New Realities

Unlocking the Potential of XR for Persons with Disabilities

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About this report

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Preface

This report was produced by Funka Nu AB, on assignment from Facebook, between 2020 and 2021. Staff at Funka's offices in Sweden, Norway, and Spain contributed to the research process, with continuous input from Facebook staff based in California. The contents of the report are drawn from an extensive review of available sources, as well as from direct engagement with relevant stakeholders. All research was carried out in full compliance with applicable restrictions due to the covid-19 pandemic.

The authors wish to thank all those who contributed their time and insights to the production of this report.

Executive summary

This report deals with extended reality (XR) – which includes virtual, augmented, and mixed reality – and how it can be used for the benefit of persons with disabilities. Extended reality, or XR, is an umbrella term that encompasses virtual reality (VR), augmented reality (AR) and mixed reality (MR). Broadly speaking, VR refers to entirely simulated digital environments, while AR refers to manipulated or enhanced real-world environments. MR can refer to virtual interactivity in real-world environments.

AR and VR have long been theorized, but it is only in recent years that they have entered the mainstream. Now, the technologies are used in a number of sectors, such as entertainment, education and manufacturing. However, these applications do not always work well for persons with disabilities. This is in spite of the fact that persons with disabilities constitute a large group of potential users. Many within the disability rights movement argue for more universal design, referring to the principle of designing with all possible users in mind from the start.

Some research has been carried out to identify accessibililty issues in early XR solutions. These issues are contingent on different user needs. Standardization bodies such as the W3C and ISO are also trying to identify accessibility issues, as well as develop remediating measures, for the purposes of creating clear guidelines and standards for accessibility in XR solutions. W3C, for instance, is currently developing a set of user requirements for XR accessibility (XAUR). A number of actors and networks have been set up to promote XR in general and XR accessibility in particular.

A number of current applications of XR technologies for the benefit of persons with disabilities have been collected. These applications can be divided, roughly, into three categories: assistive technology, rehabilitation and training solutions, and solutions for awareness and insight into what living with disability is like.

Assistive technology solutions that use XR include:

- augmented reality goggles that enhance the eyesight of persons with low vision;
- wearable devices that provide auditory and haptic feedback about physical surroundings to persons with more severe vision loss;
- applications that provide high-contrast oulines of the physical environment, or speech and audio cues from objects in that environement, helping persons with low vision navigate in unfamiliar surroundings;
- captions in 360° video that follow the viewer’s gaze and indicate from where sound is coming, for the benefit of persons with low hearing;
- automatic captions in head-mounted AR devices;
- plugins that adapt existing VR solutions to the needs of persons with motor disabilities;
- smartphone applications that provide an AR extension of physical stores, allowing persons with limited reach to browse and shop for items;

- hand exoskeletons for persons with low mobility, operated with AR HMDs;
- input sensors that allow amputees or persons with low mobility to operate and manipulate immersive environments;
- virtual reality simulations that allow persons with reduced mobility to explore inaccessible real environments – e.g., cultural heritage sites;
- augmented reality workstations that help persons with developmental disabilities in supported employment;
- immersive media players with a wide range of accessibility features.

Rehabilitation and training solutions that use XR include:

- virtual reality applications and games for treatment of pediatric amblyopia (lazy eye);
- virtual reality headsets that train the spatial hearing abilities of persons with cochlear implants;
- physical rehabilitation for persons with low mobility in virtual and augmented reality environments;
- mental health applications that provide immersive environments for cognitive behavioral therapy sessions;
- applications that provide immersive training scenarios for persons on the autism spectrum, helping them deal with challenging social situations or interpret interpersonal cues;
- AR games that teach persons with intellectual disabilities about nutrition;
- VR classroom tools that are particularly beneficial to students with disabilities.

Solutions that use XR to raise awareness about, and provide insights into, disabilities include:

- AR applications that simulate the effects of various eye conditions;
- VR applications that teach the user basic sign language through gesture recognition;
- 360° films that illustrate the sensory overload and other challenges that you might experience as a person on the autism spectrum.

Many of these solutions are already available to the public or practitioners, while others are still in development or at a prototype stage.

With this being said, the field of XR for persons with disabilities is just getting started, and stakeholders and experts point to a number of possible future applications of XR technology. For these applications to be possible, however, existing design and accessibility issues will need to be addressed.

1. Introduction

Few emerging technologies have garnered as much attention in recent years as augmented and virtual reality. Once the stuff of science fiction, AR and VR solutions are now used within a number of fields, such as entertainment, science, education, business and manufacturing.

At the same time, the question of digital accessibility – broadly, ICT that works for users with disabilities – has become a mainstream concern. It was perhaps inevitable that many practitioners would start looking for ways to combine these two developments: in short, trying to use AR and VR for the benefit of persons with disabilities.

This report offers a look at the state of the art in disability-related AR and VR solutions. What is already on the market? What is under development? What is on the horizon? We also discuss more broadly what the proliferation of AR and VR technologies means for persons with disabilities.

The next chapter gives a brief background on the origins and uses of AR and VR. It also discusses persons with disabilities as a target audience for development, as well as inclusive and universal design.

Chapter 3 looks at the question of accessibility in relation to XR, and some ongoing work to address existing accessibility issues.

Chapter 4 investigates where AR and VR for persons with disabilities stands at present, in terms of research being carried out and solutions available on the market.

Chapter 5 discusses possible future applications of AR and VR technologies for the benefit of persons with disabilities. Chapter 6 offers some concluding remarks.

1.1. Methodology

This report is the result of research carried out by Funka on assignment from Facebook during the summer and fall of 2020. It is based on the results of three research methods: desk research, a stakeholder survey, and expert interviews.

As part of our desk research, we have gathered information, publications and data on the subject of XR technologies used for the benefit of persons with disabilities. This research has been carried out with the help of keyword searches in relevant databases, as well as on the basis of our conversations with relevant experts.

The stakeholder survey was carried out online in the early stages of the study. Contacts who had been identified as relevant were invited to respond. These contacts represented academia, research institutions, industry and more. In all, some 50 contacts responded to the survey.

Following the survey, in-depth interviews were carried out with a smaller number of relevant experts. These interviews were conducted in a semi-structured fashion, meaning that while there was a pre-prepared interview guide with a few over-arching questions – usually relating to the development of a particular solution, or to possible future ventures – the interviewees were encouraged to speak extemporaneously about their work and their views on the subject of extended reality for persons with disabilities. The results of these research methods are used throughout, and in support of one each other.

The main focus of our research has been the European research and development context, but we have not applied any exclusionary criteria against other geographic regions.

2. XR and people with disabilities – a brief background

2.1. What is XR?

This section provides a brief explanation of the origins and applications of XR technologies.

Definitions

The term "augmented reality" (AR) was coined in the early 1990s by Thomas Caudell and David Mizell, then research scientists at the aerospace manufacturer Boeing (Caudell & Mizell, 1992). Broadly, it refers to technologies that alter or enhance the perception of real-world environments. This is often accomplished through the use of visual overlays that provide supplementary or contextualizing information. While augmented reality users still experience the real, physical world around them, this experience is augmented by digital content (Craig, 2013).

Virtual reality (VR) refers to technologies that create entirely simulated environments that the user can navigate in a manner approximating real, physical environments. Another key component is immersion; VR solutions often block out outside sensory stimuli, for instance through the use of goggles and headsets, in order to increase the user's sensation of verisimilitude (Burdea & Coiffet, 2003).

There is also mixed reality (MR), which usually refers to a real-world environment with interactive (not just informative) virtual objects, or to a virtual environment that is tethered to the real world. Finally, the term "extended reality" (XR) has been coined to describe the whole spectrum of augmented, virtual and mixed reality technologies.

Origins

AR and VR existed in fiction before they existed in fact. In a 1901 novella entitled *The Master Key*, for instance, author L. Frank Baum described a pair of fantastical spectacles that allow the wearer to know the character of everyone they meet by displaying a letter grade on their foreheads: "G" for "good", "E" for "evil", and so on (Baum, 1901). As modern-day observers have pointed out, this is really an AR device in all but name (Pescowitz, 2012). Meanwhile, fictional depictions of VR systems are legion, the most well-known example perhaps being the "holodeck" immersion room featured in *Star Trek*.

The earliest AR and VR inventions were developed for military use. At around the same time that Baum's story about the spectacles appeared, the Irish inventor Howard Grubb patented a "reflex" reflector sight that used optics to superimpose crosshairs on a rifle sight. This innovation solved the challenge posed by fixed iron sights – difficult to use since the human eye is incapable of focusing on close and distant objects simultaneously – by placing the targeting reticle at optical infinity. The same principle is used in modern heads-up displays. One of the first steps towards virtual reality technology was taken in the 1960s, when the computer scientist Ivan Sutherland encountered a head-mounted, binocular display that relayed images from an infrared camera mounted on a helicopter. It occurred to Sutherland that such a display could just as well relay computer-generated images, and he soon set about experimenting with this. His research would become foundational to many of the simulation tools in use today (Aukstakalnis, 2016).

Current applications

Today, extended reality technologies are applied in a number of different and increasingly sophisticated ways. Defense applications are still common – for instance, VR simulations are used by many air force organizations to train pilots (de Armas, Tori, & Netto, 2020). More familiar to the wider public are the various entertainment devices that use VR and, to a lesser extent, AR. Sony currently stands as the world's leading VR device vendor, primarily thanks to its Playstation VR entertainment system, shipping an estimated 37% of VR devices sold worldwide in 2019. The same year, the Facebook subsidiary Oculus took the runner-up position with an estimated market share of 28%, while HTC and Microsoft held market shares of 13% and 3%, respectively (Statista, 2020). Analysts are expecting the VR and AR market to grow significantly over the coming years: although the COVID-19 pandemic has cooled down investors' hopes somewhat, the compound annual growth rate (CAGR) for VR and AR spending is still projected at 77% for the 2019-2024 period (IDC, 2020).

Aside from entertainment, extended reality is also increasingly used in educational settings. Virtual and augmented reality devices – both high-end head-mounted devices (HMDs) and low-cost smartphone extensions, such as the Google Cardboard – are used to enhance lessons and learning processes. Many museums and other cultural institutions have also begun experimenting with extended reality as an educational tool – for instance, by visualizing historical events in virtual reality, or by providing informative overlays in augmented reality (Wojciechowski, Walczak, White, & Cellary, 2004). Virtual and augmented reality are also being put to use in science, not least in medical research, where it has been speculated that there may be diagnostic uses for the technologies. However, robust clinical trials and studies in this field are, thus far, few and far between (Eckert, Volmerg, & Friedrich, 2019).

There have also been some high-profile misfires in the market. In 2013, Google released its prototype Glass device amid much fanfare. Google Glass, a pair of glasses with heads-up displays that look like regular, see-through lenses, was initially promoted as a consumer device that would provide the user with AR content as she went about her daily life. As it turned out, however, the general public was put off by privacy and security concerns raised in the media, not to mention the product's hefty price tag. Efforts to bring Google Glass to the consumer market were halted in 2015, and the device is generally thought of as a failure. Yet this is not the whole story. Out of the public spotlight, the Google Glass has found success as a workplace tool in manufacturing and logistics, where it is used to help workers carry out specialized tasks without having to look away to see further details or instructions (Levy, 2017). It is far from the only product in this particular market segment, but it illustrates how extended reality technologies – like other emerging technologies – may find applications beyond the original intentions of developers.

To ensure the continued growth of the XR field, the question of radio frequency spectrum must be considered. Many applications of XR technology will require sufficient unlicensed spectrum – that is, bandwidth that has not been reserved for specific broadcasters but rather remains open to the public – to operate. As more applications enter the market, the need for unlicensed spectrum is liable to increase.

2.2. Designing for disability

The above-mentioned existing applications of XR technologies, like other emerging technologies, appear to presume a certain kind of end user: someone who can see, hear, understand, and operate to the particular extent required by the system. What, then, of those who have different needs and abilities?

According to the World Health Organization (WHO) and the World Bank, roughly 15% of the world's population have a disability (WHO & The World Bank, 2011). Looking at specific types of disability, global estimates further indicate that, for example:

- around 250 million people have a moderate to severe vision impairment, of whom about 35 million are blind (Bourne, et al., 2017)
- around 466 million people are deaf or hard of hearing (IFHOH, 2020)
- at least 65 million people require wheelchairs (WHO; ISPO; USAID, 2008)
- some 50 million people have dementia (WHO, 2019)
- One out of 160 children may be on the autism spectrum (Elsabbagh, et al., 2012)

Some live with more than one disability at the same time. Sometimes, too, disability is difficult to define and delineate; people, whether with or without disabilities, are unique.

Over the past century, societal attitudes to disability have changed dramatically. Where marginalization and discrimination were once the rule, persons with disabilities are now more included, accepted, and understood – backed up by national and international legal instruments such as the Americans with Disabilities Act (ADA) and the UN Convention on the Rights of Persons with Disabilities (UNCRPD). The intrepid and persistent activism of persons with disabilities themselves has been a key factor in this change, but the increased visibility of persons with disabilities is also due to medical progress, which means that there are more simply more people living with disabilities as a proportion of the population than there ever has been before. There are two aspects to this. One is that modern medical science can save and extend the lives of certain persons with disabilities, where this previously would not have been possible. Another, larger part is that more people are likely to grow old, and older. And the older you get, the likelier you are to have a disability.

In many high-income countries, this increase in life expectance is taking place as birth rates are decreasing. This means that older people are becoming a larger share of the population: from about 18% in 2019, to an estimated 27% by 2050 (UN, 2019). This can also be expressed through the "potential support ratio," a metric that indicates the size of the working-age population relative to how many older people there are, with the general assumption that the younger, working population should support the older, usually non-working population. As the share of old people increases, the more challenging this becomes. According to the UN, the potential support ratio is shrinking across the world: from 10 persons of working age (20-64) to every person 65 or older in 1955, to a ratio of 7:1 in 2015 (UN, 2017).

Parallel with these demographic shifts, the discourse around disability has changed, too. The academic literature generally describes this as a transition from a "medical" to a "social" – sometimes, "relative" – model of disability. In the former model, disability is primarily understood as a medical problem to be addressed by healthcare professionals. The latter, now prevailing model rather emphasizes society's role in creating disabling environments. According to the social model, disability is not just a question of a particular physical or cognitive impairment, but also a consequence of society not being designed with different needs in mind (Oliver, 1996).

An influential outgrowth of this reasoning is the concept of universal design. Originally coined by the architect Ron Mace, universal design refers to the principle of building products, environments, and services in such a way that they can be used by as many people with varying needs as possible, without adaptation or assistance. This produces better, more reliable outcomes for everyone, not only persons with disabilities – and it also happens to be cheaper than making accessibility fixes after the fact. This is not to suggest that universal design stands in opposition to accessibility – on the contrary, universal design is an effective approach to achieving accessibility (Story, Mueller, & Mace, 1998).

Finally, disability inclusion is sometimes promoted in economic terms. In 2008, the British government claimed that persons with disabilities and older people had a combined purchasing power of €300 billion a year (Leitner & Strauss, 2008). From that perspective, inaccessible market actors are missing out on considerable sums of money. This line of reasoning has been questioned, however, including by the project strategist Josh Korr, who argues that "people with disabilities might represent a large aggregate global audience, but they may represent a tiny audience for any given company." He urges realistic expectations about the revenues the group as such may provide, while at the same time hoping for good-will from non-disabled customers who appreciate the company behaving ethically

(Korr, 2015). As it turns out, this happens to have the added benefit of being the right thing to do, anyway.

3. Disability and XR: some key issues

3.1. Research on XR for persons with disabilities

The overarching question of this report is how extended reality technologies might benefit persons with disabilities. Yet this suggests another, distinct question: What prevents persons with disabilities from using existing, mainstream XR applications? What accessibility issues do XR solutions have? Plenty of recent and ongoing work deals with this question, and it is worth discussing some of that work here.

Some common XR accessibility issues

Virtual, augmented, and mixed reality technologies use three of the five human senses – sight, hearing, and touch (smell and taste remain fairly uncommon features in extended reality solutions) – as well as mobility, motor skills, and cognition. Should some of these senses and abilities be diminished in a user, it is not hard to imagine that this would impact their enjoyment of poorly designed XR solutions. If your eyesight is reduced, gains from virtual 3D environments or visual overlays will be limited. If your mobility is reduced, your ability to operate systems that are often kinetic by design may be similarly limited.

The University of Melbourne has compiled a useful outline of challenges, as well as benefits, that persons with disabilities may experience when using virtual reality technologies (University of Melbourne, 2020).

Table 1: Pros and cons of VR for persons with disabilities[1]

Disability category	Opportunities	Challenges
Mobility	• Overcome barriers in the real, physical world (e.g., exploring inaccessible cultural heritage sites) • Display yourself with or without mobility aids	• Standard input devices, such as head trackers, may be difficult to use • Can be difficult to interact with precise targets • In-app locomotion – e.g., walking or flying – can be difficult • Haptic cues may be difficult to perceive
Hearing	• Possible to provide captions from speech, both pre-recorded and real-time • Text-based navigation cues on heads-up displays	• VR experiences can rely heavily on audible cues • Ambient noise (e.g., clicks and beeps) may be hard to distinguish from interface elements • Spatialized audio may be hard to locate • Video and audio may become unsynchronized • Communication through voice chat can be hard
Cognition	• Can help you concentrate on specific tasks	• Interface may be hard to understand • Input devices may be hard to master

[1] Adapted from University of Melbourne, https://www.unimelb.edu.au/accessibility/virtual-reality . The table has been somewhat expanded.

Disability category	Opportunities	Challenges
	• Can help you train skills • Can distract from chronic and acute pain • Can help you learn social skills through simulated scenarios	• You may experience vertigo or motion sickness • VR may temporarily disturb motor skills due to difficulty to readapt • Risk of seizures or migraines
Low vision	• You may benefit from voice chat • Possible to enhance remaining vision	• Objects and events may be hard to identify • Text size and visual contrast can be difficult to adjust • Can be difficult to form single image from views presented in front of each eye
Blindness	• Haptic interfaces can improve learning outcomes • Virtual mobility and orientation activities can help users navigate in real environments • Audio feedback can give information about surrounding environment	• Hard to perceive visual content and instructions • Hard to use screen readers with VR • Sometimes difficult to use voice commands • Hard to get braille output from XR system

This outline is not exhaustive, and it does not discuss other forms of XR. AR, for instance, will present persons with disabilities with its own set of opportunities – such as HUD technology providing navigation cues to persons with low hearing – and challenges.

It is important to remember that individual experiences of virtual and augmented reality will vary, even between persons who, on paper, have similar disabilities. In fact, many persons with disabilities have reacted to virtual and augmented reality technologies with enthusiasm. Carlos Cruz Cordero, an avid gamer who has a visual impairment, describes this well in an article for AbleGamers. In the article, he describes how he has struggled with a game he otherwise enjoys, because the size of the text in the game's on-screen prompts is far too small for him to be able to read from a distance. "That text was very frustrating", he writes, "and really took me out of the game when I would have to get up and walk over to the screen to read the in-game instructions." Once he tried playing it with a Playstation VR device, however, the difference was startling:

> On the giant movie theater-sized screen inside the PSVR […] I was able to read the same prompts with much more ease. Several hours later, [I knew]: the PSVR was not only a good purchase, it made my backlog of 2D games much more accessible. I had to stop myself from crying for joy inside the headset, I was fogging up the glass in front of my eyes." (Cordero, 2019)

In this example, then, a mainstream virtual reality device functioned as a piece of assistive technology, even though that had hardly been the primary objective of its developers.

This is not to skirt around the fact that there is progress that can be made regarding accessibility in virtual reality gaming. In 2017, AJ Ryan, another gamer and accessibility expert, who himself has a mobility impairment, stated plainly that he did not “believe Virtual Reality is an accessible platform as it currently exists.” He went on to list some of the main accessibility issues with virtual reality gaming:

- Systems often rely on motion controls, which is difficult for persons with reduced mobility.
- Users have to assume a certain position – often upright – to play, something that will not be possible for everyone.
- The virtual reality market is too disparate, making it difficult to find accessibility solutions that work across platforms.
- Not all users will be able to put on or remove virtual reality headsets, as these are currently designed, on their own. This is a potential safety hazard, in particular if the HMD is physically attached to a stationary device.
- Forced game mechanisms prevent users from using and exploring the virtual environment on their own terms.
- Spatialized audio – i.e., audio that you have to be in a particular location to hear – works poorly for users with reduced mobility.
- Users with disabilities are seldom involved in the development and testing process, making the end result less accessible. (Ryan A. J., 2017)

When asked more recently whether VR gaming accessibility had improved, Ryan replied that “VR still has a long way to go.” However, he does point to the Oculus Quest 2 and other wireless HMDs as a step in the right direction, since they free the user from being “tethered” to another device. (Ryan A. , 2020)

One way to make it easier to create universally designed immersive experiences could be by integrating accessibility features and guidance into the design and programming tools used by developers. This does not appear to be happening at the moment, but it could be a valuable avenue for future work. Such work could be further accelerated in conjunction with ongoing efforts to standardize the field of XR accessibility.

3.2. Standardization

Various actors are trying to address the accessibility challenges that extended reality technologies present through the development of laws, guidelines and standards. By having a shared set of rules and requirements, the argument goes, developers and providers of extended reality solutions will be better able to meet different user needs. This is not a new idea in the accessibility field, or even in the specific realm of digital accessibility. In the U.S., Section 508 of the Rehabilitation Act sets out legal requirements for the accessibility of ICT systems at federal agencies (29 U. S. C. § 794 (d)). In Europe, the Web Accessibility Directive and the European Accessibility Act of the European Union perform similar legislative functions (2016/2102/EU; 2019/882/EU).

The Web Content Accessibility Guidelines (WCAG) constitute one of the most important instruments of digital accessibility. The WCAG are intended to help web authors and developers make the web more accessible. Maintained by the Web Accessibility Initiative (WAI) at the World Wide Web Consortium (W3C), the WCAG are now up to version 2.1. In 2012, an earlier version of WCAG became an international ISO standard, under the name ISO/IEC 40500:2012. The principles and recommendations of WCAG are widely known and followed around the world. Now, the aspiration is to extend this framework to the extended reality field as well.

The W3C XR Accessibility User Requirements

The W3C itself is one of the actors working on standardizing accessibility guidelines for XR technology. Some of W3C's previous work deals with XR as part of broader concerns, such as the webGPU, a prospective standard for fast access to 3D graphics. Now, however, W3C and its subsidiary, WAI, are taking aim at virtual, augmented, and mixed reality accessibility, with the XR Accessibility User Requirements (XAUR).

As a preliminary step towards the development of the XAUR, in 2017 W3C carried out a brief review of the then-existing literature on accessibility of virtual reality. This review identified some issues and potential benefits, as well as practical, disability-relevant applications of virtual reality technology. While some of the issues found could be remediated using existing WCAG guidelines, some issues called for a more customized approach (W3C, 2017).

The purpose of the XAUR is fairly straightforward: to outline and define what different users would need to be able to use XR solutions to the greatest extent possible. These requirements are being developed by the Accessible Platform Architectures (APA) working group, a division of WAI that deals with the practical formulation of accessibility standards. In November 2019, in Seattle, Washington, W3C and the APA working group convened the Inclusive Design for Immersive Web Standards workshop, bringing together developers, providers, experts, procurers, and, not least, users with disabilities. According to Shadi Abou-Zahra, specialist at WAI, the purpose of this workshop was to "take in information and [to] work with the community, to get a [XR accessibility] community started." (Abou-Zahra, 2020)

Following this workshop, the APA working group set about developing a first draft of user requirements for XR accessibility. Abou-Zahra describes how this work operates on several levels, from deep technological detail (e.g., what type of processing power does the graphic card need to have?), to the development of concrete guidelines based on these technological circumstances, to additional recommendations to external developers. In September 2020, a working draft was issued, along with a request for feedback (W3C, 2020). The draft includes a set of 19 user needs and corresponding requirements. These cover the following areas:

1. Immersive semantics and customization
2. Motion agnostic interactions
3. Immersive personalization
4. Interaction and target customization
5. Voice commands
6. Color changes
7. Magnification context and resetting
8. Critical messaging and alerts
9. Gestural interfaces and interactions
10. Text description transformation
11. Safe harbor controls
12. Immersive time limits
13. Reset focus and orientation
14. Second screen
15. Interaction speed
16. Avoiding sickness triggers
17. Spatial audio tracks and alternatives
18. Captioning, subtitling, and text: Support and customization
19. Mono audio option

A full overview of the working draft of the XAUR is provided in Appendix B.

Feedback was requested through the APA's dedicated GitHub repository (W3C, 2020). Speaking in early October 2020, Abou-Zahra was encouraged by the feedback that had been submitted so far – some 55 comments, 25 of which remained to be addressed. The working draft is nearing completion, Abou-Zahra explained, but feedback and other input from relevant stakeholder will continue to be welcomed as work on the XAUR matures further.

The ISO Common Access Profiles

The International Organization for Standardization, ISO, through its committee JTC 1/SC 35, on user interfaces, has also been looking into possible standards for accessibility in virtual environments. Within that committee, a special study group on Accessibility within immersive environments has been convened. They decided to draw inspiration from a standard published by the committee in 2009: ISO/IEC 24756:2009, which outlined a framework for so-called Common Access Profiles (CAP) – standardized profiles of users with varying needs – as a tool for finding and addressing accessibility problems (ISO, 2009). Could similar profiles be developed for the XR field?

Jee-in Kim, a professor at Konkuk University in Seoul, South Korea, has played an active part in this work. He describes how the CAP structure might be extended to work for developers of XR solutions or XR content, as well:

> If you take this international standard and you specify, "what are the capabilities or modalities or processing features of your content or your solution", then your user may check these CAP structures… Then he or she [can say]: "OK, I have these problems, so I need this assistive technology to bridge or remove this handicap, for me to enjoy this XR solution."

In other words, a CAP structure for XR would allow users to state their individual needs, based on which the system can suggest specific accessibility remedies, or even make automatic adjustments. Kim explains that this will be done according to what he calls an "algorithmic approach". As in the earlier CAP standard, the algorithm will use lists of modalities for input – i.e., abilities that humans may use when interacting with an interface – and output – i.e., ways in which an interface may transmit content. Adding the user's statement of their needs, a calculation will be made of the available and suggested modalities for that user. The lists of modalities developed for the earlier standard will be used as a starting point. Those lists included things such as visual, auditory and neurophysiological capabilities on the input side, as well as media types such as video, graphic elements, text, and sign language on the output side. "This should be extended," Kim adds, "so that we can cover virtual reality and extended reality."

The special study group convened for its first in-person meeting in January 2020. Soon after, the covid-19 pandemic halted international travel and with it, the possibility of further physical meetings for the foreseeable future. While the study group has sought to get on with online meetings, the work on developing a CAP structure for virtual reality has been delayed. This can also be seen in the current composition of the group. As Kim explains, while he and his fellow group members are well-versed in standards and general accessibility principles, they lack expertise on XR topics. "We would want to have some collaboration with XR and VR experts," Kim says, "so that we can identify the real issues for users who want to enjoy VR or XR experiences." (Kim, 2020)

3.3. Key actors and networks

Over the past few years, various initiatives dealing with XR for persons with disabilities, either directly or indirectly, have been launched.

The XR Association (XRA) is the global trade association for the extended reality industry, bringing together both smaller manufacturers and large actors, including Facebook, Google, HTC, Microsoft, and Sony. Its aim is to promote the worldwide growth of the XR industry. In working towards this aim, the XRA advises on public policy and carries out market research (XRA, 2020). For instance, in September 2020 the XRA published a study looking at how XR technology is being adopted in various industry segments (XRA, 2020). Recently, the XR Association released a developers' guide with specific best practices for accessibility and inclusive design in extended reality (XRA, 2020). This guide is intended as an introduction for developers of extended reality experiences. It offers a set of industry-backed best practices for developing accessible platforms that enhance experiences for all users, including users with disabilities.

EuroXR is the European association for extended reality, with a membership that includes industry actors as well as national associations, research and academic institutions, and individual stakeholders. The association was founded as EuroVR in 2010, as an outgrowth of a European research project (EuroXR, 2020). EuroXR has carried out some work on XR accessibility, most recently in the VR4Rehab project, which looks at various ways to use virtual reality as a rehabilitation tool (VR4Rehab, 2017-2020).

XR4All is an initiative by the European Commission, aiming to promote the growth and development of the European XR industry. It also acts as a rolodex of professionals working on XR across Europe (XR4ALL, 2020).

The XR Access Initiative is an international association that deals directly with the issue of accessibility in extended reality. Founded in 2019 by Cornell Tech and Verizon Media, with the support of the Partnership on Employment and Accessible Technology (PEAT), XR Access has quickly attracted over 140 members from across the world. Through its six working groups, XR Access is establishing itself as a clearinghouse for resources on how developers and providers of XR technologies can achieve more accessibility for their users. It has also organized two international summits – most recently the 2020 conference, which was held online due to the covid-19 pandemic (XR Access, 2019). According to Bill Curtis-Davidson, one of the association's initiators, XR Access is still growing and establishing itself. As of 2020, it has not been incorporated, but rather functions as a community bringing enthusiasts together (Curtis-Davidson, 2020).

The A11yVR Meetup has quickly become one of the most active volunteer spaces devoted to XR accessibility. Organized by Thomas Logan, accessibility expert and founder of the Equal Entry consultancy firm, the meetup group brings together hundreds of participants for regular online events with experts presenting new research or solutions (A11yVR, 2020).

The Inclusive Design for the Immersive Web Community Group was organized by the W3C following its workshop on Inclusive Design for the Immersive Web in 2019 (mentioned above). Its objective is to track accessibility issues arising from W3C's activities regarding XR, as well as to promote XR accessibility internally and externally. As of late 2020, there has been little activity in the group, but the pace is expected to pick up as work on the XAUR proceeds further (W3C, 2019).

4. Current XR for persons with disabilities

While the previous chapter dealt with the main accessibility issues surrounding extended reality and persons with disabilities, and the organizations involved in developing guidelines addressing these issues, this chapter looks at practical applications. What XR solutions are there that benefit persons with disabilities today, in one way or another? And what is under development?

"Solutions" here refers to a broad range of things: hardware, software, peripherals, media content and add-on functionalities to existing hardware and software. The common denominators are these solutions' use of augmented, mixed or virtual reality technology, and that they are intended to benefit persons with disabilities in some way.

The overview presented here is divided into three broad categories of disability technology: assistive technology; rehabilitation and training; and awareness and insight. Here, a key difference between the first two categories on the one hand and the third category on the other should be noted. While solutions in the former have persons with disabilities as their intended users, solutions in the latter are typically intended for persons without disabilities.

The overview is further divided into different accessibility needs (e.g., vision, hearing and cognition) and current availability – that is, is a solution available in the market to consumers or practitioners, or is it still being developed?

Finally, the word "overview" hints at the fact that this chapter does not presume to offer an exhaustive list of disability-related extended reality applications. Happily, the field is far too dynamic for that to be possible. Rather, this chapter provides the reader with examples of some of the most prominent, interesting and promising solutions for various groups that we have been able to turn up through our research.

4.1. Assistive technology

Assistive technology (AT) refers to solutions designed specifically to help persons with disabilities in their daily lives. A common example of an assistive technology is a wheelchair; a piece of equipment used specifically by persons who lack mobility to make it possible to move independently. Another familiar example would be hearing aids, which are used to enhance the hearing of persons with hearing impairments. Assistive technology sometimes contrasts with, and sometimes complements, a universal design approach, which calls for environments, products and services to be constructed with users' different needs in mind. At heart, however, assistive technology adapts products, services, devices or environments to the specific needs of persons with disabilities. It can help persons with disabilities live more active and independent lives.

This section presents the following examples of assistive technologies that use XR:

Table 2: List of assistive technology XR solutions

User need	Solutions
Vision	• eSight • IrisVision • SightPlus • OrCam MyEye • Sound of Vision • High-contrast visual patterns from spatial information • Cognitive augmented reality assistant for the blind • AR for Visually Impaired People • Virtual Guidelines
Hearing	• Captions in 360° video • AR Captioning project • HoloSound project
Mobility	• WalkinVR • Smart Shelf • Non-invasive neural-guided hand exoskeleton • Dots
Cognition	• Light Guide Systems
Other	• Immersive Accessibility (ImAc)

Vision

Augmented and virtual reality is currently being used in a number of assistive technology solutions for persons with low vision or blindness. This can appear surprising: are augmented and virtual reality not intensely visual types of media? Yet a broader conception of extended reality has opened up new potential for this community.

Available

Over the past few years, much attention has been given to devices that use augmented reality to assist persons with low vision. The technical details vary somewhat, but the general principle is that of a headset with front-facing cameras that relay images of the surrounding environment to the wearer. These images are then adjusted – through magnification, duplication, heightened contrasts or by other means – to compensate for the wearer's particular visual impairment.

For the wearer, the results can be dramatic, at least judging by a number of public demonstrations and "human interest" media stories in recent years. There are a number of videos online showing persons with low vision becoming emotionally overwhelmed as they try on augmented reality vision enhancing devices. Examples of the genre include a mother seeing her children for the first time, a young woman being able to read aloud from a book again, and a schoolboy being able to see the blackboard in the classroom.

There are already a number of different solutions in the market. One of the first, if not the first, is **eSight**. Founded in Toronto, Canada, in 2006, the company released its first prototype device in 2013. Seven years later, the eSight device is on its fourth generation and is available in Canada, the US and a number of European countries. The eSight device is technically complex, consisting of a custom-built headset with goggles that contain two high resolution screens that relay live images from a front-facing camera placed between the screens (eSight, 2020).

An alternative is the **IrisVision** device. This device is slightly cheaper than eSight, primarily due to the IrisVision's use of a modified version of the Samsung Gear VR headset that holds a similarly modified Samsung smartphone. Images from the phone's rear camera are relayed to the binocular display on the phone's screen, which is placed directly in front of the wearer's eyes. Through voice commands or a separate hand controller, the wearer can manipulate the image to match their needs. The start-up is based in Pleasanton, California, and released its first device in 2017 (IrisVision, 2020). Going forward, the developers of IrisVision plan to add diagnostic and therapeutic capabilities. This would allow the device to track information on key visual health indicators that could help the wearer's healthcare provider tailor eye care plans (Magistretti, 2019).

Figure 1: With the eSight system (center), eye conditions such as diabetic retinopathy (left) can be ameliorated (right).

A third option is the **SightPlus** system, developed by the UK company GiveVision and first released in 2014. Currently, SightPlus works in a similar way to IrisVision, relying on a modified VR headset that holds a smartphone. Now, however, GiveVision is developing a new version of the SightPlus device. Unlike the current iteration, but similar to eSight, the second-generation device will be manufactured from the bottom up in partnership with Sony and, according to GiveVision promotional material, using imaging technology first developed by the European Space Agency (ESA). GiveVision further claims that the end result will be lightweight and more energy-efficient, and thus more suited to prolonged use (GiveVision, 2020).

Beyond user testimonials, all three providers tout clinical evidence of the efficacy of their solutions. According to various clinical trials, augmented reality vision enhancing aids appear to work well for persons with a range of different conditions that affect sight, such as macular degeneration, Stargardt's disease, retinitis pigmentosa and diabetic retinopathy (Wittich, et al., 2018).

Persons with very little visual perception will benefit more from audio-based solutions than vision enhancement. One such solution is the **OrCam MyEye**, a portable camera device that translates visual information into speech. Using artificial intelligence (AI) technologies, it can recognize things such as text, faces and various products. The device should be attached to any pair of eyeglasses. OrCam was founded in 2010 in Israel and offers two slightly different devices (OrCam, 2020).

Table 3: Comparison of head-mounted AR vision aids

Product	Launched	Type
eSight	2013	Stand-alone device
SightPlus	2014	Headset holding adapted smartphone
IrisVision	2017	Headset holding adapted smartphone
OrCam	2010	Attaches to regular eyeglasses

In development

Custom-built augmented reality vision aids as they currently exist have some drawbacks. One drawback is lack of availability to consumers: since the aids are highly specialized for a niche audience, they may not be readily available in consumer marketplaces. Moreover, such aids are less likely to be effective for persons with more profound vision loss. However, promising new research may be able to address these drawbacks.

In the **Sound of Vision** project, which ran from 2015 to 2018 with funding from the European Union's Horizon 2020 program, researchers from Iceland, Romania, Hungary, Italy and Poland developed a prototype for a solution for a wearable system that analyzes visual information and converts it into an auditory and haptic (i.e., force feedback) representation of the wearer's surroundings. The device is designed for users who are completely blind and consists of a headset with two front-facing cameras, headphones and a “haptic belt”, to be worn around the waist. During use, the system captures visual information, including depth and color, and generates relevant auditory or haptic feedback for the wearer. The device is also designed to allow for a large degree of customization to the wearer’s needs and preferences (Sound of Vision, 2015-2018). The device currently only exists as a prototype – albeit a tested and validated prototype – the consortium partners are exploring ways of bringing it to the market. (Sound of Vision, 2018).

An experiment carried out by a group of researchers at Dartmouth College and Cardiff University has sought to address these drawbacks. They developed an application for the Microsoft HoloLens that creates **high-contrast visual patterns from spatial information**, in particular different so-called distance bands. These visual patterns are then overlaid on the real environment visible through the see-through HoloLens displays. In tests carried out with two cohorts – one small group of persons with low vision, and one larger group of persons with normal or corrected vision – the solution showed some promise, with ‘substantially improved accuracy and confidence’ when it came to recognizing objects. However, further study is needed before the concept is market ready. (Kinateder, et al., 2018)

Scientists at CalTech, meanwhile, are currently developing what they refer to as a **cognitive augmented reality assistant for the blind**, or CARA. Using the Microsoft HoloLens, the system creates a 3D map of the surrounding visual environment. It then generates audio cues as well as high-contrast visual cues that identify objects and obstacles in the environment to the user. This will help the user navigate independently. Tests carried out with real users with vision loss showed encouraging results. In addition to the CARA system, the researchers also developed an open-source benchmarking environment for similar vision aids, something to which they hope other AT developers will contribute in the interest of creating a standardized testing methodology. This, the researchers state, “should stimulate competition to exploit the ongoing revolution in wearable computers and machine vision toward creative solutions in the domain of assistive technology.” (Liu, Stiles, & Meister, 2018)

The concept of “sonifying” objects in the visual environment – that is, generating speech or other audio cues that describe the object in question – is being pursued by many researchers and developers. Among them are a team of master’s students at UC Berkeley, who developed the **AR for VIPs** (augmented reality for visually impaired people) project. This project tested an AR system that used object sonification, as well as spatial mapping and text recognition, to help low vision users navigate in physical spaces. “Low vision users can have problems identifying and reading signs, such as [for] bus stops,” explains Dylan Fox, one of the researchers on the project. “Our solution identifies the presence or absence of objects, using the HoloLens spatial mesh, [and] then allows users to capture and read text.”[2] The researchers were particularly focused on addressing what they

[2] From survey.

termed “the 5-meter problem”. This refers to the recurring complaint by persons with low vision that existing assistive technologies for navigation, many of which use GPS, are of little to no help once you come within five meters (16’4”) of your destination. Ultimately, the results of the project were mixed: while testers with low vision could conceive of some scenarios where such a solution would be helpful, they all felt that the device used – the Microsoft HoloLens – was too large and heavy to allow for comfortable prolonged use. In early tests, participants also felt overwhelmed by the sheer amount of auditory feedback generated by the system. (AR for VIPs, 2019)

Bartiméus, a Dutch civil sector body that brings together expertise for and about persons with low vision and blindness, has carried out a number of projects that involve extended reality. Among other things, they have built an augmented reality smartphone prototype application called **Virtuele Geleidelijn** (“Virtual Guideline”) that provides auditory and haptic feedback to help low vision and blind users navigate in indoor environments. This feedback is based on a pre-built “3D map” of a particular route. (Bartiméus, 2018) “For the next version of the app,” explains Paul de Nooij, project manager at Bartiméus, “we will scan a building, as a map, and then within that map generate routes.” (de Nooij, 2020)

Hearing

Available

In recent years, 360° video – which enables a viewer to “look around” a scene as they would in a real environment – has emerged as a popular and simple way of creating immersive experiences. For persons who are deaf or hard of hearing who rely on captions (also called subtitles), 360° video can present a unique accessibility challenge: In videos with spoken audio tracks, where should captions and subtitles be placed?

In 2017, the research and development department at the BBC, the UK’s public broadcaster, tested four **different alternatives for displaying captions in 360° video**:

- Repeated across three fixed positions, evenly spaced out
- Always in front of the viewer, regardless of where they look
- In front, but with slight delay when viewer looks elsewhere
- Each caption strip fixed where viewer happens to be looking when it appears

The BBC’s researchers had expected the third option to be the most popular, with the captions easy to find but unobtrusive. As it turned out, however, users preferred the second option, where the captions simply follow the viewer’s gaze without delay. As the lead researcher summed up the results:

> Overall […] the simple obvious solution is the one that appears to work the best. Perhaps, as engineers we have a tendency to over-think

> problems, but this has certainly been a good reminder of the value of user testing. (Brown, 2017)

Captions that follow the viewer's gaze seem to have become the standard solution, used by YouTube among other providers of 360° video. However, researchers at Verizon have continued to investigate the issue. According to Larry Goldberg, Head of Accessibility at Verizon Media, they are currently developing and prototyping solutions that would allow users to decide for themselves how and where captions should appear. They are also looking at ways of indicating the location of speakers in virtual reality spaces.[3]

In development

A major area of development of assistive technology for persons with hearing disabilities is within captioning in immersive environments. The W3C is currently working on establishing best practices in this regard, through its Immersive Captions Community Group (W3C, 2020). At the University of Washington's Makeability Lab, a specialist center for human-computer interaction, researchers are exploring the use of real-time captions in augmented reality to help persons with hearing loss. The overall concept is to machine-generate captions from speech and then display these captions in an augmented reality head-mounted device. Two projects testing this concept are running currently: the AR Captioning project, and the HoloSound project. (Makeability Lab, 2016)

In the **AR Captioning project**, researchers are doing broad-based research to investigate whether real-time captioning, which works well in stationary settings, can help address challenges that persons with low hearing or deafness experience in so-called "moving conversations" – that is, oral communication that occurs between participants who are walking or otherwise mobile. (Makeability Lab, 2020) User testers from the target group have identified several such challenges: e.g., that moving conversations tend to be "brief and shallow", and thus more difficult to follow; that hearing persons tend to be less attuned to the needs of their hearing-impaired conversation partners in mobile situations; that physical activities make it more difficult to communicate through sign language and the like; and that variations in the physical environment such as lighting and background noise make speech and sign communication more difficult to perceive. The participants in the AR Captioning project were then asked to evaluate three different methods of delivering real-time captions: through a smartphone application, through a smartwatch (i.e., an interactive device that resembles a wristwatch) and, finally, through a head-mounted display (HMD, in the testing scenario the Microsoft HoloLens). Most participants preferred the HMD, since it did not demand that the wearer divide their visual attention. In subsequent tests with HMDs, the researchers trialed different ways of displaying captions and their utility in real-life settings. These tests further validated the approach, though some testers occasionally found the captions distracting. Based on these results, the researchers

[3] From survey.

have outlined initial recommendations for designing and implementing captions in head-mounted displays:

- Captions should be properly aligned with the wearer's line of sight to avoid splitting attention between the captions and the environment
- The font and background color of the captions should change automatically with the surrounding lighting conditions
- The HMD wearer should be able to stop captions generated from their own voice, in order to reduce the amount of information displayed
- The HMD should also offer contextualizing information: who is speaking and where, what is the speaker's tone of voice, and are there other sounds in the environment?
- The wearer should be able to customize the placement and appearance of captions in the system. (Jain, et al., 2018)

The **HoloSound** project provides a proof of concept of some of these recommendations, while also delving further into deep learning as a tool for identifying and locating sounds. The prototype consists of a Microsoft HoloLens running a dedicated application, an external microphone placed on top of the wearer's head, and a modified Raspberry Pi 4 single-board computer that connects to a cloud-based server. These components enable a system that provides

- Automatic speech transcription
- Recognition of common sounds
- Localization of sounds

To enable recognition of common sounds, the researchers have "trained" the system with nearly 30 hours of sound effects (e.g., doorbells, fire alarms, ringing phones) from publicly available databases. The underlying source code is available without restrictions at GitHub (Guo, et al., 2020).

Mobility

Available

The Polish software company 2MW has developed **WalkinVR**, a driver plugin that helps adapt existing VR solutions to the needs of persons with motor disabilities. It provides for four adaptations in particular: using VR with the assistance of another person; creating virtual replacements for certain physical movements that the user cannot perform; adjusting the default position of controllers; and, finally, hand tracking functionalities that register a user's movement even when they are not holding a physical VR controller. (2MW, 2020)

In development

Engineers in Dundee and Barcelona have built a prototype **Smart Shelf** system for shops. This system uses Radio Frequency Identification (RFID) tags to collect and display the contents of a physical shelf in a smartphone-enabled augmented reality environment. This is intended to help wheelchair users, who often cannot reach items placed high up on store shelves, go shopping more independently. At the beginning of their research, the developers carried out a user study with this target audience to better understand their needs and preferences in terms of shopping in stores. Based on this user study, the researchers assembled a prototype shelf filled with sample products. RFID tags – notably a cheap and passively powered technological solution – were affixed to each of these products, which were in turn catalogued on a cloud server with identifying information. The shelf also contains an RFID reader uploading real-time information about the availability and approximate locations of products to the same cloud server, as well as markers communicating with a dedicated smartphone application. While running this application, the user points their smartphone camera toward the shelf markers. This generates an augmented reality view in which the user can browse the actual, current contents of the shelf. The user can then add items to their shopping list. Items added will be retrieved by store staff and brought to the store's check-out area, where the user can pick them up when leaving the store. The Smart Shelf solution has undergone only limited trials, but the response from those who did participate has been encouraging. Further development is planned. (Rashid, Melià-Seguí, Pous, & Peig, 2017)

A team of researchers in Tübingen and Stuttgart, Germany, have developed what they describe as a "**non-invasive neural-guided hand exoskeleton**". In layman's terms, this is a mechanical cast worn over a hand with reduced motor function that allows the wearer to grip, manipulate and handle physical objects. The intended target audience is persons who have reduced motor functions following a stroke or a spinal cord injury. The system was designed to be operated through a brain-computer interface (BCI), with the help of a custom-built EEG cap (Soekadar, et al., 2016). As it turned out, however, this resulted in a high error rate. In order to increase accuracy and usability, the research team started looking into possible supplementary input methods. A survey with various real users identified augmented reality glasses as one of the most popular supplementary input methods (Ableitner, Soekadar, Schilling, Strobbe, & Zimmermann, 2019). A first attempt at a practical implementation of augmented reality glasses – in conjunction with eye-tracking technology – as a supplementary input method has recently been carried out by Sebastian Koch, a master's student at Stuttgart Media University. However, further study is needed to validate the feasibility of using augmented reality as a supplementary input method for exoskeleton solutions (Koch, 2020).

At the Royal College of Art and Imperial College in London, the United Kingdom, a group of master's students have developed a prototype system called, simply, **Dots.** The "dots" in question are adhesive and movable stickers containing inertial measurement unit (IMU) sensors. By placing the dots on the user's movable body parts, the system allows persons with reduced mobility or grip to control immersive interfaces through body and gesture recognition. The placement of the dots is entirely up to the user and her needs, but the system has shown particular promise in tests with upper-body amputees. (Gong, Wang, & Xiao, 2020)

Cognition

Available

The Belgian supported employment enterprise Mariasteen has for the past several years been using **Light Guide Systems** augmented reality systems as workplace aids for its several hundred employees with developmental disabilities. The device provides the employees with real-time, continuous guidance on how to complete tasks in their assembly work. Additionally, the system can help the user identify and address mistakes. The LGS system used at Mariasteen is not a wearable AR device, but rather a workbench with an interactive surface display. For Mariasteen, the gains have been clear: productivity has increased, while quality defects are becoming rare. More importantly, the employees themselves have reported satisfaction with the help they receive from the new system, which makes them feel more confident and less stressed. (Light Guide Systems, 2020) Light Guide System (Dominiek Savio Gits)

Other

Available

Between 2017 and 2020, a consortium of European partners in academia, broadcasting and the disability rights movement carried out **the Immersive Accessibility (ImAc) project**. The project sought to make immersive media more accessible by investigating the needs of a diverse set of users – in particular, users with visual impairments or blindness and hearing impairments or deafness. The end result was a media player. (Immersive Accessibility, 2020)

Pilar Orero, professor of Audiovisual Translation at the Universitat Autonoma in Barcelona, Spain, led work on the ImAc project. The user testing carried out in the project produced some rather surprising results:

> [We found that] a blind person is less lost in an immersive environment than a deaf person. A deaf person is completely lost in an immersive environment, because they don't know where the sound comes from. So they don't know where to focus.

To Orero, the finding that users with low hearing or deafness may struggle more in immersive environments than users with low vision or blindness was "fascinating, but very bad for research." Although the consortium was able to go ahead with the project as planned – for instance, by building the dedicated media player for immersive accessibility – the surprising result indicated to her that the field is still in the early stages of understanding how immersive media works for different users. (Orero, 2020)

4.2. Rehabilitation and training

Rehabilitation and training refers to solutions that help persons with temporary or permanent disabilities counteract the impact of their impairments, through mitigation or remediation. Applied correctly, XR can reduce the effects of disability on the individual.

This section presents the following examples of rehabilitation and training solutions that use XR:

Table 4: List of rehabilitation and training XR solutions

User need	Available
Vision	• V-HAB
Hearing	• VIRTUALHEARING 3D
Mobility	• Kwido • Tecnobody
Cognition	• Psious • Floreo • INTERHYTHM • Talking Place • Collaborative Mixed Reality Aid • AR game on nutrition for persons with intellectual disabilities
Other	• Merge

Vision

In development

The **V-HAB project**, which is led by researchers at the University of Applied Sciences and Arts of Western Switzerland and funded by the European Union's Horizon 2020 program, looks at how virtual reality can be used to improve rehabilitation for children with pediatric amblyopia (commonly known as lazy eye). Starting in 2021, the project partners will develop virtual reality games that, it is hoped, will make PA therapy more efficient as well as more engaging for children. (CORDIS, 2020)

Hearing

In development

There has also been some interest in using virtual reality principles to benefit persons with cochlear implants (CI). These are implanted hearing aids that compensate for reduced function in the cochlea, a part of the inner ear, by generating electrical impulses from sounds in the environment. Persons who have undergone CI surgery usually need to undergo rehabilitation to build up language skills. However, comparatively little attention is paid to training CI users' spatial hearing abilities – that is, the ability to identify from where a sound is coming. A research project carried out by researchers at the Neuroscience Research Center in Lyon, France, seeks to address this with virtual reality. The **VIRTUALHEARING3D** project, which began in 2017 and is expected to continue until 2021, investigates whether virtual reality headsets can be used to test and improve the ability of persons with CI to identify the spatial location of sounds. (ANR, 2016) In a fully immersive VR scenario, test participants are asked to identify the origin of various sounds in that environment, with the system encouraging “active listening” – i.e., moving your head and body in relation to the source of the sound. Tests performed thus far have been relatively positive, indicating that this could be a hearing rehabilitation method worth developing further. (Valzolgher, et al., 2020)

Mobility

Available

The Spanish software developers Ideable are behind the **Kwido** suite of technology solutions for the elderly (often referred to as AHA in the European research community). As part of that initiative, they recently carried out the virtuAAL project. virtuAAL looked into the potential uses of extended reality for rehabilitation of older persons with disabilities. (VirtuAAL, 2019) The project partners tested both augmented and virtual reality approaches to rehabilitation. Interestingly, they found that VR solutions worked better than less immersive AR solutions. For that reason, explains Ideable CEO Iñaki Bartolomé, Kwido decided not to proceed with augmented reality. “It was strange,” he says. “They [the testers] didn’t understand it very well – what augmented reality is, and the interaction.” When it came to the virtual reality solutions, it was a different story entirely: Although the experience of touching and grasping virtual objects was initially jarring for some participants, says Bartolomé, “after one session playing, they [were] able to play the game.” He chalks the short learning curve up to the simplicity of the design. “There’s not many instructions, you know, it’s just behaving as [you would] in normal life.” (Bartolomé, 2020)

Tecnobody is an Italian company that manufactures interactive exercise devices. They offer a suite of technological solutions for rehabilitation and training, including solutions that use virtual reality principles to correct gestures and other movements. While this suite can be used as exercise equipment for general audiences and gyms, some of the developed solutions are also being used as rehabilitation tools for persons with reduced mobility – in particular the D-WALL device, which provides the user with a virtual environment for real-time feedback. In this virtual environment, the user can try to match their movements to a virtual guide and receive continuous information on their progress. (Tecnobody, 2020)

Cognition

Available

Another interesting application of VR technology is the **Psious** mental health platform. It uses virtual, immersive environments to conduct therapy sessions. These simulations replicate real-world situations that persons with psychological conditions may find challenging and provide treatment according to cognitive-behavioral therapy (CBT) principles. Specific conditions addressed include depression, obsessive-compulsive disorder (OCD), and a range of phobias. Psious is available to practitioners in a number of countries as a subscription service. There are different account levels, but the subscription minimally includes both software and hardware – i.e., a virtual reality HMD. (Psious, 2020)

Floreo, a startup based in Washington, D.C., operates a virtual reality therapy platform specifically for persons on the autism spectrum. Over the past few years, Floreo has built a library of simulations of situations that persons on the autism spectrum may find challenging. Available simulations include classroom settings, general small talk, and body language recognition. These simulations are run on a custom-built application for iOS, together with any smartphone-interfacing HMD. The iOS application is also tethered to a corresponding application running on an Apple iPad, through which a parent or other interlocutor can follow along with the therapy session and, if necessary, control the simulation. (Floreo, 2017)

With funding from the U.S. National Institutes of Health (NIH), Floreo has also developed a set of simulations of police encounters. While not an everyday occurrence, interactions with law enforcement can carry certain risks for persons on the autism spectrum, as a number of distressing incidents over the past few years have shown. Across the United States and elsewhere, police departments have taken steps to further educate officers on how to interact with persons with disabilities, including persons on the autism spectrum. The developers of Floreo, however, argue that this is not enough; to further reduce the risk of dangerous and traumatizing situations, they believe, persons on the autism spectrum themselves should also be prepared for such encounters. In the simulations, which display an immersive 3D environment, the user is approached by police officers. The simulations contain a set of questions commonly asked by law enforcement (e.g., “Can I talk to you?”, “What’s your name?”, “What are you doing here?”). The questions can be generated in the system or selected by the interlocutor using the iPad application. Through repeated practice, the user will become familiar with the situation and, it is hoped, will be better able to handle it should they experience it in reality. The police interaction simulations have been subject to extended user testing, and as of 2020, Floreo collaborates with several police departments across the United States to further disseminate this solution. (Parish-Morris, et al., 2018)

In development

A somewhat more speculative initiative is the **INTERHYTHM** project. Run by a European research consortium under the leadership of scientists at University College London, UK, between 2016 and 2018, this project investigated the topic of behavioral mimicry. This refers to the way in which people engaged in conversation copy their counterpart’s posture and gestures. This is an important social skill, but also often a challenge for persons on the autism spectrum. Apart from studying the neurological factors behind behavioral mimicry, the project partners also sought to build a practical testing environment that used virtual reality, motion tracking, and functional near-infrared spectroscopy (fNIRS). The testing environment presented participants with virtual reality simulations of social situations where behavioral mimicry would be expected. Motion tracking allowed for interactivity in the virtual environment, while fNIRS was used to carry out concurrent neural imaging. At the project’s end in 2018, it had resulted in a proof of concept, tested with real users.

There are plans for further developments, with the hope of establishing it as a therapeutic tool. (INTERHYTHM, 2016-2018)

Talking Place is an immersive virtual reality smartphone application that allows users to train for job interviews, as well as improve their social skills. It has been developed by Mimerse, a Swedish healthcare technology startup, in cooperation with the Swedish Public Employment Service, a government agency dealing with labor market issues. The application provides modular simulations of interviews and other social situations that may be stressful to persons with cognitive disabilities. The application works with all virtual reality headsets and can be used independently by the user. (Mimerse, 2020)

A project currently underway in Sweden is taking a more research-oriented approach to the idea pursued by Floreo, of using virtual reality as a rehabilitation tool for persons on the autism spectrum. Under the leadership of the software startup Tensaii, the consortium has identified key scenarios together with the intended target audience. Based on these scenarios, the project partners then developed what they refer to as a **Collaborative Mixed Reality Aid (CMRA)** with adaptive AI functionalities. This solution has been tested and evaluated by the target audience. This feedback will be used to further develop the current prototype solution. (CMRA, 2019)

In Sweden, the non-profit Rural Economy and Agricultural Societies (*Hushållningssällskapet*) recently launched a project that aims to build an **AR game that will teach persons with intellectual disabilities about nutrition**. The project coordinators argue that this can improve the physical, mental and social well-being of persons within the cohort. The coordinators describe the game, in which the player uses a smartphone with GPS to collect and plant virtual seeds in the physical environment, as similar in function to *Pokémon Go.* (Hushållningssällskapet, 2018)

Other

Available

Merge is a Texas-based provider of AR and VR technologies. The company develops solutions for healthcare and science, among other things, but it has a particular presence in the field of education. There, Merge's products have proved to be valuable learning tools, not least for students with learning disabilities. (Merge, 2020) Class VR, another AR and VR solutions provider based in the UK, has worked more directly with that user group, including through collaboration with special education institutions. (ClassVR, 2020)

4.3. Awareness and insight

VR has also been used to create simulation exercises that demonstrate how persons with disabilities experience their surroundings. The intended target audience of such exercises is not persons with any specific disabilities, but rather the general public. Used in this way, XR can help bring about more understanding of the lived experiences and needs of persons with disabilities.

This section presents the following examples of solutions for awareness and insight that use XR:

Table 5: List of awareness and insight XR solutions

User need	Available
Vision	• Eyeware
Hearing	• VR sign language learning
Cognition	• Project CAPE • Funka VR films

Vision

Available

In the UK, the Transport Systems Catapult innovation center has joined forces with the Royal National Institute of Blind People (RNIB) to create the **Eyeware** mobile application. With the help of any smartphone-enabled VR headset, the application simulates the eyesight you might have with some of the most common eye conditions, at various stages of progression. This application has been tested with representatives of the RNIB and is now available as a free download. Currently, the application simulates five conditions: glaucoma, cataracts, diabetic retinopathy, age-related macular degeneration, and retinitis pigmentosa. (Catapult, 2017)

Hearing

In development

Cédric Girardin, an apprentice at the Computer Sciences department at the Berne University of Applied Sciences in Berne, Switzerland, recently built a prototype app that uses VR to teach the German sign language alphabet. The app uses the Oculus Quest platform and hand recognition technology. In the application, the user is asked to match their hand positions to one of 23 hand signs displayed in the virtual environment. Once a match has been recognized, the system moves on to the next sign. Further developments of the application are not planned at the moment, but the source code is available on GitHub. (Girardin, 2020)

Cognition

Available

One of the most well-known examples of such a project is the immersive 360° film produced by the **CAPE project at the BBC**, the UK's public broadcaster. In this film, the user gets to experience a workplace setting through the eyes of a person with an autism spectrum disorder. (BBC Careers, 2016) Other films have been produced in a similar vein, including *Too Much Information* by the British National Autistic Society and *The Party* by The Guardian Online. (The National Autistic Society, 2016) (Bregman, Fernando, & Hawking, 2017)

With inspiration from these examples, Funka has carried out virtual reality projects of its own for the Nordic market. In Norway, Funka produced two films showing how a person with an autism spectrum disorder might experience a meeting in an office setting. The first film shows a “bad” meeting from a cognitive standpoint, while the second film shows what a “good” meeting might look like. It is hoped that these films will help employers understand how they can make their workplace practices more inclusive. (Funka, 2018) A similar follow-up project for the Swedish market is currently being finalized. (Funka, 2019)

5. Extended reality for persons with disabilities in the future

“The world of accessible virtual reality is really just beginning” Larry Goldberg, head of accessibility at Verizon, has said, describing the field as “a big, wide-open space.” (AbilityNet, 2020) As we have seen in previous chapters, plenty of work is already underway, but much of it remains tentative, speculative, or both. What, then, might the future hold? What will emerge to fill this wide-open space? Here, we discuss some key questions regarding the future of accessible and disability-specific extended reality.

For a long time, extended reality was a niche market that was mostly geared toward technology professionals. This has changed dramatically over the past decade. Now, extended reality is entering the mainstream and reaches more audiences than ever before. Inevitably, this puts increased focus on the accessibility of it all.

As we have seen, extended reality has the potential to create added value for persons with disabilities. It can give users access to environments that would otherwise be closed to them, it can help them minimize the effects of whatever physical impairments they may have, and it can also help others understand those effects better. Yet there are also obstacles to adoption on a wider scale. Some of these obstacles stem from the novelty of extended reality as such, which means that there are comparatively few established practices for designers and developers to follow, while other obstacles have more to do with social and ethical mores.

If these obstacles can be removed, new pathways for research and innovation will be opened. Those pathways may lead to solutions that contribute to the inclusion of persons with disabilities in education, the labor market, and in society at large. Indeed, it is possible that those pathways will lead to solutions beyond what we can imagine today.

5.1. Obstacles to adoption

One factor inhibiting the adoption of augmented reality as assistive technology is the design of devices currently on the market. As we have seen, researchers and developers have used head-mounted displays (HMD) to address various accessibility needs, such as low vision or low hearing. However, many of these devices are highly conspicuous in appearance, whether due to their size or other unusual design elements. People who wear such devices in public settings run the risk of stigmatization and negative reactions from others, as the initial launch of the Google Glass showed (Kudina & Verbeek, 2019). The risk of social rejection may make persons with disabilities hesitant or embarrassed to use assistive technology that relies on HMD. (Goodman, Jain, Froehlich, Craft, & Findlater, 2019)

How might this obstacle to adoption by persons with disabilities be cleared? Somewhat counterintuitively, there is some evidence to suggest that it would actually help to make the devices more distinctive. In a 2016 survey, participants were asked to describe how they would react to persons wearing HMD in a public or social setting, with the help of two videos showing a person walking to a bus stop. In the first video, the actor wore a Google Glass; in the second video, the actor wore a Google Glass but also used visual markers of disability status – in this case, dark sunglasses and a white cane to indicate a vision disability. Participants considered the latter use case more socially acceptable, and even more so when they received information about the particular assistive purpose of the HMD. (Profita, Albaghli, Findlater, Jaeger, & Kane, 2016) Another aspect not studied in this survey is the possibility of normalization over time: as HMDs become more commonplace as consumer devices, wearing one in public may become more accepted.

Pilar Orero, professor of Audiovisual Translation at the Universitat Autònoma in Barcelona, Spain, points to the need for further development in terms of how immersive content is produced. “There is no language” for 360 and immersive content, she explains. As an example, she points to the development of film and other audiovisual media:

> When movies had no sound, the visual language was (mock pantomimes) “I! – Love! – You!”, because there was no “I love you”. So I had to exaggerate to show what I meant. […] The audiovisual language has been developing, from no sound to sound, to color, all the way to 3D. And in 3D, the language is completely different. But what the language is for 360 – we don’t know. […] Anybody who’s producing anything in 360, I don’t think they know how to do it. (Orero, 2020)

5.2. Possible future applications

Aside from this, some research points to possible future applications of XR technologies. McMahon et al. have looked at how AR, rather than a traditional map application, might be used as a navigational tool for students with cognitive disabilities (McMahon, Cihak, & Wright, 2015). A team of Polish researchers have carried out speculative work, looking at how workstations could be enhanced with virtual reality for the benefit of workers with low mobility (Budziszewski, Grabowski, Milanowicz, & Jankowski, 2016). Researchers in the UK, meanwhile, have evaluated new virtual reality cognitive behavioral therapies, already in use, as a rehabilitation and treatment tool for persons on the autism spectrum (Maskey, et al., 2019; Maskey, et al., 2019) (Maskey, et al., 2019). Similarly, Geraets et al. have evaluated virtual reality as a CBT tool for patients with generalized social anxiety disorder (Geraets, et al., 2019).

At the end of the survey with stakeholders, we asked for our respondents’ views on what potential XR might hold for persons with disabilities. A lightly edited selection of their responses is presented in the table below.

Table 6: Survey responses on XR potential

General comments about AR, VR, and persons with disabilities
How might AR and VR technologies be used to benefit persons with disabilities?
Persons with disabilities in general “In strenghtening and helping to create a more communicative and independent life for every individual.” “To provide accessiblity, provide VR and AR simulations for skills building, create individualised learning experiences.” “To enhance reality with additional information, possibly in real time, which allows you to gradually or instantly compensate for the fragile condition in which they are.” “For access to services and entertainment from home.” “For enhanced self care, social connection, learning opportunity, enhanced independence.” “To gain new experiences and be able to move around independently.” “To enable remote immersive learning and communication.”
Persons with low vision or blindness “AR for better recognition of objects, VR headset for navigating indoor spaces” “AR for context and awareness of the environment around them plus the usual OCR, facial and object recognition.” “Auditory feedback.” “Compensatory functions, enhanced self care; social connection; learning opportunity; enhanced independence.” “Incredible sensors, computer vision, can be combined with existing ‘dumb AR’ techniques like contrast enhancement.” “One could think of an augmented reality system focused exclusively on sound stimuli (e.g., Navigators for visually impaired people), or tactile ones.”
Persons with low hearing or deafness “An augmented reality system can be useful in case of hearing impairment, because it can insert visual information regarding the sounds of the surrounding environment.” “AR for indicating sources of sound.” “Captioning glasses.” “Create visual cues to replace audio cues, including IRL subtitles.” “Help to identify sounds around the person and display alerts.” “In strenghtening and helping to create a more communicative and independent life for every individual.” “Visual aid.”
Persons with low mobility

General comments about AR, VR, and persons with disabilities
"AR/VR for access to services and entertainment from home." "Augmented reality can help correct postures and incorrect movements, and stimulate physical rehabilitation." "Enable low mobility to work remotely, even from prone positions." "Help visiting some location not accessible with wheelchair." "Help piloting an environment using eye tracking (available in Hololens)." "In strenghtening and helping to create an independent life for every individual." "Virtual travel." "Simulate otherwise inaccessible experiences. Remote piloting of robots." "Users could travel virtually to some interesting places." "Persons with tetraplegia or something similar could use AR glasses in combination with special input methods (e.g., eye tracking) as an alternative to mobile phones and tablets."
Persons with cognitive disabilities "A more motivating way of stimulating their minds and the possibility of performing executive function games related to real daily activities in real scenarios." "Combined with traditional PC-based cognitive assistance software, VR can allow time, space and order, which they can use to work remotely at most current and future workplaces." "Exposure to new experiences, support for multi-modal learning. During the pandemic, many things are not available, so VR/AR could provide opportunities to expand possibilities." "In strenghtening and helping to create a more communicative and independent life for every individual." "Instructions are shown one step at a time." "Learning activities to practice real world skills." "Overlaying of information to help with poor working memory, implementation of hyporeality to reduce risk of becoming overwhelmed." "Support training, provide information to supplement what they may have a hard time with." "Tailored training is a very under explored area." "Therapy tools in VR." "With VR/AR scenarios teachers and educators can imagine starting from a scenario without stimuli and gradually adding them one at a time, favoring a gradual learning. This is especially useful with people with autism."
In which sectors would AR and VR technologies be of particular benefit to persons with disabilities?
"Education, especially for people with special needs. Job training, navigation systems. "Mental health care. We have done a project together with a municipality in Sweden that proves the use of VR for e.g. social skills training and stress reductions for people with slight cognitive disabilities."

General comments about AR, VR, and persons with disabilities
“Areas related to self care, such as housing, retail, community connections, financial, leisure, medicine, education - would ensure access, adaptions, equity and quality of life through the life course.” “Cognitive stimulation, combating phobias.” “Higher education, education at all levels. Vocational training, travelling and tourism.” “Hospitals, homes for the elderly, training aids for the disabled, shopping, education, distance working.” “Industrial design.” “Lifelong learning, supported employment, independent living, community engagement.” “Medical, education, manufacturing, entertainment.” “Particularly useful in jobs where people are mobile. But also applications for immersion in an educational context.” “Rehabilitation, Accessibilty market.”
Other comments
“AR is sometimes hard to use and expensive for people with disabilities, VR devices are much more mature. “ “I believe people with disabilities should be involved in the AR and VR content especially individuals with Intellectual disabilities.” “Much AR/VR implementation still doesn't take into account accessibility.”

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Appendix A: Stakeholder survey

The following survey was set up in the web-based survey tool Alchemer (formerly SurveyGizmo) and circulated to relevant stakeholders during August and September, 2020.

How can AR and VR technologies benefit persons with disabilities?

Funka is studying how augmented reality (AR) and virtual reality (VR) technologies can be used to benefit persons with disabilities. Can AR and VR solutions remove accessibility barriers, promote the inclusion of disabled people in society, or increase awareness of disability rights? We want to hear what you think! We're carrying out this research on behalf of Facebook, so this is a good opportunity to bring your work to the attention of a major actor in the field.

The survey will take up to 15 minutes to complete. Please feel free to skip any questions that are unclear or irrelevant to you.

Do you have questions, comments or concerns? Please get in touch with Emil Gejrot at emil.gejrot@funka.com!

Click here to read more about our research.[4]

About you

First, tell us a bit about yourself. Any information you provide will be handled in accordance with the General Data Protection Regulation (GDPR).

1. What is your name?

[Text box]

2. Where do you work?

[Please enter the name of your organization]

3. Can we contact you if we have further questions?

Depending on your answers to the survey, we may have some further questions. Please select “Yes” and provide your email address if you’re happy for us to get in touch.

- Yes – [please provide your email address].
- No

[4] The link led to the following unindexed page on the English-language version of Funka’s web site: https://www.funka.com/en/projekt/ar-and-vr/tell-us-about-your-ar-and-vr-work/ (Retrieved 29 October 2020).

4. Have you or your organization worked on AR or VR technologies?

- Yes, on AR
- Yes, on VR
- Yes, both
- No

Specific AR and VR solutions

Here, we would like to learn a bit more about specific AR and VR solutions that benefit persons with disabilities. This can be either...

- ...solutions that you or your organisation have developed
- ...solutions that you or your organisation have helped develop
- ...solutions that you have used
- ...or just solutions that you have heard about

You can add as many solutions as you like by clicking the "Add another solution" button at the bottom of the page.[5] **If you don't know the answer to a question, just leave it blank!**

5. Solution

a. What is the name of the solution?

[Please state the name of the solution]

b. How do you know about this solution?

- My organisation developed it
- My organisation helped develop it
- I have used it
- I have heard about it

c. What type of solution is it?

- An AR solution
- A VR solution
- A solution that uses both AR and VR technologies

d. What does the solution do?

Please describe briefly what the solution does and how it works.

[Free text]

e. How mature is the solution?

- At the conceptual (pre-development) stage

[5] By clicking this button, question 5, along with its sub-questions a-i, was repeated at the bottom of the page.

- In development
- Prototype or demo version
- On the market

f. Who is the solution for?

Please select all that apply.

- Persons with disabilities in general
- Persons with low vision or blindness
- Persons with low hearing or deafness
- Persons with low mobility
- Persons with cognitive disabilities
- Persons without disabilities
- Other – [Please specify]

g. Which accessibility barriers or problems does the solution address?

Please describe briefly how the solution addresses specific barriers to accessibility or other accessibility problems.

[Free text]

h. How has the solution been tested with real users?

Please describe briefly any user testing carried out during the development of the solution. In particular, state if and how persons with disabilities participated in such testing.

[Free text]

i. How will the solution develop in the future?

Please describe briefly possible future developments of the solution, including planned updates and upgrades.

[Free text]

General comments about AR, VR and persons with disabilities

6. How might AR and VR technologies be used to benefit persons with disabilities?

Please describe briefly how you think that AR and VR technologies could benefit persons with different kinds of disabilities. If you don't have anything to say about any of these groups, leave the corresponding text boxes blank.

- Persons with disabilities in general – [text box]
- Persons with low vision or blindness – [text box]
- Persons with low hearing or deafness – [text box]

- Persons with low mobility – [text box]
- Persons with cognitive disabilities – [text box]

7. In which sectors would AR and VR technologies be of particular benefit to persons with disabilities?

If you think the use of AR and VR technologies within specific industries or sectors would be of particular benefit to persons with disabilities, please describe

- Which industries or sectors
- How the use of AR/VR in those industries or sectors could benefit persons with disabilities.

[Free text]

8. Do you have any other comments about AR, VR and persons with disabilities?

If you have any other comments regarding AR and VR technologies and persons with disabilities, please enter them here.

[Free text]

Thank you!

Thank you for sharing your insights with us. If you have provided your email address, we may get in touch to ask some further questions. You will also receive an email with a copy of your responses to this survey.[6]

If you would like to get in touch with us, please contact Emil Gejrot at emil.gejrot@funka.com.

[6] Respondents who had provided their email addresses and completed the survey received an email with their responses attached in a PDF. These emails and PDFs were generated automatically by the Alchemer system.

Appendix B: XR Accessibility User Requirements

Here, we present table view of the XAUR as they appear in the working draft of 16 September 2020.

This table uses material copied and derived from XR Accessibility User requirements, https://www.w3.org/TR/xaur/ . Copyright © 2020 W3C®.

Table 7: W3C XR Accessibility User Requirements

Category	User need	Requirements
1. Immersive semantics and customization	A user of assistive technology (AT) wants to navigate, identify locations, objects and interact within an immersive environment.	1a. Navigation must be intuitive and robust. Navigation, location and object descriptions must be accurate and identified in a way understood by AT. 1b. Controls need to support alternative mapping, rearranging of position, resizing and sensitivity. 1c. Objects that are important within any given context of time and place can be identified in a suitable modality. 1d. Allow filtering and the ability to query items and their content for more details.
2. Motion agnostic interactions	A person with a physical disability may want to interact wth items in an immersive environment in a way that doesn't require particular bodily movement to perform any given action.	2a. Allow the user performing an action in the environment, in a device independent way, without having to do so physically. 2b. Ensure that all areas of the user interface can be accessed using the same input method. 2c. Allow multiple input methods to be used at the same time.
3. Immersive personalisation	Users with cognitive and learning disabilities may need to personalize the immersive experience in various ways.	3a. Support Symbol sets so they can be used to communicate and layered over objects and items to convey affordances or other needed information in way that can be understood according to user preference.

Category	User need	Requirements
		3b. Allow the user to turn off or 'mute' non-critical environmental content such as animations, visual or audio content, or non-critical messaging.
4. Interaction and target customization	A user with limited mobility, or users with tunnel or peripheral vision, may need a larger "Target size" for a button or other controls.	4a. Ensure fine motion control is not needed to activate an input. 4b. Ensure hit targets are large enough with suitable spacing around them. 4c. Ensure multiple actions or gestures are not required at the same time to perform any action. 4d. Support 'Sticky Keys' requirements such as serialization for various inputs when the user needs to press multiple buttons.
5. Voice commands	A user with limited mobility may want to be able to use Voice Commands within the immersive environment, to navigate, interact and communicate with others	5a. Ensure Navigation and interaction can be controlled by Voice Activation. 5b. Voice activation should preferably use native screen readers or voice assistants rather than external devices to eliminate the additional step needed to pair devices.
6. Color changes	Color blind users may need to be able to customise the colors used in the immersive environment. This will help with understanding affordances of various controls or where color is used to signify danger or permission.	6a. Provide customised high contrast skins for the environment to suit their particular luminosity and color contrast requirements.
7. Magnification context and resetting	Screen magnification users may need to be able to check the context of their view in immersive environments.	7a. Allow the screen magnification user to check the context of their view and track/reset focus as needed. 7b. Where it makes sense (such as in menus) interface elements can be enlarged and the menu reflowed to enhance the usability of the interface up to a certain magnification requirement.

Category	User need	Requirements
8. Critical messaging and alerts	Screen magnification users may need to be made aware of critical messaging and alerts in immersive environments often without losing focus. They may also need to route these messages to a 'second screen' (see **REQ 14** Second Screen).	8a. Ensure that critical messaging, or alerts have priority roles that can be understood and flagged to AT, without moving focus.
9. Gestural interfaces and interactions	A blind user may wish to interact with a gestural interface, such as a virtual menu system.	9a. Support touch screen accessibility gestures (e.g. swipes, flicks and single, double or triple taps with 1, 2 or 3 fingers). See **REQ 14** Second Screen. 9b. Using a virtual menu system - enable a self-voicing option and have each category, or item description, spoken as they receive focus via a gesture or other input. As the blind user gestures to trigger both movement and interaction they may get more detail about items that are closer to them. The user must be allowed to query and interrogate these items and make selections. 9c. Allow for the re-mapping of gestures to associate different actions with different input types or gestures. This may be a virtual switch that can map to new macros on the fly. This will allow the user to change defaults and employ gestures to carry out new actions offered by the immersive environment as required.
10. Text description transformation	A deaf or hard of hearing person, for whom English or any other written language, may not be their first language and may have a preference for signing of text alternatives or equivalents.	10a. Allow object or item text descriptions to be presented to the user via a signing avatar.
11. Safe harbor controls	People with Cognitive Impairments may be easily overwhelmed in Immersive Environments.	11a. Allow the user to set a "safe place" – quick key, shortcut or macro.

Category	User need	Requirements
12. Immersive time limits	Users with cognitive impairments may be adversely affected by spending too much time in any immersive environment or experience, or may lose track of time.	12a. Allow the user to set a time limit for any immersive session.
13. Reset focus and orientation	A screen magnification user or user with a cognitive disability or learning impairment may easily lose focus and be disorientated in immersive environments.	13a. Ensure the user an reset and calibrate their orientation/view in a device independent way. 13b. Ensure field of view in Immersive environments, are appropriate, and can be personalised - so users are not disorientated.
14. Second screen	A deaf-blind user communicating via a RTC application in XR may have sophisticated 'routing' requirements for various inputs and outputs and the need to manage same.	14a. Allow the user to route text output, alerts, environment sounds or audio to a braille or other second screen device. 14b. Ensure that the user can manage the flow of critical messaging, or content to display on a second screen. 14c. Support touch screen accessibility gestures (e.g. swipes, flicks and single, double or triple taps with 1, 2 or 3 fingers) on a second screen device to allow the user to navigate menus and interact.
15. Interaction speed	Users with physical disabilities or cognitive and learning disabilities may find some interactions too fast to keep up with or maintain.	15a. Allow users to change speed at which they travel through an immersive environment, or can perform interactions. 15b. Allow timings for interactions or critical inputs to be modified or extended. 15c. Provide an XR angel or helper for the user with a cognitive or learning disability. 15d. Provide clear start and stop mechanisms.

Category	User need	Requirements
16. Avoiding sickness triggers	Users with vestibular disorders, Epilepsy, and photo sensitivity may find some interactions trigger motion sickness and other affects. This may be triggered when doing teleportation or other movements in XR.	16a. Avoid interactions that trigger epilepsy or motion sickness and provide alternatives. 16b. Ensure flickering images are at a minimum, will not trigger seizures (more than 3 times a second), or can be turned off or reduced.
17. Spatial audio tracks and alternatives	Deaf and hard of hearing users may need spatialized audio content with audio description in order to perceive it.	17a. Provide spatialized audio content and audio descriptions to emulate three dimensional sound forms in immersive environments.
18. Captioning, subtitling, and text: Support and customization	Users with vision impairments may need to customize captions, subtitles and other text in XR environments.	18a. Provide support for captioning and subtitling of multimedia content. 18b. Allow customizable context sensitive reflow of captions, subtitles and text content in XR environments. The suitable subtitling area may be smaller than what is required currently for television
19. Mono audio option	Users with hearing loss in just one ear may miss information in a stereo or binaural soundscape.	19a. Allow mono audio sound to be sent to both headphones so that the user can perceive the whole soundscape through either ear.