	Shopping & Industrial Design & Training and Simulation	15
PU18	18-24	Male	Mid SW Comp.	VR Developer	Industrial Design & Training and Simulation	3
PF19	25-34	Male	Mid SW Comp.	Project Manager & VR Developer	Education	7
PF20	25-34	Male	Mid SW Comp.	VR Developer	Education	5
PA21	25-34	Male	Large SW Comp.	Product Manager & VR Developer	Education	4

study, followed by the results of the survey conducted with VR respondents (RQ1, RQ2 & RQ3).

4.1 VR Practitioners' Understanding VR Accessibility

4.1.1 Interview with VR Practitioner Perspectives. Most VR practitioners had experience in VR development, often assuming various roles across different types of IT companies and departments. Despite this, only a few VR practitioners deeply understood the concept of VR accessibility, as evidenced by the comprehensiveness of their responses. Conversely, many VR practitioners were either unaware of or unfamiliar with the concept of VR accessibility (see Table 1 for details). Furthermore, we also found that some VR practitioners might have potentially addressed some accessibility issues in VR projects, such as visual impairment, hearing impairment, and so on. For example, PA11 provided an overview of VR accessibility from their experience:

> *"I realized that [VR accessibility] actually when we work on VR projects, we often involve these aspects [e.g., visual, hearing impairments]. It is just that the concept of accessibility is quite broad, and we may not cover everything... Because it [VR product] is often focused on user experience or interaction for general end-users." (PA11)*

Additionally, PA8 also mentioned that *"Newcomers [new employees or graduates] lack understanding of VR accessibility may not be aware of these standards [VR accessibility] until they gain work experience."* Some VR practitioners stated that they were unaware of VR accessibility during their university studies (PA11 & PU18). However, we speculate that knowledge of VR accessibility methods may be limited in the teaching of related programs (e.g., design, computer science, and software engineering). Hence, this limitation may influence VR practitioners' understanding and attitude towards VR accessibility in future developments.

4.1.2 Survey with VR Practitioner Perspectives. In a series of Likert questions (Table 2), we found that VR respondents with fewer years of work experience were unfamiliar with VR accessibility (far too much, slightly too much: ≈33%, ≈34%, ≈48%, ≈41%, ≈54%, respectively). Conversely, we also found that many VR UI/UX designers and VR product managers had a better understanding of VR

Table 2: Scaled rates about VR accessibility in different types of 1. work experience (years), 2. job roles, and 3. work experience in traditional software development. 5-point Likert scale from 1 point (lowest/far too little) to 5 points (highest/far too much). *(N=202).*

Title	Number	1	2	3	4	5
1. Scaled rates about the understanding of VR accessibility among different years of experience.						
Less than 1 year	24%	31%	19%	17%	25%	8%
1-4 years	40%	16%	30%	20%	28%	6%
5-9 years	22%	7%	18%	27%	44%	4%
10-14 years	8%	18%	24%	18%	35%	6%
More than 15 years	5%	Null	36%	9%	36%	18%
2. Scaled rates about the understanding of VR accessibility across different job roles.						
VR UI/UX designers	10%	5%	19%	10%	43%	24%
VR developers	19%	11%	24%	24%	34%	8%
VR engineers	16%	19%	28%	16%	34%	3%
3D modelers	11%	17%	35%	13%	35%	Null
Audio and visual designers	10%	29%	24%	14%	29%	5%
VR project managers	12%	8%	12%	25%	50%	4%
VR testers	9%	26%	26%	26%	11%	11%
VR trainers	4%	12%	38%	25%	25%	Null
VR business analysts	8%	31%	19%	31%	12%	6%
3. Scaled rates about the understanding of VR accessibility based on experience in traditional software development.						
Lack of experience in traditional software development	48%	28%	23%	17%	27%	5%
As a team leader, project manager	38%	4%	25%	19%	43%	5%
As a team member	14%	14%	28%	31%	21%	7%

accessibility (far too much, slightly too much: ≈67%, ≈54%, respectively). Furthermore, VR respondents with a lack of experience in traditional software development had a poor understanding of VR accessibility (far too much, slightly too much: ≈32%, ≈48%, ≈28%, respectively).

4.2 VR Accessibility in the Software Development Life Cycle

4.2.1 VR Accessibility in Requirements engineering activities. **Interviewee Perspectives.** Most VR practitioners stated that their main objective was to elicit user needs and requirements, commonly using interviews (including online) and surveys. However, diverse perspectives emerged during our interview study. Specifically, some VR practitioners from VR gaming and entertainment emphasized the importance of market surveys and competitor analyses (PA8, PU9, PU10, and PA14). PU10 noted that: *"In the first stage [before the prototype development phase], we usually refer to the practices of mature games in the market. The game designers summarize and re-plan based on these practices. The so-called user requirements are derived from market rules."* PA8 further detailed the process of gathering requirements:

> *"The first step would be to identify market opportunities. Then, we gather information from news or developer conferences. For example, if a particular VR headset achieves millions of sales, we validate the data's authenticity and examine the market conditions. After that, we continue with further research." (PA8)*

VR practitioners in VR gaming and entertainment held similar insights. Furthermore, P14 also shared a novel approach for using VR to identify user needs within the context of architectural design:

> *"When we ask clients to view models or interact with objects in VR [for interior design and architecture] In these cases, we can utilize VR tools to allow users to experience and collect their requirements during the process." (PA14)*

Furthermore, PA7 shared an example where a VR product was developed for the orphanage education system. To gather the high-quality requirements from users with disabilities, they conducted on-site visits and interviews in the orphanage. PF19 also discussed about identifying the special needs of students with autism. We found that VR products in the education and health sectors often prioritize VR accessibility requirements during the requirements elicitation phase. Moreover, PA16 also emphasized their consideration of VR accessibility requirements in the exhibition VR project. However, some VR practitioners noted that they conducted on-site visits without emphasizing VR accessibility requirements (PU3, PU4, PU5, PA13) (see subsection 4.3 for details).

Most VR practitioners indicated that they did not prioritize capturing VR accessibility requirements based on user feedback during the project iterations. Some VR practitioners also mentioned gathering user feedback via online testing and community forums; however, they often overlooked VR accessibility requirements (PA8, PU9, PU10). Furthermore, PA7's analysis of VR requirements found that: *"Children in the orphanage preferred female voiceovers."* Such inconsistency might affect the analysis of the VR accessibility requirements for children with disabilities. Additionally, PA15 highlighted their reliance on *"Qualitative analysis-subjective judgment"* method for analyzing VR accessibility requirements.

Some VR practitioners also mentioned their adoption of the *"persona and use stroy"* methods for requirements analysis (PA7, PU10, PA16). For example, PA7 stated that: *"If we are a product for the B2C projects [Business-to-consumer], except the B2B projects [Businss-to-business] and the B2G projects [Business-to-government], then we must consider the use of persona."*

Survey with VR Practitioner Perspectives. In a series of Likert questions (Figure 2-(1)), we found that VR practitioner respondents considered VR accessibility requirements for users with disabilities. Among them, the requirements for hearing impairments, operation difficulties, and motion sickness (strongly agree, somewhat agree: ≈56%, ≈57%, ≈65%, respectively) were the most considered in their VR projects. Conversely, several other requirements were rarely considered in their VR projects, especially olfactory impairments (strongly disagree, somewhat disagree: ≈50%).

Additionally, we found that VR practitioner respondents showed different attitudes about whether VR accessibility was a key task in requirements engineering (RE) phases (strongly agree, somewhat agree: ≈48%). However, many VR practitioner respondents agreed that traditional software accessibility requirements were different from VR accessibility requirements in the RE phases (strongly agree, somewhat agree: ≈68%, see Figure 2-(2) for details).

4.2.2 VR Accessibility Design and Development. **Interviewee Perspectives.** Many VR practitioners explored technical solutions to tackle VR accessibility challenges, often from a non-expert perspective. Specifically, PA11 provided an example of such an accessible technical solution:

> *"We consider it [voice recognition and interaction]...but we also incorporate other operations such as clicking or moving. We have used voice commands for control. For example, you can say "rotate" or "jump" instead of using hands or controllers. Additionally, we have developed a body movement recognition system, which allows interaction through users' body movements." (PA11)*

Many VR practitioners stated that they did not pay attention to open-source accessibility toolkits (e.g., the seeingVR-visual impairments toolkit [124]). Some VR practitioners considered that the development of accessible VR toolkits is complex, given the complexities involved in understanding the situation of disabled users (PU3, PA7, PA8, PU10, PA16, PU17, PF20). For example, PA8 stated that: *"From multiple perspectives, developing such a tool is not only challenging but also requires scientific validation."* Furthermore, some VR practitioners considered that a VR system designed for users with disabilities could include multiple tailored versions (PF1, PA7).

Most VR practitioners stated that VR development processes were different from traditional software development processes, except for object-oriented programming language (e.g., C# in Unity3D [109]). Some VR practitioners highlighted that the user experience for VR products was more demanding than traditional software products (PU10, PU11, PA16). For example, PA11 stated that avoiding frame drops or latency was a crucial goal in ensuring a high-quality user experience in development processes, noting that: *"In VR software design and development, there should be a greater emphasis on user experience because it is a virtual product. It focuses on realism, creating an immersive experience for users, which is different from traditional projects. The main goal is to provide users with a sense of presence."*

Additionally, PU3 mentioned the use of Adobe Photoshop [83] to design the user interface (UI), which was then imported into a 3D scene for walkthrough. While some prototyping tools such as Figma [34] are available for VR UI/UX design, many VR practitioners considered that that is inconvenient to assess UI/UX immersively during walkthrough (PU2, PA7, PU10, PA13 & PF15). Furthermore, PU10 considered that the UI and interaction design for VR games were different from that of traditional software, and standard tools might not fully support UI of VR game walkthroughs. PA8 also highlighted that the experience from traditional game interaction methods was not applicable to VR games: *"It [interactions] becomes important to respect players' intuitive understanding and design based on real-world standards. For example, how to flip a book requires rethinking and redesigning."*

Furthermore, PU2 stated that: *"Users primarily focus on functionality. They rarely have specific requirements for models...they should at least resemble the intended object."* Meanwhile, PF20 stated that full-body 3D avatars might have distortions and limb animation issues, leading to social barriers on social VR platforms.

Few VR practitioners considered that VR software projects involved a large number of files and resources, potentially making VR project management more complicated (PU13 and PA16). P16 stated that VR project management approaches were similar to traditional software project management (e.g., GitHub [39]). Meanwhile, PA7 stated that considering VR accessibility features and resources might increase the pressure on VR project management:

> *"We replaced this with a dialogue between the NPC [non-player character] and the real character [for users] to solve some of the problems of route guidance [visual impairments]...Then we used a lot of audio. I remember that before we did it for the disabled, the amount of audio in the project was just over 40 megabytes. After we finished it, it was nearly 2 gigabytes of audio." (PA7)*

Finally, many VR practitioners stated a lack of clear standards for VR accessibility development (PU2, PU5, PU12, PA13, PA14,

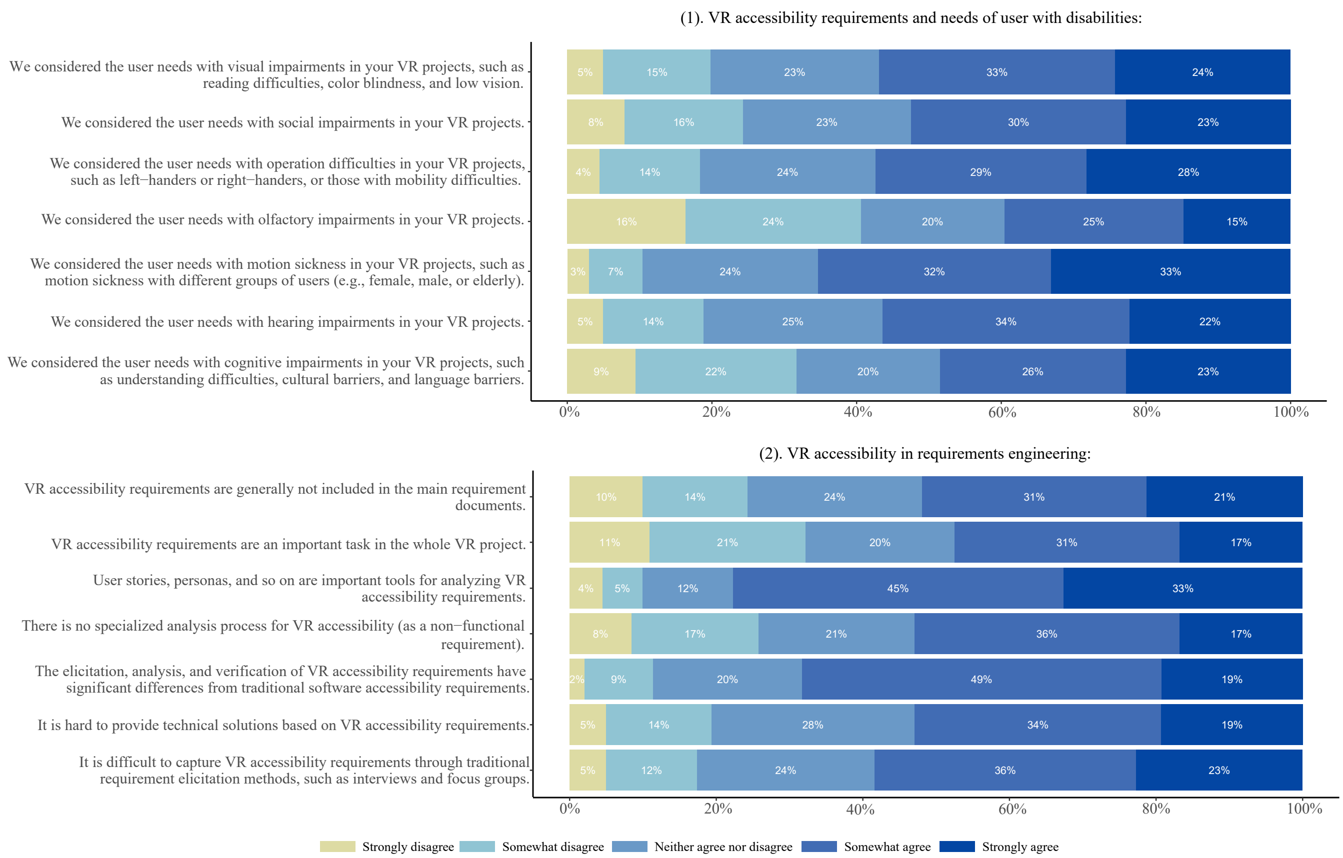

Figure 2: Scaled rates about VR accessibility practices in requirements engineering.

PU17). Some VR practitioners considered that establishing fixed standards for VR accessibility development might render VR products outdated, especially given the rapid advancements in the VR field (PU12, PU17). Furthermore, most VR practitioners considered that they paid little attention to the accessibility documentation provided by VR manufacturers, and none were aware of the XAUR standards released by W3C.

Respondent Perspectives. In a series of Likert questions (Figure 3- (1)), we found that making design decisions for VR accessibility was challenging when considering users with disabilities (strongly agree, somewhat agree: ≈60%). Meanwhile, the principles of universal design may not be directly applicable to VR accessibility design (strongly agree, somewhat agree: ≈50%). Prioritizing VR accessibility in the design phase could potentially compromise the overall user experience (strongly agree, somewhat agree: ≈57%). Additionally, we found that there were no mature open-source frameworks for VR accessibility features in the development phase (strongly agree, somewhat agree: ≈64%, Figure3-(2) for details).

4.2.3 VR Accessibility Testing & Evaluation. **Interviewee Perspectives.** Many VR practitioners did not understand approaches to test VR accessibility features. Some VR practitioners noted that testing was primarily conducted by in-house employees, with disabled users rarely included (PF1, PU2, PU3, PU6, PU9, PA21). PU2 stated that: *"In fact, sometimes themselves [VR end-users] may not have the expertise in professional testing that we possess. So, there are usually no major issues with internal testing."* Some VR practitioners stated that the testing of VR products was commonly processed by VR developers, 3D modelers, VR designers, or QA (Quality Assurance) professionals (PU2, PU9, PA14, PU18). On the other hand, PU5 stated they often recruit users who are unfamiliar with VR to evaluate the product's learnability. PF19 stated that: *"We...invite teachers and students (incl. students with disabilities) to evaluate and test it [VR product]. They try out the content [digital content] and provide feedback."*

Some VR practitioners stated that they commonly test for smoothness (to prevent motion sickness), interactions, user interface responsiveness, and visual clarity. (PU10, PA11, PA13). They also emphasized testing for hardware compatibility, including VR headsets designed for users with short-sighted and bone conduction technology for users with hearing impairments (PU3, PU4). However, PF19 indicated a reluctance to invest additional effort in VR accessibility testing during internal evaluations. Furthermore, none of the VR practitioners reported using tools specifically for VR accessibility testing (see Figure 4 for survey details).

Additionally, many VR practitioners indicated that they rarely considered recruiting disabled users for VR system evaluations (PU6, PA8, PU9, PU10, PA13, PA14, PF15). Conversely, some VR

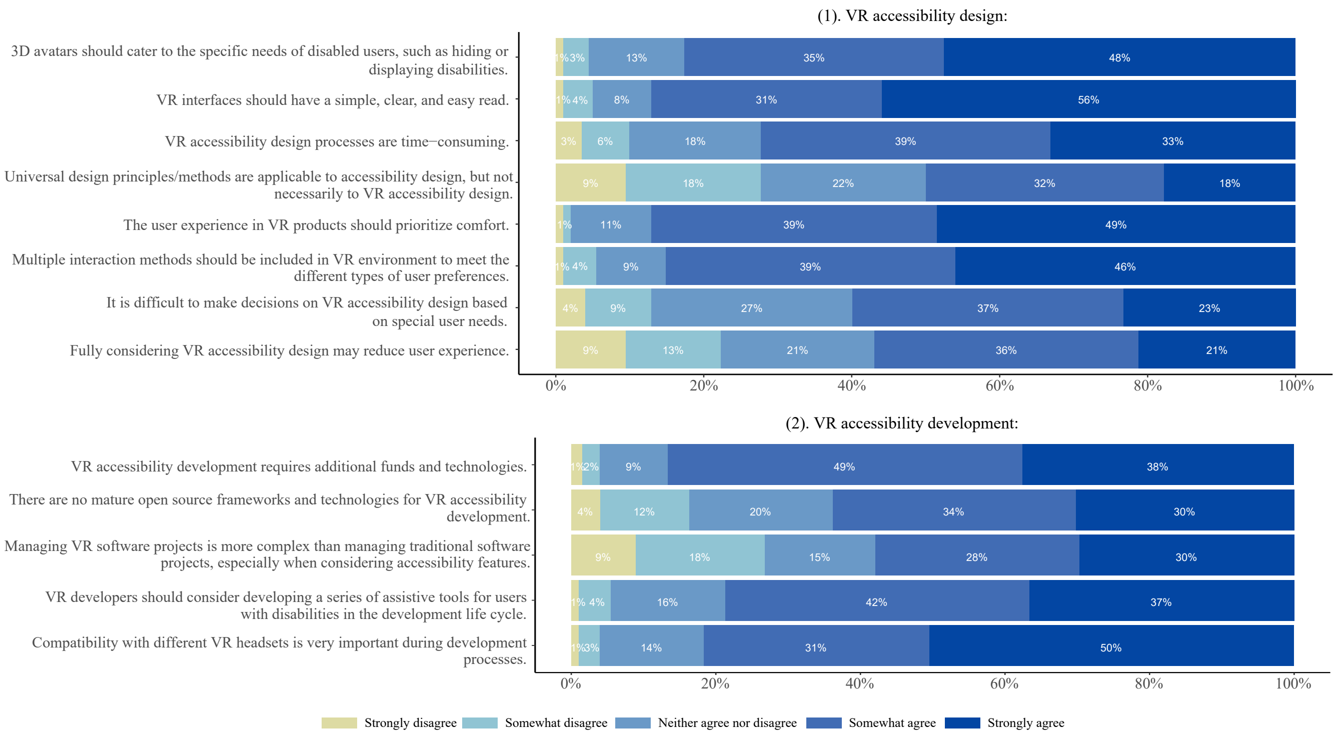

Figure 3: Scaled rates about VR accessibility practices in design and development.

practitioners highlighted their recruitment of users with disabilities for evaluations and even invited experts for guidance (PA7, PF19). However, despite these efforts, there was still a gap in their professional knowledge of how to effectively evaluate VR systems for users with disabilities (PU5, PU10, PA13, PA14, PF15, PF19). Although most VR practitioners prioritized evaluating effectiveness, usability, feasibility, and learnability, they overlooked the importance of evaluating VR accessibility features for users with disabilities. PU12 emphasized that involving experts from the culture sector in the evaluation of cultural products of VR is a priority, while the evaluations of general users are usually not a priority, and disabled users might ultimately be overlooked. Furthermore, many VR practitioners stated that they provided training for VR system users, including software manuals, and hardware instructions (PU3, PU5, PU6, PA7, PA14, PA16). However, most VR practitioners have not fully considered users with disabilities during the VR training process. Conversely, PF19 mentioned providing training tailored for users with disabilities, but without the involvement of accessibility experts.

Respondent Perspectives. In a series of Likert questions (Figure4), we found that VR respondents were overall negative about VR accessibility testing and evaluation. Few VR respondents referred to the XAUR standard or other standards for testing VR systems (strongly agree, somewhat agree: ≈18%). Furthermore, most VR practitioner respondents reported that extra efforts were necessary for VR accessibility testing and evaluation (strongly agree, somewhat agree: ≈77%, see Figure4 for details).

4.3 VR Practitioners' Reasons for (Not) Considering VR Accessibility

Interviewee Perspectives. Reasons VR participants did not consider VR accessibility include:

Human Factors and Experience. Some VR practitioner participants considered that human factors played an important role in not considering VR accessibility. PA13 noted an example that: *"Their [color blindness] perception of colors varies, and each person's perception is unique. It's not realistic to develop a customized program for each individual."* P18 stated that they only considered operational preferences, such as whether a user is left-handed or right-handed users, and overlooked more complex requirements of users with disabilities, like those with cognitive impairments. Furthermore, PF15 considered that excessive focus on VR accessibility could make the VR product less user-friendly for general users. PA13 shared an example that: *"From what I have observed so far, few VR products, including AR, pay attention to the readability, usability, and accessibility for special user groups."* On a different note, PU10 stated that: *"Actually, I'm more focused on hardware improvements that enhance user experience or game interaction. In terms of VR accessibility, it doesn't seem as crucial at this stage."*

Regional Aspects. Some VR practitioner participants considered the regional aspect as an important reason for not considering VR accessibility (PU12, PA13, PA14, PA21). PU12 considered that economic aspects could be significant limitations on VR accessibility. For example, in some economically developing regions, VR might

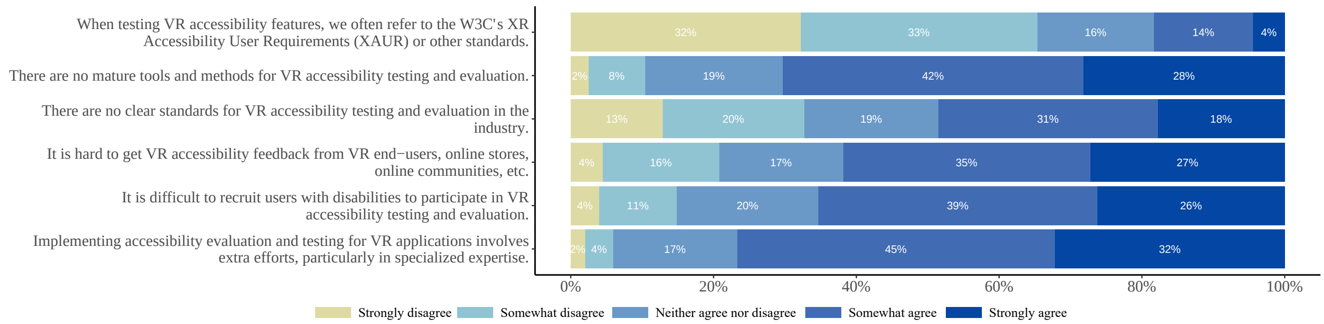

Figure 4: Scaled rates about VR accessibility practices in testing and evaluation.

still be considered an emerging technology that many people are unfamiliar (PU12). Furthermore, PA13 considered that: *"VR standards may not be fully developed yet...Currently, most countries have not introduced relevant standards, so we can only rely on the experience of developers and designers to achieve [VR accessibility]. This may result in the presence of many subpar products. For example, many people feel dizzy when wearing VR headsets, and some may even experience nausea."* Some VR practitioner participants stated that economically developed regions paid more attention to accessibility standards and laws than economically developing regions (PA13, PA14, PA21). Therefore, IT companies or practitioners in economically developing regions might always overlook the accessibility of digital products, or may even lack an understanding of accessibility.

Cost Markets, and Teams. Some VR practitioner participants considered the costs and markets as important reasons for not considering VR accessibility (PA7, PA8, PU12, PA14). PA14 stated that they always overlooked disabled users unless catering to them could yield a profit. PA8 stated that: *"In our case, we don't prioritize it because it requires significant investment and development capabilities, which only large companies or studios can afford. For smaller or medium-sized companies...it [VR accessibility] becomes a lower priority."* PU17 stated that considering VR accessibility depended on the size of the target user group; if the target user groups were small, VR accessibility was not considered. PA7 and PU12 considered that accessibility was prioritized more in B2C (business-to-customers) than in B2B (business-to-business) and B2G (business-to-government) VR projects. Furthermore, some VR practitioners stated that lack of professional knowledge and teams was one of the reasons for unconsidered VR accessibility (PA2, PA13, P18).

Hardware Issues. Most VR practitioner participants indicated that hardware issues were an important reason for not considering VR accessibility. PA14 considered that VR headsets still have many limitations, as they might be uncomfortable for some users to wear. PA14 also stated that if they encountered accessibility issues caused by hardware, they often had to compromise. PU17 stated that: *"Some hardware manufacturers may have established industry standards for accessibility, but there is a gap between hardware manufacturers and software development."*

Respondent Perspectives. Most VR practitioner respondents indicated hardware issues as a key reason not considering VR accessibility (mentioned 105 times). Furthermore, some VR respondents indicated other reasons for not considering VR accessibility, including evaluation issues and ethical issues (mentioned 6, and 4 times, respectively; see Figure 5 for details).

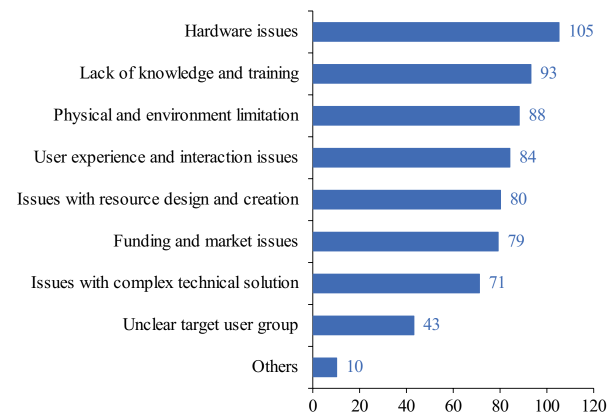

Figure 5: Reasons for not considering VR accessibility by VR practitioner respondents.

4.4 VR Practitioners' Challenges When Working with VR Accessibility

Hardware Features. Most VR practitioner participants stated VR hardware features were still an important challenge. For example, PA13 stated that it was not feasible for users with visual impairments to depend on toolkits, primarily because: *"It [toolkit] cannot physically correct vision in the same way lenses do."* Furthermore, PU2 stated that tethered VR headsets might restrict the user's head movements. PA14 considered that weight reduction of VR headsets was one of the key factors in overcoming physical limitations. Currently, the Oculus Quest 2 system also has a series of basic accessibility settings, such as vision (e.g., color correction), mobility (e.g., controller vibration intensity), and hearing [29, 73, 75, 77]. However, PA14 considered that: *" They [VR headsets] may not have a comprehensive accessibility option or functionality within the entire system."* Similarly, hardware issues were one of the reasons for not considering VR accessibility (see subsection 4.3 for details about the reasons for unconsidered VR accessibility).

User groups and requirements. Some VR practitioner participants considered that the diversity of disabled users and their varied needs were the main challenges (PU3, PU5, PU10, PA13, PF15, PU17). PU10 considered that the foundational frameworks for VR might not cater to the diverse needs of various special user groups. PF15 emphasized that catering to the diverse needs of users with disabilities was a key challenge. VR practitioners (e.g., software engineers) could not comprehensively consider the requirements of these users. Furthermore, some VR practitioner participants considered that unfamiliarity with VR products among users or clients could hinder the collection of high-quality requirements from them. Meanwhile, unclear user requirements emerged as the main reason for overlooking VR accessibility (mentioned 52 times, see Figure 5 for details on unconsidered reasons, see subsection 4.2.1 for details about requirements challenges).

Design and Development. Some VR practitioner participants considered that there were a series of challenges in software design and development (PU3, PU10 PU5). For example, PU10 stated that: *"There are various types of VR headsets, and their development revolves around OpenXR. However, the most challenging aspect is to achieve accessibility standardization for VR accessibility."* Furthermore, many VR practitioners considered that developing VR accessibility features was a complex task. For the survey with VR practitioners, complex technical solutions were one of the reasons for not considering VR accessibility (mentioned 71 times, see Figure 5 for details; see subsection 4.2 for details about the challenges of design and development).

Testing and Evaluation. Some VR practitioner participants mentioned that testing and evaluating VR accessibility was a key challenge (PU9, PA13, PA14, PU18). PA14 shared a case that: *"We thought they [users] would be easy to test when salespeople demonstrated it to users, but in reality, users felt pressured during the testing process. For users with disabilities, it might pose an even greater challenge."*. PU9 stated that: *"It's difficult to...find disabled users for testing. Beyond that, it [recruits users with disabilities] raises ethical issues."* (we discussed some challenges regarding testing and evaluation in subsection 4.2.3).

Insufficient Professional Knowledge. Some VR practitioner participants considered that insufficient professional knowledge was a key challenge (PU5, PA7, PU12, PA13). PA15 stated that they encountered many challenges when communicating with users who are deaf and hard of hearing, such as *"Our company currently doesn't have trainers specialized in communicating with deaf and mute people, so we can only rely on written expressions. We communicate through written text to facilitate understanding."* Furthermore, PF15 stated that lack of consideration for users with disabilities could lead to psychological harm and even legal issues, especially when presenting content that users might find distressing or terrifying. Interestingly, PU12 shared an example reflecting culture conflict: *"Their point was that it is a traditional cultural heritage or architecture that should be treated with seriousness, and we shouldn't make it too playful [VR for Culture and Tourism]."* For the survey with VR practitioners, the lack of knowledge for testing and evaluation was one of the reasons for unconsidered VR accessibility (mentioned 93 times, see Figure 5).

5 DISCUSSION AND FUTURE WORK

In this section, we discuss the findings of the insights gained from our study and propose a series of future research directions.

5.1 Understanding VR Accessibility from the Perspectives of VR Practitioners with Different Backgrounds

VR practitioners from different professional backgrounds significantly influence their perception of VR accessibility. Specifically, VR practitioners with more years of experience are typically more familiar with VR accessibility. However, VR practitioners in specific job roles, such as audio and visual designers, VR testers, 3D modelers, and VR business analysts, may not be as familiar with VR accessibility. These VR practitioners often have varied educational backgrounds, such as art, media, and software engineering. Although traditional software accessibility is a well-established area of study in design and computer science education [9, 13, 21, 35, 95], the integration of VR accessibility into VR-related education remains a significant gap. Some VR practitioners noted that new employees or graduates often lack an understanding of VR accessibility, as they did not understand the concept of accessibility during their university education. Traditional software practitioners also considered that education is a key factors limiting understanding of accessibility [9], but VR may presents additional challenges and limitations. Furthermore, we found that a lack of professional knowledge is still a significant challenge. While this aligns with the challenges of traditional software accessibility, specific VR products may require collaboration among experts from different fields to enhance their inclusivity and usability. For example, VR culture tourism products, which are typically aimed at the general public [121], may also attract visitors from special user groups. However, it remains a questions how VR culture tourism products can support disabled users experiencing culture tourism at home or on-site [121]. Therefore, we believe that specific VR products necessitate collaboration among experts from diverse backgrounds to better integrate VR accessibility with other human aspects such as age, gender, culture, and motivation.

VR practitioners with experience in traditional software design and development are more familiar with the importance of VR accessibility, especially project managers and team leaders. This disparity can be attributed to the more mature of accessibility in traditional software (Web Content Accessibility Guideline (WCAG) was initially released in 1999) [6, 40, 68, 69, 113].

Overall, our discussion highlighted factors that limit the understanding of VR accessibility, including job roles, experience, and educational background. However, we did not comprehensively explore additional human-centric aspects such as geographical, culture, economic, personal value and so on [48, 49]. Future researchers should focus on how these human aspects influence VR practitioners' understanding of VR accessibility in design and development. Additionally, we recommend a comprehensive investigation open-source VR projects and VR App stores to assess the VR accessibility and inclusivity of specific VR products for users with disabilities. Such studies would help VR practitioners and researchers better understand of the true thoughts and needs of end-users.

5.2 VR Accessibility Requirements

User needs and requirements are the initial phase of the software development life cycle, where eliciting high-quality user needs is a crucial factor for the success of software projects [5, 127]. Despite this, non-functional requirements, particularly accessibility requirements, are often overlooked by software development teams [9, 17]. Similarly, we found a similar trend among VR practitioners, who frequently overlook VR accessibility requirements, especially during the requirements elicitation phase. VR teams, especially those developing VR products for general end-users, are more likely to overlook VR accessibility requirements. Some VR practitioners mentioned that addressing special user needs with accessibility requirements presents significant challenges. Recent work indicated that while requirements engineering (RE) methods provide various strategies to enterprises, there is difficulty in employing appropriate RE methods for specific VR products, such as gaming and health [58]. Moreover, some practitioners noted that the initial requirements for VR games originate from the market rather than user needs. Thus, overlooking VR accessibility requirements in the early stage may align with business strategies and objectives, but could affect the inclusiveness of VR products. Furthermore, the efficacy of RE methods in meeting VR accessibility requirements is currently uncertain.

Furthermore, a VR practitioner highlighted a novel application in which they used the VR platform to gather user requirements for a specific architectural design. Recent studies suggested using VR visual simulators to simulate and capture accessibility requirements for users with visual impairments [115, 116]. This approach can help users experience the perspective of visually impaired users through a first-person perspective and facilitating a comprehensive series of RE activities within a virtual environment. Therefore, we believe that researchers focus on using VR technology in higher education to enhance students' understanding of first-person perspective from users with disabilities and the immersive experience.

5.3 Incorporating VR Accessibility in Design and Development

Compared to traditional software design and development, VR software design and development is less mature. Some industry reports and studies highlight unique characteristics of VR software design and development, such as immersive experiences, complex development processes, specialized hardware requirements, user interaction behaviors, development costs and tools, physical activity, and social aspects [23, 61, 76, 81]. These unique characteristics introduce new challenges for VR software projects. Some VR practitioners point out that integrating accessibility requirements into VR design and development can increase more uncertainty and project costs, a challenge also known in traditional software accessibility design and development. However, identifying more appropriate accessibility design and development strategies for specific VR applications remains a significant research gap. Additionally, the field of software engineering (SE) lacks a focus on VR-related research. Future research can also explore whether traditional SE theories adequately address the unique needs of VR software design and development.

Furthermore, designing and creating accessible digital content in VR, such as UI elements, visual and audio components, or 3D assets like 3D avatars and scenes, presents unique challenges [24, 65, 93, 123]. Some VR practitioners point out that VR accessibility requires a significant amount of resources, such as animation for 3D avatars and audio assets. However, this can lead to increased project management pressure, large project files, and even complications during resource iteration.

Previous work explored VR accessibility toolkits, including visual and auditory simulators, which have been shown to enhance the interaction and experience of disabled users in virtual environments [93, 124]. However, we found that some VR practitioners do not use these open-source toolkits in VR accessibility design and development processes. They are also concerned regarding the evaluation of these toolkits. Additionally, VR respondents also gave negative feedback. Reasons for this may include: toolkits not meeting specific VR scenario requirements, and outdated project versions. Therefore, we recommend that VR practitioners and researchers continuous update and improvement of VR accessibility toolkit. It is also crucial to improve collaboration with the industry stakeholders to evaluate the usability of VR accessibility toolkits in industrial VR software projects.

In recent years, the introduction of advanced VR and Mixed Reality (MR) features like XR headsets released by Apple Vision Pro [4] and Oculus Quest 3 [74] has diversified the market. However, the variety in models, prices, functionalities, designs, interactions, and hardware specifications among VR headsets is not standardized. Therefore, VR practitioners may need to develop multiple versions of VR projects to accommodate different VR headset models. Some VR practitioners mentioned that hardware issues are significant yet often overlooked factors that pose challenges in VR accessibility design and development. Although OpenXR provides a common API, some VR practitioners considered it does not adequately address VR accessibility issues [1]. Furthermore, some VR headsets can support basic accessibility features, such as for visual impairments. However, there is a lack of empirical research to confirm their effectiveness. Therefore, I recommend that future research in VR comprehensively evaluate whether current VR or XR headsets adequately meet the needs of users with accessibility requirements.

5.4 The Need for Better VR Accessibility Testing and Evaluation Standards

Software testing is a pivotal area of research in SE, with the testing software accessibility emerging as a significant research direction [15, 107]. Previous studies developed various methods and tools to enhance the quality of software accessibility testing. A previous study also introduced an open-source solution for evaluating basic VR accessibility features within virtual environments [102]. However, a recent case study indicated that the majority of open-source VR projects lack any form of automated testing [92]. Meanwhile, we found that most VR practitioners do not use tools or open-source frameworks for evaluating VR accessibility features. They still rely on stakeholders to test VR accessibility features. Moreover, some VR practitioners faced challenges in recruiting disabled users for testing and the potential ethical risks. So, we proposed a hypothesis:

VR simulators could potentially be used to test and evaluate the accessibility of VR products in the future [115, 116, 124]. Additionally, we found that general VR products may not adequately prioritize evaluating their compliance with accessibility and inclusivity standards. We also found that most VR practitioners do not refer the XAUR guidelines to evaluate VR accessibility features. A significant reason is that VR practitioners are unaware of the immaturity of XAUR. Therefore, there are significant gaps in the testing and evaluation of VR accessibility. We recommend that researchers develop efficient methods and tools for VR accessibility testing and enhance the XAUR guidelines in industry.

Overall, we recommend that researchers should focus on comparing VR practitioners' self-assessments of VR accessibility with user feedback on the accessibility of VR products, particularly across different phases of the software development life cycle.

6 LIMITATIONS

Our sample does not represent all VR practitioners. To mitigate sampling bias, we recruited interviews from various platforms and channels. Nonetheless, most interviewees in our sample self-identified as male, consistent with the gender-biased software development profession (more than 90% of the software developers are male [97]). Hence, the attitudes of the interviewees towards VR accessibility may not represent the attitudes of all VR practitioners. However, their responses provided novel and valuable insights into the interviewees' understanding and VR accessibility practices in the industry, which is the main objective of our study. Finally, our study may be subject to selection bias. For instance, the data from respondents might be overly optimistic, overlooking cases of failure in VR accessible design and development. We also acknowledge that there are still many issues with the accessibility of VR products in the industry, including existing VR products.

To mitigate survey bias, we recruited respondents from various regions in different types of platforms and channels. However, our survey mainly provides a broad statistical description and does not provide detailed analyses based on specific attributes (e.g., human aspects, incl. regions, cultures, and so on). Therefore, we suggest that future researchers collect more diverse survey data and provide deeper insights into the statistical nuances of the data.

Overall, our study used a mixed-methods design, incorporating both interview-based and survey-based studies. Therefore, the results of the study should be interpreted with these limitations in mind.

7 CONCLUSION

In this paper, we presented findings from interviews with 21 VR practitioners and surveys of 202 VR practitioners to empirically explore insights into VR accessibility. The mixed-methods design of our study provided a comprehensive view of VR practitioners' perspectives on VR accessibility. VR practitioners highlighted existing practices the software development life cycle and identified various challenges related to VR accessibility, as well as reasons for not considering VR accessibility. Finally, we concluded with a discussion of the implications of our findings and suggested future research directions. Our firsthand insights contribute to advancing VR accessibility at the intersection of virtual reality and software engineering.

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REFERENCES

[1] XR Access. 2023. A community committed to making virtual, augmented, and mixed reality (XR) accessible to people with disabilities. Retrieved July 2024 from https://xraccess.org/

[2] Troy Allman, Rupinder K. Dhillon, Molly A.E. Landau, and Sri H. Kurniawan. 2009. Rock Vibe: Rock Band® computer games for people with no or limited vision. In *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility* (Pittsburgh, Pennsylvania, USA) *(Assets '09)*. Association for Computing Machinery, New York, NY, USA, 51–58. https://doi.org/10.1145/1639642.1639653

[3] Ronny Andrade, Steven Baker, Jenny Waycott, and Frank Vetere. 2018. Echo-house: exploring a virtual environment by using echolocation. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction* (Melbourne, Australia) *(OzCHI '18)*. Association for Computing Machinery, New York, NY, USA, 278–289. https://doi.org/10.1145/3292147.3292163

[4] Apple. 2024. Apple Vision Pro. Retrieved March 2024 from https://www.apple.com/apple-vision-pro/

[5] Aybüke Aurum and Claes Wohlin. 2005. *Engineering and managing software requirements*. Vol. 1. Springer.

[6] Shiri Azenkot, Margot J. Hanley, and Catherine M. Baker. 2021. How Accessibility Practitioners Promote the Creation of Accessible Products in Large Companies. *Proc. ACM Hum.-Comput. Interact.* 5, CSCW1, Article 148 (apr 2021), 27 pages. https://doi.org/10.1145/3449222

[7] Laura Bajorunaite, Stephen Brewster, and Julie R. Williamson. 2022. "Reality Anchors": Bringing Cues from Reality into VR on Public Transport to Alleviate Safety and Comfort Concerns. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI EA '22)*. Association for Computing Machinery, New York, NY, USA, Article 383, 6 pages. https://doi.org/10.1145/3491101.3519696

[8] Steven Baker, Jenny Waycott, Romina Carrasco, Ryan M. Kelly, Anthony John Jones, Jack Lilley, Briony Dow, Frances Batchelor, Thuong Hoang, and Frank Vetere. 2021. Avatar-Mediated Communication in Social VR: An In-Depth Exploration of Older Adult Interaction in an Emerging Communication Platform. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 491, 13 pages. https://doi.org/10.1145/3411764.3445752

[9] Tingting Bi, Xin Xia, David Lo, John Grundy, Thomas Zimmermann, and Denae Ford. 2022. Accessibility in Software Practice: A Practitioner's Perspective. *ACM Trans. Softw. Eng. Methodol.* 31, 4, Article 66 (jul 2022), 26 pages.

[10] Syed Masum Billah, Yu-Jung Ko, Vikas Ashok, Xiaojun Bi, and IV Ramakrishnan. 2019. Accessible Gesture Typing for Non-Visual Text Entry on Smartphones. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300606

[11] Larissa Braz and Alberto Bacchelli. 2022. Software Security during Modern Code Review: The Developer's Perspective. In *Proceedings of the 30th ACM Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering* (Singapore, Singapore) *(ESEC/FSE 2022)*. Association for Computing Machinery, New York, NY, USA, 810–821. https://doi.org/10.1145/3540250.3549135

[12] Jie Cai and Donghee Yvette Wohn. 2022. Coordination and Collaboration: How Do Volunteer Moderators Work as a Team in Live Streaming Communities?. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 300, 14 pages. https://doi.org/10.1145/3491102.3517628

[13] Shiya Cao and Eleanor Loiacono. 2019. The state of the awareness of web accessibility guidelines of student website and app developers. In *Social Computing and Social Media. Design, Human Behavior and Analytics: 11th International Conference, SCSM 2019, Held as Part of the 21st HCI International Conference, HCII 2019, Orlando, FL, USA, July 26-31, 2019, Proceedings, Part I 21*. Springer, 32–42.

[14] Kathy Charmaz. 2006. *Constructing grounded theory: A practical guide through qualitative analysis*. sage.

[15] Sen Chen, Chunyang Chen, Lingling Fan, Mingming Fan, Xian Zhan, and Yang Liu. 2022. Accessible or Not? An Empirical Investigation of Android App Accessibility. *IEEE Transactions on Software Engineering* 48, 10 (2022), 3954–3968. https://doi.org/10.1109/TSE.2021.3108162

[16] Kenny Tsu Wei Choo, Rajesh Krishna Balan, and Youngki Lee. 2019. Examining Augmented Virtuality Impairment Simulation for Mobile App Accessibility

Design. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3290605.3300605

[17] Lawrence Chung, Brian A Nixon, Eric Yu, and John Mylopoulos. 2012. *Non-functional requirements in software engineering*. Vol. 5. Springer Science & Business Media.

[18] Jazmin Collins, Crescentia Jung, Yeonju Jang, Danielle Montour, Andrea Stevenson Won, and Shiri Azenkot. 2023. "The Guide Has Your Back": Exploring How Sighted Guides Can Enhance Accessibility in Social Virtual Reality for Blind and Low Vision People. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (New York, NY, USA) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 38, 14 pages. https://doi.org/10.1145/3597638.3608386

[19] Nick Corriveau Lecavalier, Émilie Ouellet, Benjamin Boller, and Sylvie Belleville. 2020. Use of immersive virtual reality to assess episodic memory: A validation study in older adults. *Neuropsychological rehabilitation* 30, 3 (2020), 462–480.

[20] Kirsten Cowan and Seth Ketron. 2019. A dual model of product involvement for effective virtual reality: The roles of imagination, co-creation, telepresence, and interactivity. *Journal of Business Research* 100 (2019), 483–492.

[21] Michael Crabb, Michael Heron, Rhianne Jones, Mike Armstrong, Hayley Reid, and Amy Wilson. 2019. Developing Accessible Services: Understanding Current Knowledge and Areas for Future Support. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300446

[22] John W Creswell and Dana L Miller. 2000. Determining validity in qualitative inquiry. *Theory into practice* 39, 3 (2000), 124–130.

[23] Marie Dealessandri. 2020. The best practices and design principles of VR development. Retrieved June 2024 from https://store.steampowered.com/steamvr?l=english

[24] Tilman Dingler, Kai Kunze, and Benjamin Outram. 2018. VR Reading UIs: Assessing Text Parameters for Reading in VR. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3170427.3188695

[25] Discord. 2023. Discord. Retrieved August 2023 from https://discord.com/

[26] Haihan Duan, Jiaye Li, Sizheng Fan, Zhonghao Lin, Xiao Wu, and Wei Cai. 2021. Metaverse for Social Good: A University Campus Prototype. In *Proceedings of the 29th ACM International Conference on Multimedia* (Virtual Event, China) *(MM '21)*. Association for Computing Machinery, New York, NY, USA, 153–161. https://doi.org/10.1145/3474085.3479238

[27] Joseph S Dumas and Janice Redish. 1999. *A practical guide to usability testing*. Intellect books.

[28] Anthony Elliott, Brian Peiris, and Chris Parnin. 2015. Virtual Reality in Software Engineering: Affordances, Applications, and Challenges. In *2015 IEEE/ACM 37th IEEE International Conference on Software Engineering*, Vol. 2. 547–550. https://doi.org/10.1109/ICSE.2015.191

[29] Equal Entry. 2003. Meta Quest 2 Accessibility Settings. Retrieved June 2024 from https://www.youtube.com/shorts/a18Czixh2Sk

[30] ETSI. 2021. Accessibility requirements for ICT products and services. Retrieved July 2024 from https://www.etsi.org/deliver/etsi_en/301500_301599/301549/03.02.01_60/en_301549v030201p.pdf

[31] FaceBook. 2023. FaceBook. Retrieved January 2024 from https://www.facebook.com/

[32] Sharif Mohammad Shahnewaz Ferdous. 2017. Improve accessibility of virtual and augmented reality for people with balance impairments. In *2017 IEEE Virtual Reality (VR)*. 421–422. https://doi.org/10.1109/VR.2017.7892356

[33] Andrea Ferracani, Marco Faustino, Gabriele Xavier Giannini, Lea Landucci, and Alberto Del Bimbo. 2017. Natural Experiences in Museums through Virtual Reality and Voice Commands. In *Proceedings of the 25th ACM International Conference on Multimedia* (Mountain View, California, USA) *(MM '17)*. Association for Computing Machinery, New York, NY, USA, 1233–1234. https://doi.org/10.1145/3123266.3127916

[34] Figma. 2023. Work together to build the best products. Retrieved January 2024 from https://www.figma.com/design-overview/

[35] Paula Forbes, Lorna Gibson, Vicki L. Hanson, Peter Gregor, and Alan F. Newell. 2009. Dundee User Centre: A Space Where Older People and Technology Meet. In *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility* (Pittsburgh, Pennsylvania, USA) *(Assets '09)*. Association for Computing Machinery, New York, NY, USA, 231–232. https://doi.org/10.1145/1639642.1639690

[36] G3ICT. 2009. G3ict "ICT Accessibility Self-Assessment Framework". Retrieved July 2024 from https://g3ict.org/publication/g3ict-ict-accessibility-self-assessment-framework

[37] Danko D Georgiev, Iva Georgieva, Zhengya Gong, Vijayakumar Nanjappan, and Georgi V Georgiev. 2021. Virtual reality for neurorehabilitation and cognitive enhancement. *Brain sciences* 11, 2 (2021), 221.

[38] Kathrin Gerling, Patrick Dickinson, Kieran Hicks, Liam Mason, Adalberto L. Simeone, and Katta Spiel. 2020. Virtual Reality Games for People Using Wheelchairs. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3313831.3376265

[39] GitHub. 2023. GitHub Community. Retrieved January 2024 from https://github.com/community

[40] W3C Working Group. 2021. XR Accessibility User Requirements. Retrieved January 2024 from https://www.w3.org/TR/xaur/

[41] GSA. 2023. IT Accessibility Laws and Policies. Retrieved January 2024 from https://www.section508.gov/manage/laws-and-policies/

[42] Ria J. Gualano, Lucy Jiang, Kexin Zhang, Andrea Stevenson Won, and Shiri Azenkot. 2023. "Invisible Illness Is No Longer Invisible": Making Social VR Avatars More Inclusive for Invisible Disability Representation. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (New York, NY, USA) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 73, 4 pages. https://doi.org/10.1145/3597638.3614480

[43] Christene Harris and Bo Sun. 2022. Assessing the Effect of Interactivity Design In VR Based Second Language Learning Tool. In *2022 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. 18–25. https://doi.org/10.1109/ISMAR55827.2022.00015

[44] Elmar Hashimov. 2015. Qualitative Data Analysis: A Methods Sourcebook and The Coding Manual for Qualitative Researchers: Matthew B. Miles, A. Michael Huberman, and Johnny Saldaña. Thousand Oaks, CA: SAGE, 2014. 381 pp. Johnny Saldaña. Thousand Oaks, CA: SAGE, 2013. 303 pp.

[45] Douglas D Heckathorn. 2011. Comment: Snowball versus respondent-driven sampling. *Sociological methodology* 41, 1 (2011), 355–366.

[46] Fiona Heilemann, Gottfried Zimmermann, and Patrick Münster. 2021. Accessibility guidelines for VR games-A comparison and synthesis of a comprehensive set. *Frontiers in Virtual Reality* 2 (2021), 697504. https://doi.org/10.3389/frvir.2021.697504

[47] Stefan Henß, Martin Monperrus, and Mira Mezini. 2012. Semi-automatically extracting FAQs to improve accessibility of software development knowledge. In *2012 34th International Conference on Software Engineering (ICSE)*. 793–803. https://doi.org/10.1109/ICSE.2012.6227139

[48] Dulaji Hidellaarachchi, John Grundy, Rashina Hoda, and Kashumi Madampe. 2022. The Effects of Human Aspects on the Requirements Engineering Process: A Systematic Literature Review. *IEEE Transactions on Software Engineering* 48, 6 (2022), 2105–2127. https://doi.org/10.1109/TSE.2021.3051898

[49] Dulaji Hidellaarachchi, John Grundy, Rashina Hoda, and Ingo Mueller. 2022. The Influence of Human Aspects on Requirements Engineering-Related Activities: Software Practitioners' Perspective. *ACM Trans. Softw. Eng. Methodol.* (jul 2022). https://doi.org/10.1145/3546943 Just Accepted.

[50] E Tory Higgins. 1996. Activation: Accessibility, and salience. *Social psychology: Handbook of basic principles* (1996), 133–168.

[51] Toshiharu Horiuchi, Sumaru Niida, and Yasuhiro Takishima. 2019. OtonoVR: Arbitrarily Angled Audio-Visual VR Experience Using Selective Synthesis Sound Field Technique. In *Proceedings of the 27th ACM International Conference on Multimedia* (Nice, France) *(MM '19)*. Association for Computing Machinery, New York, NY, USA, 2211–2213. https://doi.org/10.1145/3343031.3350602

[52] Syed Fatiul Huq, Abdulaziz Alshayban, Ziyao He, and Sam Malek. 2023. A11yDev: Understanding Contemporary Software Accessibility Practices from Twitter Conversations. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 217, 18 pages. https://doi.org/10.1145/3544548.3581455

[53] iFLYTEK. 2023. iFLYTEK. Retrieved January 2024 from https://global.xfyun.cn/

[54] Matthieu Ischer, Naëm Baron, Christophe Mermoud, Isabelle Cayeux, Christelle Porcherot, David Sander, and Sylvain Delplanque. 2014. How incorporation of scents could enhance immersive virtual experiences. *Frontiers in psychology* 5 (2014), 736.

[55] Jason Jerald. 2015. *The VR Book: Human-Centered Design for Virtual Reality*. Association for Computing Machinery and Morgan & Claypool.

[56] Yewon Jin, SeonYul Lee, SeoHyeong Kim, Jiyeon Seo, Kyuha Jung, Hajin Lim, and Joonhwan Lee. 2023. DiVRsity: Design and Development of Group Role-Play VR Platform for Disability Awareness Education. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference* (Pittsburgh, PA, USA) *(DIS '23)*. Association for Computing Machinery, New York, NY, USA, 161–174. https://doi.org/10.1145/3563657.3596047

[57] Crescentia Jung, Jazmin Collins, Ricardo E. Gonzalez Penuela, Jonathan Isaac Segal, Andrea Stevenson Won, and Shiri Azenkot. 2024. Accessible Nonverbal Cues to Support Conversations in VR for Blind and Low Vision People. In *Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility* (St. John's, NL, Canada) *(ASSETS '24)*. Association for Computing Machinery, New York, NY, USA, Article 20, 13 pages. https://doi.org/10.1145/3663548.3675663

[58] Sai Anirudh Karre, Y. Raghu Reddy, and Raghav Mittal. 2024. Requirement Engineering Methods for Virtual Reality Software Product Development - A

Mapping Study. *ACM Trans. Softw. Eng. Methodol.* (feb 2024). https://doi.org/10.1145/3649595 Just Accepted.
- [59] Jonathan W. Kelly, Lucia A. Cherep, Alex F. Lim, Taylor Doty, and Stephen B. Gilbert. 2021. Who Are Virtual Reality Headset Owners? A Survey and Comparison of Headset Owners and Non-Owners. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. 687–694. https://doi.org/10.1109/VR50410.2021.00095
- [60] Angelos Kostis and Paavo Ritala. 2020. Digital artifacts in industrial co-creation: how to use VR technology to bridge the provider-customer boundary. *California Management Review* 62, 4 (2020), 125–147.
- [61] Veronika Krauß, Alexander Boden, Leif Oppermann, and René Reiners. 2021. Current practices, challenges, and design implications for collaborative ar/vr application development. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–15.
- [62] Steve Lawrence and C Lee Giles. 2000. Accessibility of information on the web. *intelligence* 11, 1 (2000), 32–39.
- [63] Jonathan Lazar, Alfreda Dudley-Sponaugle, and Kisha-Dawn Greenidge. 2004. Improving web accessibility: a study of webmaster perceptions. *Computers in human behavior* 20, 2 (2004), 269–288.
- [64] Marie-Luise Leitner, Christine Strauss, and Christian Stummer. 2016. Web accessibility implementation in private sector organizations: motivations and business impact. *Universal Access in the Information Society* 15 (2016), 249–260.
- [65] Ziming Li, Shannon Connell, Wendy Dannels, and Roshan Peiris. 2022. SoundVizVR: Sound Indicators for Accessible Sounds in Virtual Reality for Deaf or Hard-of-Hearing Users. In *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility* (Athens, Greece) *(ASSETS '22)*. Association for Computing Machinery, New York, NY, USA, Article 5, 13 pages. https://doi.org/10.1145/3517428.3544817
- [66] LinkedIn. 2023. LinkedIn. Retrieved January 2024 from https://www.linkedin.com/
- [67] Yao Lyu and John M. Carroll. 2022. Cultural Influences on Chinese Citizens' Adoption of Digital Contact Tracing: A Human Infrastructure Perspective. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 252, 17 pages. https://doi.org/10.1145/3491102.3517572
- [68] Kelly Mack, Emma McDonnell, Dhruv Jain, Lucy Lu Wang, Jon E. Froehlich, and Leah Findlater. 2021. What Do We Mean by "Accessibility Research"? A Literature Survey of Accessibility Papers in CHI and ASSETS from 1994 to 2019. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 371, 18 pages. https://doi.org/10.1145/3411764.3445412
- [69] Jennifer Mankoff, Holly Fait, and Tu Tran. 2005. Is Your Web Page Accessible? A Comparative Study of Methods for Assessing Web Page Accessibility for the Blind. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Portland, Oregon, USA) *(CHI '05)*. Association for Computing Machinery, New York, NY, USA, 41–50. https://doi.org/10.1145/1054972.1054979
- [70] MAXQDA. 2023. The #1 software for qualitative and mixed methods data analysis. Retrieved January 2024 from https://www.maxqda.com/
- [71] Joshua McVeigh-Schultz, Anya Kolesnichenko, and Katherine Isbister. 2019. Shaping Pro-Social Interaction in VR: An Emerging Design Framework. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300794
- [72] Voov Meeting. 2023. Voov Meeting. Retrieved January 2024 from https://voovmeeting.com/
- [73] Meta. 2020. Introducing Oculus Quest 2, the Next Generation of All-in-One VR. Retrieved June 2024 from https://about.fb.com/news/2020/09/introducing-oculus-quest-2-the-next-generation-of-all-in-one-vr/
- [74] Meta. 2023. Meta Quest 3: New mixed reality VR headset. Retrieved March 2024 from https://www.meta.com/au/quest/quest-3/
- [75] Meta. 2023. VRC.Quest.Accessibility.5. Retrieved June 2024 from https://developer.oculus.com/resources/vrc-quest-accessibility-5/
- [76] David Moreno-Lumbreras, Gregorio Robles, Daniel Izquierdo-Cortázar, and Jesus M. Gonzalez-Barahona. 2024. Software development metrics: to VR or not to VR. *Empirical Softw. Engg.* 29, 2 (feb 2024), 49 pages. https://doi.org/10.1007/s10664-023-10435-3
- [77] Martez Mott, John Tang, Shaun Kane, Edward Cutrell, and Meredith Ringel Morris. 2020. "I Just Went into It Assuming That I Wouldn't Be Able to Have the Full Experience": Understanding the Accessibility of Virtual Reality for People with Limited Mobility. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, Greece) *(ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 43, 13 pages. https://doi.org/10.1145/3373625.3416998
- [78] Alan F Newell and Peter Gregor. 1999. Extra-ordinary human–machine interaction: what can be learned from people with disabilities? *Cognition, Technology & Work* 1 (1999), 78–85.
- [79] The University of Melbourne. 2003. Accessibility of Virtual Reality Environments. Retrieved June 2024 from https://www.unimelb.edu.au/accessibility/guides/vr-old
- [80] Joseph O'Hagan, Julie R. Williamson, Florian Mathis, Mohamed Khamis, and Mark McGill. 2023. Re-Evaluating VR User Awareness Needs During Bystander Interactions. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 876, 17 pages. https://doi.org/10.1145/3544548.3581018
- [81] Perforce. 2023. What Is Virtual Reality (VR) Game Development? Trends, Examples, and Essential Tools for Creating a VR Game. Retrieved August 2024 from https://store.steampowered.com/steamvr?l=english
- [82] Dewayne E Perry, Adam A Porter, and Lawrence G Votta. 2000. Empirical studies of software engineering: a roadmap. In *Proceedings of the conference on The future of Software engineering*. 345–355.
- [83] Adobe Photoshop. 2023. Photoshop. Retrieved January 2024 from https://www.adobe.com/products/photoshop.html
- [84] Tatjana Pladere, Ellen Svarverud, Gunta Krumina, Stuart J Gilson, and Rigmor C Baraas. 2022. Inclusivity in stereoscopic XR: Human vision first. *Frontiers in Virtual Reality* 3 (2022), 1006021.
- [85] Christopher Power, André Freire, Helen Petrie, and David Swallow. 2012. Guidelines Are Only Half of the Story: Accessibility Problems Encountered by Blind Users on the Web. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12)*. Association for Computing Machinery, New York, NY, USA, 433–442. https://doi.org/10.1145/2207676.2207736
- [86] Prolifc. 2003. Online participant recruitment for surveys and market research. Retrieved June 2024 from https://developer.oculus.com/blog/introducing-the-accessibility-vrcs/?locale=en_US
- [87] Qualtrics. 2023. Qualtrics. Retrieved January 2024 from https://www.qualtrics.com/
- [88] Meta Quest. 2023. Designing Accessible VR. Retrieved July 2024 from https://developer.oculus.com/resources/design-accessible-vr/
- [89] Hugo Romat, Nathalie Henry Riche, Christophe Hurter, Steven Drucker, Fereshteh Amini, and Ken Hinckley. 2020. Dear Pictograph: Investigating the Role of Personalization and Immersion for Consuming and Enjoying Visualizations. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376348
- [90] RStudio. 2023. RStudio Desktop. Retrieved July 2024 from https://posit.co/download/rstudio-desktop/
- [91] Kimiko Ryokai and Yong (Leon) Li. 2020. VR SandScape: Working with Multiple Perspectives in a Hybrid VR/SAR Collaborative Play Space. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Canada) *(CHI PLAY '20)*. Association for Computing Machinery, New York, NY, USA, 350–354. https://doi.org/10.1145/3383668.3419892
- [92] Dhia Elhaq Rzig, Nafees Iqbal, Isabella Attisano, Xue Qin, and Foyzul Hassan. 2023. Virtual Reality (VR) Automated Testing in the Wild: A Case Study on Unity-Based VR Applications. In *Proceedings of the 32nd ACM SIGSOFT International Symposium on Software Testing and Analysis* (<conf-loc>, <city>Seattle</city>, <state>WA</state>, <country>USA</country>, </conf-loc>) *(ISSTA 2023)*. Association for Computing Machinery, New York, NY, USA, 1269–1281. https://doi.org/10.1145/3597926.3598134
- [93] Abir Saha and Anne Marie Piper. 2020. Understanding Audio Production Practices of People with Vision Impairments. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, Greece) *(ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 36, 13 pages. https://doi.org/10.1145/3373625.3416993
- [94] Eirini Schiza, Maria Matsangidou, Kleanthis Neokleous, and Constantinos S Pattichis. 2019. Virtual reality applications for neurological disease: a review. *Frontiers in Robotics and AI* 6 (2019), 100.
- [95] Weishi Shi, Saad Khan, Yasmine El-Glaly, Samuel Malachowsky, Qi Yu, and Daniel E. Krutz. 2020. Experiential Learning in Computing Accessibility Education. In *Proceedings of the ACM/IEEE 42nd International Conference on Software Engineering: Companion Proceedings* (Seoul, South Korea) *(ICSE '20)*. Association for Computing Machinery, New York, NY, USA, 250–251. https://doi.org/10.1145/3377812.3390901
- [96] João Sousa e Silva, Ramiro Gonçalves, Frederico Branco, António Pereira, Manuel Au-Yong-Oliveira, and José Martins. 2019. Accessible software development: a conceptual model proposal. *Universal Access in the Information Society* 18 (2019), 703–716.
- [97] Statista. 2022. Software developer gender distribution worldwide as of 2022. Retrieved January 2024 from https://www.statista.com/statistics/272698/global-market-share-held-by-mobile-operating-systems-since-2009/
- [98] Mohammad Tahaei, Ruba Abu-Salma, and Awais Rashid. 2023. Stuck in the Permissions With You: Developer & End-User Perspectives on App Permissions & Their Privacy Ramifications. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 168, 24 pages. https://doi.org/10.1145/3544548.3581060

[99] Mohammad Tahaei, Kami Vaniea, Konstantin (Kosta) Beznosov, and Maria K Wolters. 2021. Security Notifications in Static Analysis Tools: Developers' Attitudes, Comprehension, and Ability to Act on Them. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 691, 17 pages. https://doi.org/10.1145/3411764.3445616

[100] Yuk Ming Tang and Ho Lun Ho. 2020. 3D modeling and computer graphics in virtual reality. In *mixed reality and three-dimensional computer graphics*. IntechOpen.

[101] Vildan Tanriverdi. 2001. *A Virtual Reality Interface Design (Vrid) Model and Methodology*. Ph. D. Dissertation. USA. Advisor(s) Jacob, Robert J. AAI3004806.

[102] Mauro Teófilo, Vicente F Lucena, Josiane Nascimento, Taynah Miyagawa, and Francimar Maciel. 2018. Evaluating accessibility features designed for virtual reality context. In *2018 IEEE international conference on consumer electronics (ICCE)*. IEEE, 1–6.

[103] Sean Thomas, Ylva Ferstl, Rachel McDonnell, and Cathy Ennis. 2022. Investigating how speech and animation realism influence the perceived personality of virtual characters and agents. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 11–20. https://doi.org/10.1109/VR51125.2022.00018

[104] Yang Tian, Chi-Wing Fu, Shengdong Zhao, Ruihui Li, Xiao Tang, Xiaowei Hu, and Pheng-Ann Heng. 2019. Enhancing Augmented VR Interaction via Egocentric Scene Analysis. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 3, Article 105 (sep 2019), 24 pages. https://doi.org/10.1145/3351263

[105] Garreth W. Tigwell. 2021. Nuanced Perspectives Toward Disability Simulations from Digital Designers, Blind, Low Vision, and Color Blind People. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 378, 15 pages. https://doi.org/10.1145/3411764.3445620

[106] ROAD TOVR. 2017. New Report from ILMxLab Disability Visibility Project Shares Insights on VR Accessibility Design. Retrieved July 2024 from https://www.roadtovr.com/disability-visibility-project-and-ilmxlab-share-lessons-learned-about-vr-accessibility-design/

[107] Shari Trewin, Brian Cragun, Cal Swart, Jonathan Brezin, and John Richards. 2010. Accessibility Challenges and Tool Features: An IBM Web Developer Perspective. In *Proceedings of the 2010 International Cross Disciplinary Conference on Web Accessibility (W4A)* (Raleigh, North Carolina) *(W4A '10)*. Association for Computing Machinery, New York, NY, USA, Article 32, 10 pages. https://doi.org/10.1145/1805986.1806029

[108] Twitter. 2023. Twitter. Retrieved January 2024 from https://twitter.com/

[109] Unity3D. 2023. Coding in C in Unity for beginners. Retrieved June 2024 from https://unity.com/how-to/learning-c-sharp-unity-beginners/

[110] Atiyeh Vaezipour, Danielle Aldridge, Sebastian Koenig, Deborah Theodoros, and Trevor Russell. 2022. "It's really exciting to think where it could go": a mixed-method investigation of clinician acceptance, barriers and enablers of virtual reality technology in communication rehabilitation. *Disability and rehabilitation* 44, 15 (2022), 3946–3958.

[111] Abel Vargas, Paloma Díaz, and Telmo Zarraonandia. 2020. Using Virtual Reality and Music in Cognitive Disability Therapy. In *Proceedings of the International Conference on Advanced Visual Interfaces* (Salerno, Italy) *(AVI '20)*. Association for Computing Machinery, New York, NY, USA, Article 35, 9 pages. https://doi.org/10.1145/3399715.3399916

[112] HTC VIVE. 2023. Getting Started With Accessibility: Adding Subtitles. Retrieved July 2024 from https://developer.vive.com/resources/accessibilty/tutorials/getting-started-with-accessibility-adding-subtitles/

[113] W3C. 2012. W3C Web Content Accessibility Guidelines 2.0 Approved as ISO/IEC International Standard. Retrieved January 2024 from https://www.w3.org/press-releases/2012/wcag2pas/

[114] Yi Wang, Chetan Arora, Xiao Liu, Thuong Hoang, Vasudha Malhotra, Ben Cheng, and John Grundy. 2025. Who uses personas in requirements engineering: The practitioners' perspective. *Information and Software Technology* 178 (2025), 107609. https://doi.org/10.1016/j.infsof.2024.107609

[115] Yi Wang, Ben Cheng, Thuong Hoang, Chetan Arora, and Xiao Liu. 2021. Virtual Reality Enabled Human-Centric Requirements Engineering. In *2021 36th IEEE/ACM International Conference on Automated Software Engineering Workshops (ASEW)*. 159–164. https://doi.org/10.1109/ASEW52652.2021.00041

[116] Yi Wang, Xiao Liu, Ben Cheng, Chetan Arora, and Thuong Hoang. 2022. VR4HcRE: Virtual Reality Platform for Human-centric Requirements Elicitation. In *2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. 788–793. https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00168

[117] WeChat. 2023. WeChat. Retrieved January 2024 from https://www.wechat.com/

[118] Ryan Wedoff, Lindsay Ball, Amelia Wang, Yi Xuan Khoo, Lauren Lieberman, and Kyle Rector. 2019. Virtual Showdown: An Accessible Virtual Reality Game with Scaffolds for Youth with Visual Impairments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3290605.3300371

[119] Wenjuanxing. 2023. Wenjuanxing. Retrieved January 2024 from https://www.wjx.cn/

[120] Wikipedia. 2023. WeChat red envelope. Retrieved August 2023 from https://en.wikipedia.org/wiki/WeChat_red_envelope

[121] Sara Wolf, Michael Weber, and Jörn Hurtienne. 2023. Virtual Tourism, Real Experience: A Motive-Oriented Approach to Virtual Tourism. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>Hamburg</city>, <country>Germany</country>, </conf-loc>) *(CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 309, 7 pages. https://doi.org/10.1145/3544549.3585594

[122] Zenodo. 2024. Interview and Survey questions. Retrieved June 2024 from https://zenodo.org/records/13753343

[123] Kexin Zhang, Elmira Deldari, Zhicong Lu, Yaxing Yao, and Yuhang Zhao. 2022. "It's Just Part of Me:" Understanding Avatar Diversity and Self-Presentation of People with Disabilities in Social Virtual Reality. In *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility* (Athens, Greece) *(ASSETS '22)*. Association for Computing Machinery, New York, NY, USA, Article 4, 16 pages. https://doi.org/10.1145/3517428.3544829

[124] Yuhang Zhao, Edward Cutrell, Christian Holz, Meredith Ringel Morris, Eyal Ofek, and Andrew D. Wilson. 2019. SeeingVR: A Set of Tools to Make Virtual Reality More Accessible to People with Low Vision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300341

[125] Zippia. 2023. 25+ Amazing Virtual Reality Statistics [2023]: The Future Of VR + AR. Retrieved August 2024 from https://www.zippia.com/advice/virtual-reality-statistics/

[126] ZOOM. 2023. ZOOM. Retrieved January 2024 from https://zoom.us/

[127] Didar Zowghi and Chad Coulin. 2005. Requirements elicitation: A survey of techniques, approaches, and tools. *Engineering and managing software requirements* (2005), 19–46.