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Systematic Review

Breaking through Barriers: A Systematic Review of Extended Reality in Education for the Visually Impaired

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Abstract: Education for those who are visually impaired usually relies on modified materials and unique teaching methods. Nonetheless, the advent of Extended Reality marks a considerable change by providing immersive and interactive experiences that can surpass the challenges encountered in conventional learning due to visual impairments. This study aims to systematically review and analyse the existing literature on the use of extended realities in the education of individuals with visual impairment. This systematic review followed the Preferred Reporting Items for Systematic Reviews (PRISMA) statement as a formal systematic review guideline for data collection to ensure the quality and replicability of the revision process. Data were obtained from research studies over the period 2013–2023. The analysis included a total of 71 papers from Science Direct, ERIC, JSTOR, Taylor & Francis Online, and Scopus databases. The results show that Europe had the most publications on these topics during the past decade and that most papers were focused on higher education. Additionally, virtual reality was the most investigated topic. The findings indicate that extended reality has the potential to promote inclusion for the visually impaired in educational settings and provide them with enhanced educational experiences in many educational disciplines.

Keywords: extended reality (XR); virtual reality (VR); augmented reality (AR); education; blind; visually impaired (VI); special education; inclusion; PRISMA

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1. Introduction

The education of visually impaired (VI) people is crucial in ensuring they have equal access to information and opportunities. Thus, ensuring they can access accessible educational resources is essential in promoting their educational inclusion and success [1,2]. Traditionally, education for individuals with visual impairments has relied on adapted materials and specialized methodologies [3]. However, the expanding field of Extended Reality (XR) offers a paradigm shift, where immersive and interactive experiences can bridge the gap between conventional learning and the limitations imposed by visual impairments. The increasing popularity of XR, which includes Augmented Reality (AR) and Virtual Reality (VR), is completely reshaping the field of education, and more research is being conducted to identify the potential impacts these emerging technologies have on teaching and learning, especially for students with disabilities [4].

Both AR and VR are technologies that aim to enhance the experience of a person by blending reality with technology. AR focuses on improving real-life experiences by providing additional and relevant information. It achieves this by utilizing devices that can augment a new layer of information, above that of the real world. The applications of AR allow users to access and interact with digital information that enhances their real-world experience. Additionally, VR creates a fully immersive and interactive experience by transporting the user into a completely virtual world. Using specialized equipment such as headsets or gloves, the consumer can engage all their senses and be fully present in this digitally created environment. This technology removes the user from their physical surroundings and allows them to explore and interact with the virtual world as if it were real. While AR enhances real-world experiences by overlaying digital information onto the physical environment, VR creates a wholly new and independent experience. In AR, the focus is on incorporating digital elements into the user's existing reality, whereas VR involves creating an entirely new reality for the user to explore.

New devices for XR interaction are constantly being developed or becoming more affordable, making Virtual and Augmented Environments more accessible and popular. However, VI users often encounter digital barriers that exclude them from participating in certain activities. This creates a significant problem and prevents them from enjoying the benefits of these technological advances [5]. The researchers conducted this study with the understanding that XR for individuals with visual impairments may exhibit distinct characteristics, approaches, and modes of operation due to their unique needs. Recognizing this is crucial for enhancing the inclusivity of XR and enabling individuals with visual impairments to access its educational and general life benefits. Thus, based on this understanding, the researchers included the augmentation of sounds as well as haptic and tactical feedback in real-world environments to provide sensory information and enable an XR experience for VI users, presenting a new definition of AR, tailored to meet specific needs while also addressing the challenges faced by these individuals. Additionally, the immersion of VI users in virtual environments through spatial audio along with haptic feedback was considered by the researchers as part of an adapted definition for VR specifically designed for VI users.

This systematic review dives into the existing body of research on XR in education for the VI, illuminating its potential and the considerations for its effective implementation. Its main goal is to identify and critically analyse the trends and themes surrounding the use of extended realities in education for the VI. In addition, the document analyses the challenges and limitations of implementing XR in the education of VI students. The review concludes by providing recommendations for future research in this field, aiming to contribute to the existing literature and identify gaps for further investigation in the use of XR for individuals with visual impairments in education. The next section presents the methodology and provides a detailed explanation of the data collection and analysis procedures used in the research.

2. Methodology

2.1. Method

A systematic review aims to address inquiries using a clear, methodical, and repeatable search approach. It employs inclusion and exclusion criteria to determine which studies are incorporated or excluded. Subsequently, data from the included studies are organized and gathered to combine findings and provide insights into their practical application while also highlighting any shortcomings or inconsistencies [6]. This process helps to identify gaps in the existing research and suggest areas for future investigation. To achieve this goal and to answer the research questions, this systematic review implemented the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA is a set of essential elements for reporting in systematic reviews and meta-analyses based on evidence. It serves as a guide for reporting systematic reviews with different objectives [7]. Our systematic review procedure is presented in Figure 1, based on the PRISMA flow diagram. To ensure the quality and replicability of the revision process, this paper strictly followed the PRISMA guideline checklist, which is a peer-accepted methodology. In addition, a review protocol was developed that outlined the article selection criteria, search strategy, data extraction, and data analysis procedures.

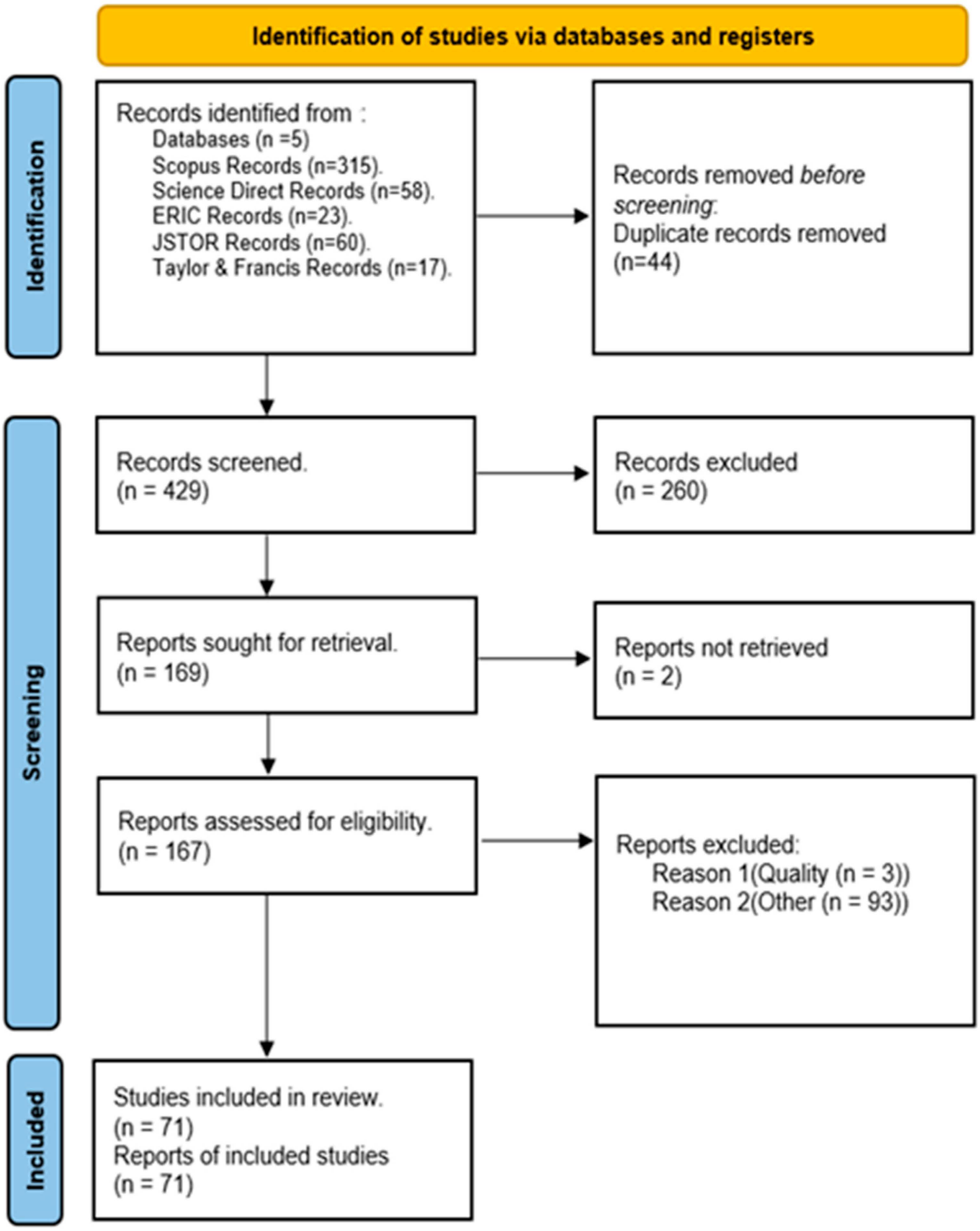

Figure 1. PRISMA flow diagram.

2.2. Research Aim and Questions

This research aims to systematically review and analyse the existing literature on the use of XR in the education of individuals with visual impairments to gain a comprehensive understanding of its potential and impact in improving learning outcomes and promoting inclusion for this population. The research questions were as follows:

RQ01: What are the prevalent trends and themes surrounding the use of XR in the education of individuals who are blind or have visual impairments?
RQ02: What challenges and limitations exist in implementing XR in the education of individuals who are blind or have visual impairments?
RQ03: What recommendations can be made for future research on the use of XR in the education of individuals who are blind or have visual impairments?

2.3. Data Sources and Search Strategies

We conducted a comprehensive search of five reputable electronic databases, namely Science Direct, ERIC, JSTOR, Taylor & Francis Online, and Scopus, covering the period between 2013 and 2023. These databases are widely recognized as reliable sources of educational scientific data, which is why we relied on them for our research. Our search was restricted to peer-reviewed articles published in English. Two researchers (M.H. and H.G.) independently searched the databases using a variety of search terms and strategies, including Boolean operators, to ensure that we captured as many relevant studies as possible. Appendix A presents the search terms. It is important to note that different databases have different research strategies and roles; thus, the researchers needed to adapt the research protocol to the database requirements.

2.4. Screening and Inter-Rater Reliability

In the first phase of screening, titles and abstracts were reviewed independently by two of the researchers (M.H. and H.G.), who used the above-mentioned criteria to determine papers' eligibility to be included in the study. The full text of potentially relevant studies was then retrieved, a full-text screening was conducted and reviewed for final inclusion, and the whole screening process was then reviewed by the third reviewer (P.T.). All discrepancies were resolved by consensus with one of the researchers (M.H. and H.G., or P.T.). The reasons for the inclusion and exclusion of the articles were discussed at regular meetings. The researchers sought to determine inter-rater reliability using Cohen's kappa (κ), a coefficient for inter-rater reliability based on the number of codes in a coding scheme [8]. Kappa values of 0.40–0.60 are characterised as fair, 0.60–0.75 as good, and over 0.75 as excellent [9]. Coding consistency for the inclusion or exclusion of articles between rater (M.H. and H.G.) was $\kappa = 0.86$. Therefore, inter-rater reliability can be considered excellent for the coding of inclusion and exclusion criteria.

2.5. Study Quality Assessment and Bias Mitigation Criteria

The researchers followed a procedure to further assess the quality of all studies that were included. The quality assessment checklist, which presented a set of quality criteria for this study, was adopted from earlier systematic literature review studies [10–12] due to their similarity to the present field of research, and the University of West England Critical Appraisal Framework [13]. As shown in Appendix B, a three-dimensional Likert scale checklist with distinct illustrations was used to evaluate the quality of the reviewed literature. Therefore, the score range of this assessment questionnaire was between 0 and 10. Two researchers scored the literature with high inter-rater reliability ($k = 0.86$). The quality assessment process resulted in the exclusion of 3 articles of the 167 articles retrieved and assessed for quality and eligibility, as presented in (Figure 1).

To eliminate the impact of bias in this systematic review search strategy, the following three criteria to mitigate the impact of bias were adapted from [10,14] and taken into consideration: the first criterion was to reduce the publication selection bias, which was achieved through acquiring only peer-reviewed journals from well-established databases such as Scopus. The second criterion was to avoid article selection bias. To achieve this, the researchers agreed on a set of specific research questions and key terms that would be utilised during the search, and a multistage process was used to extract information, where all authors assessed the content of each study based on predetermined inclusion and exclusion criteria. The studies included in this process should be focused entirely on the educational uses of XR for the VI. The third criterion involved addressing the potential for inaccuracies in data extraction and misclassification. To ensure accuracy, the researchers thoroughly reviewed all selected papers and established a process to resolve any disagreements that arose during the assessment. Multiple meetings were held before reaching the final stage, leading to updates on findings from previous studies. The final data were organized systematically into clustered categories.

2.6. Data Extraction and Analysis

The studies selected for data extraction were arranged chronologically and alphabetically by the first author's name. Each article was assigned a unique code. To conduct the thematic content analysis, we utilized the strategies and procedures developed by [15], which involve several stages: becoming familiar with the data, coding the data, generating themes, reviewing themes, defining and naming themes, and finally, writing up the findings. The data extraction and mapping were conducted using Google Sheets and Microsoft Excel, coding each included study across the categories defined in the following coding structure. The process includes coding and generating categories to increase understanding and generate knowledge abstraction; several codes were combined under other, broader themes that are aligned with our three research questions.

3. Findings and Discussion

3.1. Overview of Included Research Papers

The research papers that were extracted spanned a decade, from 2013 to 2023. The year with the most publications was 2018, with a total of 12 papers. The paper count for each year is presented in Figure 2. It is also noticeable that the years 2018–2020 had the highest number of publications.

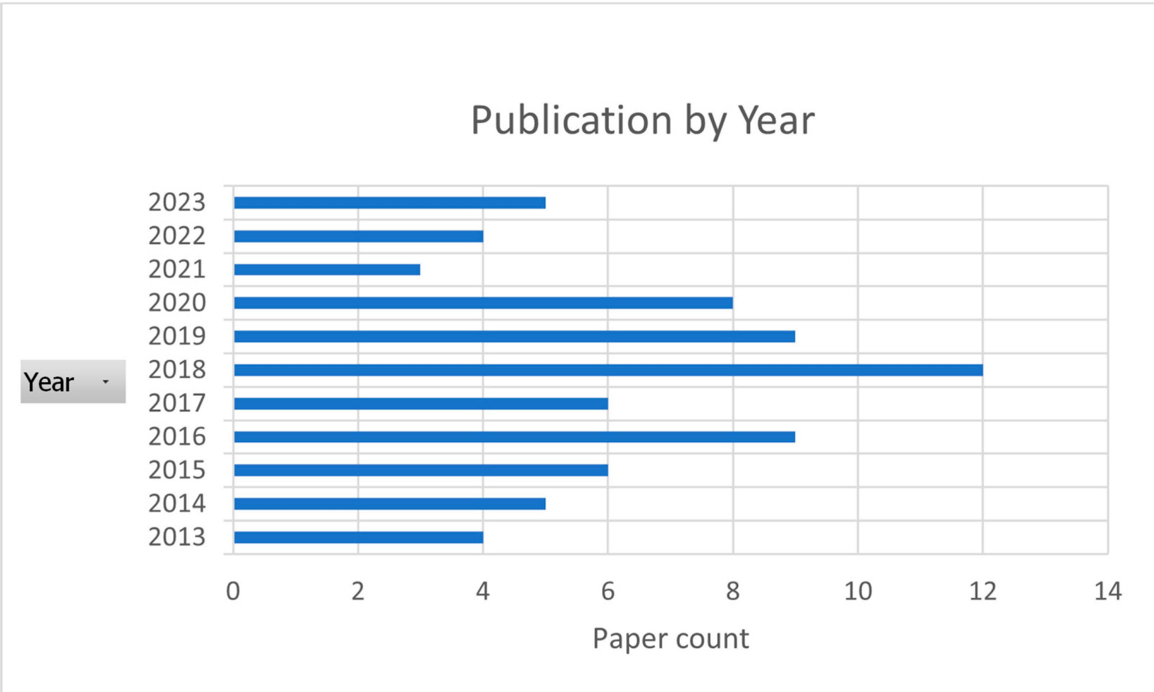

Figure 2. Publication by year.

Publications originated from various regions, with Europe leading in terms of the number of publications, at 30, while the United Kingdom had the lowest number of publications, at 2, as presented in the following (Figure 3). However, when considering the country-level analysis, it was found that the United States had the highest number of publications in this field, with 10 publications, followed by Japan, with 7 publications, as presented in Figure 4.

The papers that were analysed covered various educational levels. Figure 5 presents the number of publications for K-12, higher education, and education in general, as some studies did not specify the educational level or had mixed groups.

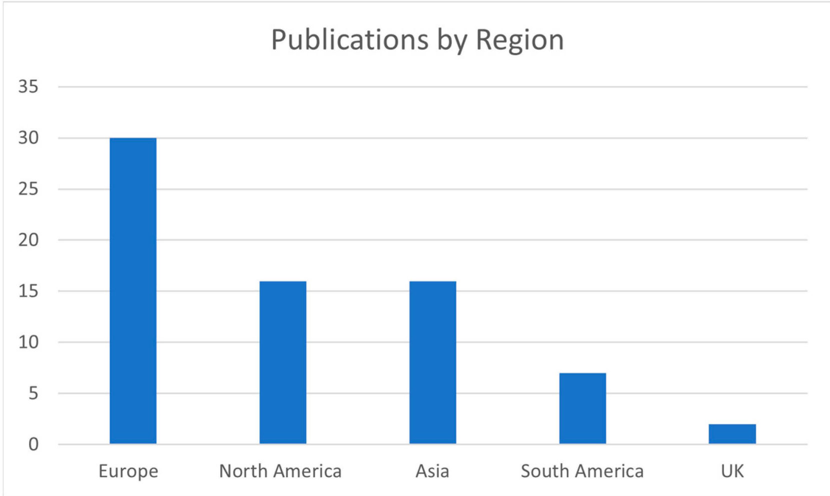

Figure 3. Publications by region.

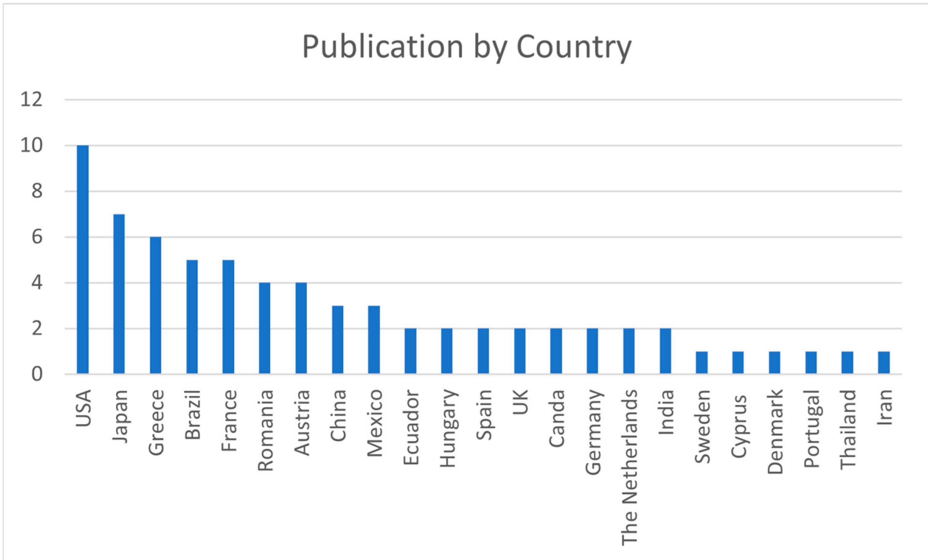

Figure 4. Publications by country.

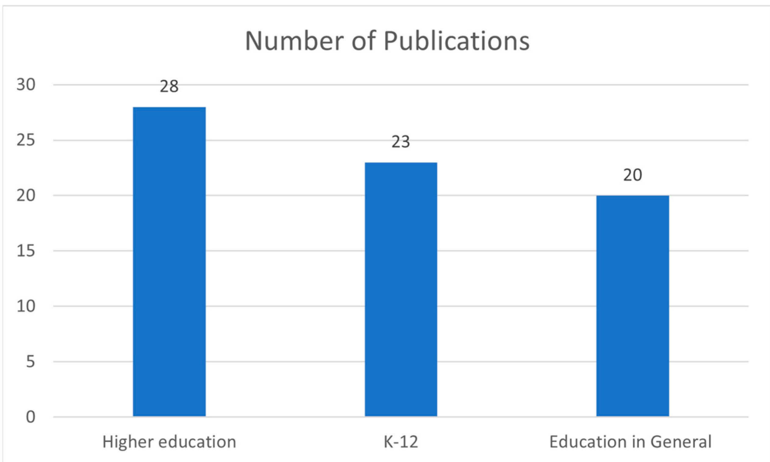

Figure 5. Publications by educational level.

Based on our analysis of the research methods used in the papers we extracted, we found that the majority of them used a mixed-methods approach. In fact, out of all the papers, 30 of them employed this method. The figure below (Figure 6) illustrates the various methodological approaches used in all the papers.

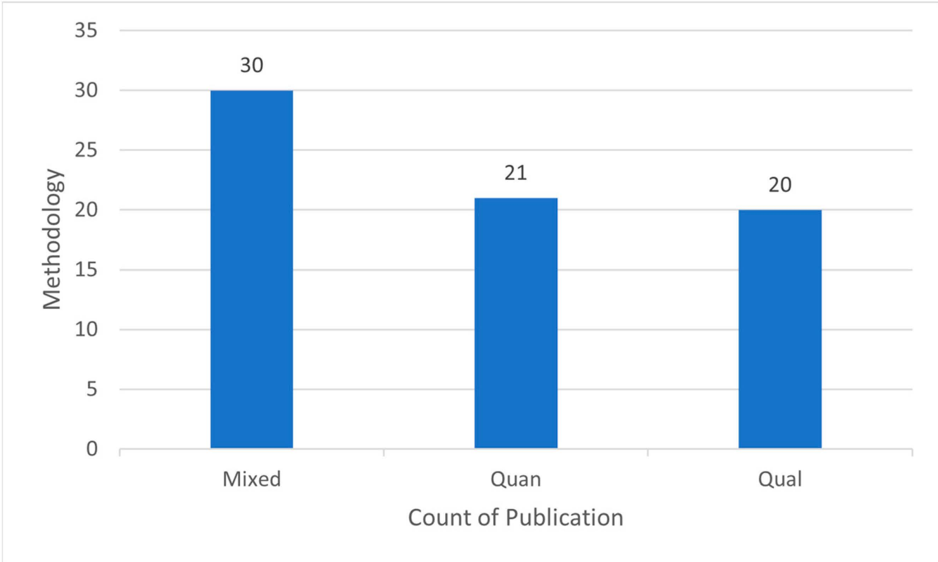

Figure 6. Publications by methodological approach.

3.2. RQ01: What Are the Prevalent Trends and Themes Surrounding the Use of XR in the Education of Individuals Who Are Blind or Have Visual Impairments?

To answer the research question, the researchers started by identifying the various applications of XR, including VR, AR, mixed reality (MR), and XR in general. These applications were studied in the context of education for people who are VI, using the definition of extended realities presented earlier. The researchers began by examining which types of XR were implemented in the analysed research. The following figure (Figure 7) presents the results.

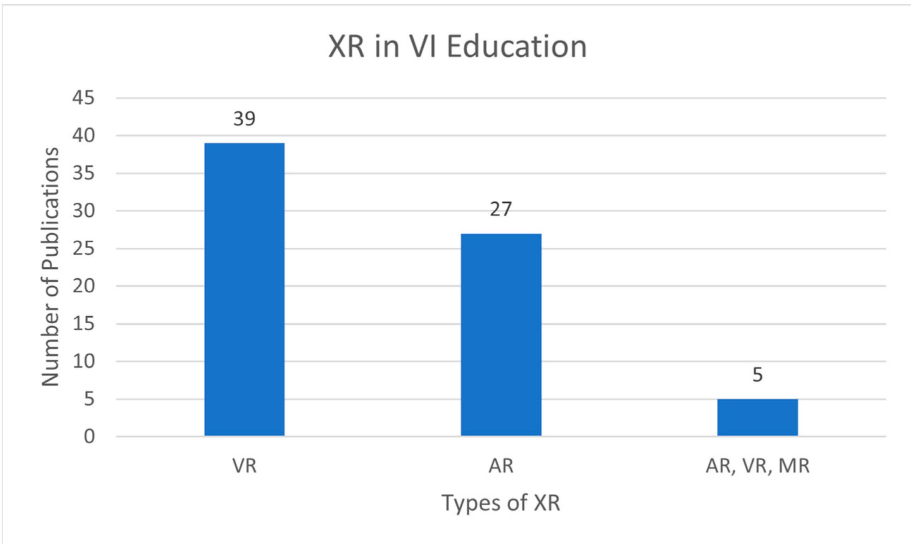

Figure 7. Publications by methodological approach.

The researchers then conducted a qualitative analysis through a thematic analysis to identify trends and themes surrounding the use of XR in the education of individuals who are blind or have visual impairments. This thematic analysis revealed several themes: Educational Assistive Technology and Inclusive Education, Orientation and Mobility training (O&M), Spatial Cognition, Educational Games, Multisensory Realities and Sensory Substitution, Authoring Tools, Academic Disciplines, Educational Maps, Spatialized Audio, and Design Guidelines.

3.2.1. Exploring the Potential of XR as an Educational Assistive Technology and in Inclusive Education

XR offers significant potential as an assistive technology in educational settings, particularly for students with diverse learning needs. By leveraging XR, educators can create inclusive learning environments that meet the individualized needs of all students. This section explores the various applications of XR as an educational assistive technology and its contribution to promoting inclusive education. This review on the potential of XR in educational assistive technology and inclusive education, particularly focusing on augmented reality, has unearthed significant insights. The research conducted by [16] illustrated how AR could serve as an effective assistive tool for colourblind individuals, enabling them to recognize objects and colours within controlled settings, although real-world application might present challenges. This underscores AR's role in fostering inclusivity within educational contexts. The study by [17] introduced a novel navigation system tailored to VI users that accurately identified building entrances using image databases, suggesting its utility in enhancing independent mobility among this demographic. In line with affordability and practicality concerns, the [18] project focused on developing cost-effective smart glasses designed for reading signs, a key aid facilitating blind people's move towards autonomy, and thus making strides toward widespread inclusionary practices. The study presented in [19] delved into the creation of a Prehistory Game aimed at VI audiences, focusing on the effectiveness of museum accessibility improvements obtained via audio-centric app games featuring user-friendly designs, a notable endeavour towards enriching cultural experiences amongst visually disadvantaged communities.

The exploration conducted by [20] combined tactile sensory feedback with kinaesthetic learning to create advanced assistant systems that aim to enhance academic pursuits for the blind. This highlights the importance of vocal guidance and texture exhibitions in improving the comprehension of figures and recognition of object positioning. These methods outshine conventional methods and lead to pedagogical advancements. The authors of [21] and their team developed the PERCEPT framework, marking a pioneering approach to indoor navigation systems specifically designed for VI users. This model integrates passive and active radio-frequency identification techniques while offering directional guidance through recognizably significant landmarks via mobile applications. It unveils the potential of XR technologies, such as AR, to fundamentally transform the landscape of wayfinding solutions, signifying a shift towards more inclusive educational environments through the integration of assistive technology. This evolution challenges traditional perceptions surrounding accessible learning methodologies.

Regarding the use of VR for VI learning, the systematic literature review revealed several studies that explored the potential of XR as an educational assistive technology, with a specific focus on VR. A study by [22] highlighted the importance of designing virtual learning environments to meet the diverse needs of learners with visual impairments. This led to the development of AudioChile, a 3D interactive sound environment aimed at enhancing problem-solving skills in children with visual disabilities. The study obtained positive results in improving problem-solving skills, emphasizing the potential of XR in addressing the needs of learners with visual impairments. Furthermore, [23] developed a Virtual-Environment-Based Training System targeting blind wheelchair users. This system utilized three-dimensional audio and EEG signals to improve the quality of life and independence of individuals with visual impairments. The study demonstrated the effectiveness of VR with EEG signals in facilitating efficient interactions and promoting social inclusion for VI wheelchair users.

Ref. [24] investigated the feasibility of using VR to understand the vision problems faced by high school students with myopia. The study found that VR technology enabled teachers to better understand the difficulties students faced in noisy environments, improving their knowledge and awareness of these vision problems. This suggests that VR can have great potential in improving teacher training and creating safe and immersive learning experiences. In the same domain, a study by [25] explored the use of VR to train individuals with visual impairments in utilizing sensory substitution devices. The study highlighted the benefits of VR in providing auditory and haptic representations of the environment, which can be particularly advantageous for individuals with visual impairments. The Sound of Vision project implemented virtual training environments with realistic and fantastical settings, demonstrating the advantages of providing diverse environments and instant feedback for training. Finally, Ref. [26] investigated the use of virtual haptic perception as an educational assistive technology for the VI. The research showed that blind children were able to effectively explore, learn, and recognize virtual 3D shapes using a haptic device. They were able to complete virtual learning tasks and accurately identify various characteristics of virtual objects. This suggests that virtual haptic perception can effectively enhance educational experiences for individuals with visual impairments.

Studies have shown that VR and other XR technologies can significantly improve educational experiences for students with visual impairments by enhancing various skills, promoting inclusion, and improving training methods. This technology allows for immersive learning tailored to individual needs in inclusive settings, with VR being the most common method. Applications like virtual haptic perception and AR offer support in areas including shape recognition and mobility. Despite promising results, further research is necessary to fully leverage XR's potential in educational assistive technologies.

3.2.2. XR in Orientation and Mobility Education (O&M)

Orientation and Mobility (O&M) constitute a crucial component within the educational framework for individuals with visual impairments. Numerous programs dedicated to O&M are enacted within educational institutions and specialized environments, aiming to equip learners with visual impairments with the necessary competencies to orient themselves autonomously and securely in their surroundings. These initiatives emphasize skill acquisition ranging from the proficient use of a white cane, mastering navigation through auditory signals, and grasping spatial concepts to fostering situational awareness. The advent of XR has markedly enriched O&M training for those living with visual impairments by providing immersive interactions that significantly bolster the learning process.

The systematic review we conducted revealed several uses of XR in O&M. A study by [27] examined the advantages, challenges, and future potential of XRs in empowering individuals with visual impairments and found that XR has the potential to support individuals with visual impairments to navigate confidently and independently. Another study by [28] implemented a VR platform for O&M training focused on glaucoma. This platform aimed to assist trainers, provide a safe learning environment, and educate the public about visual impairment. Participants found the platform engaging and enjoyable. The study suggested further research to address limitations and evaluate the platform's use for O&M training and public education. Furthermore, in a study by [29], Sensory-Substitution Devices (SSDs) were used to make graphical virtual environments more accessible for blind individuals. The study showed that blind participants could perceive and interact with virtual environments using EyeMusic. This approach has potential for O&M training, visual rehabilitation, and virtual learning in new environments.

We reviewed the literature on the constraints that may impede progress in the domain of learners with visual impairments. The literature identified elevated expenses associated with hardware and software procurement, as well as the limited availability of resources, as some of the constraints. However, we found many studies that explored possible solutions.

One such example is the work by [30,31]. They focused on using smartphones, which are widely accessible to learners with visual impairments. The researchers explored interactive and cost-effective O&M training methods for VI children, utilizing technological aids like smartphones, Arduino, or mobile location-based games. These approaches were found to improve engagement through gamification and their practical applications in real-world settings, but they cannot replace traditional O&M training entirely. Another example came from the works of [32,33]. They focused on advancing the concept of the white cane. They showed that the Cane Game is an effective, low-cost educational tool for teaching cane-sweeping techniques to students with attention and kinaesthetic challenges but less so for those resistant to cane use. Ref. [33] introduced a virtual cane algorithm enabling successful navigation in virtual environments for blind users, suggesting its potential when used alongside other sensory substitution devices to improve accessibility. We argue that these approaches are practical and achievable due to the use of available resources and the compound effect of training that learners with visual impairments receive in educational contexts and life. A third example is presented in the works [34–39]; these works focused on using sound. Ref. [34] introduced a 3D audio-based game that improved orientation skills, while their later work combined 3D sounds with haptic feedback to enhance auditory performance and navigation abilities in the VI. Allain et al.'s Legend of Iris effectively trained blind children's navigation skills via an engaging audio game. Seki's AOTS system [38], featuring a virtual environment with realistic sound interactions, facilitated learning about walls and paths for blind users. Finally, Ref. [39] developed the HAGA software platform in 2016, using multimodal cues to assist blind individuals in forming cognitive spatial maps, which showed potential benefits for real-world application.

Lastly, some researchers used a different approach to solve these challenges. These studies focused on enhancing navigation and spatial learning for individuals with visual impairments. Ref. [21] developed an algorithm to generate optimal indoor navigation routes using landmarks, which were validated in a virtual environment. Ref. [40] explored a treadmill-style interface for non-visual spatial learning, showing that it was more effective than keyboard-based navigation but required improvements. Ref. [41] created a web-based library of standardized audio-tactile symbols to aid education and training in orientation and mobility for the VI.

Overall, studies highlight the potential of XR and other innovative technologies in enhancing O&M training for individuals with visual impairments. From audio AR and VR platforms to educational games and sensory-substitution devices, these tools offer unique opportunities to improve navigation skills, spatial perception, and overall independence for individuals with visual impairments. Further research and development in this field are needed to explore the full potential of these technologies and address any limitations [29,32].

3.2.3. Spatial Cognition

Spatial cognition is crucial for individuals with visual impairments when it comes to education and mobility. XR technologies, such as VR and AR, have the potential to enhance spatial cognition skills. By creating immersive and interactive environments, XR can provide experiential learning that complements traditional educational methods. Several studies have explored the use of XR in meeting the unique needs of VI students and enhancing their spatial cognition.

This systematic review revealed that researchers have developed various innovative technologies to aid individuals with visual impairments in spatial learning and navigation skills. Ref. [27] created a vision rehabilitation game utilizing 3D spatialized sound, which enhanced auditory localization, body rotation, and spatial understanding in VI children and teenagers. Ref. [42] used VR and Kinect to develop a system for pose recognition in unfamiliar walking environments, showing potential for navigation assistance. Ref. [40] introduced a treadmill-style locomotion interface for non-visual spatial learning, showing improved performance compared to traditional methods. Ref. [43] focused on building VR mobile applications for blind individuals to explore unknown spaces virtually. Ref. [39]

designed a software platform using auditory cues and vibrotactile feedback for cognitive spatial mapping, aiding blind individuals in real-world navigation tasks. Ref. [34] investigated 3D audio-based games for spatial skill training, proving beneficial for rehabilitation and skill development. Lastly, Ref. [44] explored an audio game, "Flying a Quadcopter", for sound localization training in individuals with visual impairments, demonstrating the potential for improving spatial skills through auditory cues.

Overall, research has shown that XR technologies, including vision rehabilitation games, virtual environments with pose recognition, locomotion interfaces, VR applications, navigation software platforms, and audio-based games, have the potential to enhance spatial cognition skills for individuals with visual impairments. These technologies have been found to improve motor coordination, self-confidence, localization skills, and overall spatial learning. However, further research and testing are necessary to optimize these technologies and ensure their practicality for marketable products.

3.2.4. Educational Games and Gamification

The implementation of educational games in XR has the potential to enhance the learning experience of students who are blind or have visual impairments. With the aid of auditory and tactile interfaces, these games can create immersive and interactive environments that promote inclusive learning, enhance spatial awareness, and foster the development of motor skills. Furthermore, this systematic review revealed that educational game codes occurred the most in the body of research that was analysed, which shows that researchers are aware of the benefits that it could offer to any intervention.

Ref. [45] conducted research on gamification design for individuals with visual impairments, focusing on sensory augmentation and substitution techniques in VI interaction design. They discussed the challenges of integrating information from different modalities, such as sound and tactile interfaces. The study highlighted various types of sound design in gamification, including auditory display, earcon, and text-to-speech, and emphasized the benefits and challenges of echolocation. Furthermore, the researchers discussed the use of tactile interfaces, particularly in projects like The Sound of Vision and the DualPanto project, which offer innovative tactile sensory substitution research. Jadán [46] developed the inclusive board game Q'inqu to support blind players and those who are unable to read, utilizing braille-coded cards and AR features. Ref. [47] explored the implementation of Accessible AR in chemistry teaching games. Ref. [36] researched multimodal training to improve the audio game-playing performance of individuals with visual impairments. Refs. [48,49] investigated the design and implementation of audio games for educational and immersive purposes. Ref. [50] explored the influence of specially designed audio games on regulating players' emotions. Additionally, studies by [51,52] focused on the sonification and interaction design of games for individuals with visual impairments and the design guidelines for audio-based game features. Ref. [53] analysed a non-narrative audio game emphasizing auditory cues. Refs. [37,54] developed games focusing on audio-based navigation for immersive and educational purposes. Lastly, Ref. [48] researched an AR audio game, while [55] evaluated sound design implications in audio games for VI players.

Educational games leveraging XR hold promise for enhancing learning and spatial awareness for VI students. Through auditory and tactile interfaces, they offer immersive educational experiences. Key aspects such as sound localization, haptic feedback, and AR integration have been studied, demonstrating benefits in promoting inclusion, improving motor skills and self-confidence, enriching curriculum delivery, and boosting student engagement. Despite the challenges faced in their development and implementation, they are promising avenues for innovative education solutions.

3.2.5. Multisensory Realities and Sensory Substitution

Multisensory realities and sensory substitution have emerged as innovative approaches to enhance learning experiences and improve autonomy for individuals with visual impairments. These technologies utilise tactile manipulatives, audio feedback, AR, and VR to create immersive and interactive educational environments. Using computer vision, optical motion capture, and sensory substitution devices, individuals with visual impairments can engage with STEM diagrams, virtual environments, maps, and educational content, allowing for hands-on learning, collaboration, and cognitive enrichment. Studies have explored the feasibility and effectiveness of these technologies, as well as the design considerations and challenges involved. Overall, these advancements have shown promising potential in creating inclusive educational opportunities for individuals with visual impairments by incorporating multiple senses and transforming the way they interact with information and their environment.

Several studies have explored the use of multisensory realities and sensory substitution for the education of individuals with visual impairments. Ref. [24] found that the Kasi Learning System, incorporating tactile manipulatives, audio feedback, and computer vision, improved the learning experience for VI students in STEM education. Ref. [56] developed a VR tactile educational tool for VI children, indicating the importance of incorporating different sounds for each part to enhance learning. Ref. [57] designed a Multisensory AR Map for blind and visually impaired people, emphasizing the involvement of the target population in the design process to enhance autonomy. Ref. [29] explored how sensory-substitution devices could enable blind individuals to perceive and interact with virtual environments for training and rehabilitation. Ref. [58] focused on audio–tactile content using AR, which was engaging for VI students but faced accessibility challenges. Ref. [59] connected the tactile radar to a computer to create tactile games suitable for visually disabled individuals. Ref. [25] aimed to improve autonomy through training with sensory substitution devices in virtual environments. Overall, these studies demonstrate the potential of innovative technologies in enhancing the learning and autonomy of individuals with visual impairments in educational settings.

The reviewed research highlights the effectiveness of technologies like the Kasi Learning System and VR tools in enhancing learning for individuals with visual impairments by supporting independent STEM use, improving virtual interaction, and boosting motivation. However, challenges remain in terms of their accuracy and tactile feedback. Future work should focus on advanced virtual environments and improved sensory devices to further aid VI users, underscoring their potential to substantially improve their autonomy, the research outcomes, and quality of life.

3.2.6. Authoring Tools for Educational Purposes

Authoring tools for educational extended realities play a crucial role in enhancing learning experiences for individuals with visual impairments. These tools enable the creation of spatial representations, interactive maps, and audio–tactile content using AR technology. The aim is to promote inclusivity, collaborative learning, and the autonomy of individuals with visual impairments. Researchers have focused on developing AR authoring tools that facilitate the creation of spatial representations with multimedia annotations [60]. Similarly, the design of multisensory AR maps allows individuals with visual impairments to explore existing maps and construct their own, utilising spatial AR technology and audio feedback [57]. Moreover, the creation of audio–tactile content using AR has shown promising results in terms of usability and accessibility for individuals with visual impairments [58]. The involvement of the target population and stakeholders in the design process ensures the effectiveness and adoption of these technologies. These advancements provide valuable insights into how to improve accessibility and learning outcomes for VI students.

Ref. [60] developed an AR authoring tool that enables the creation of spatial representations with multimedia annotations, emphasising inclusivity and collaborative learning experiences. Ref. [57] designed a multisensory AR map for blind and low-vision populations, stressing participatory design and accessibility in map exploration. Ref. [58] focused on creating audio–tactile content using AR, finding usability for both low-vision users and users who are blind, with certain accessibility concerns that could be addressed for improved inclusivity. These studies highlight the significance of involving the target population in the design process and showcase the potential benefits of AR in enhancing learning, spatial skills, and accessibility for individuals with visual impairments.

3.2.7. Academic Discipline

Research studies have explored the use of XR technologies to aid individuals with visual impairments in various academic disciplines. In the field of Mathematics, Ref. [47] developed a VR tactile educational tool for VI children, highlighting the necessity for improvements in haptic devices for enhanced recognition accuracy. Ref. [61] created a tangible system, LETSMath, to assist blind children in learning mathematics through tactile and auditory feedback blocks and interactive tablet-mediated games. In Chemistry, Ref. [47] researched the use of Accessible AR to teach chemistry concepts to users with low vision, focusing on the creation of an immersive learning experience through AR technology and audio feedback. Ref. [24] evaluated the Kasi Learning System to support VI students in using STEM diagrams independently, highlighting the system's effectiveness in providing multisensory interactive learning experiences.

In the field of sport education, The Floor-Volleyball Motion Feedback System for VI players, designed by [62], simplifies complex motions into a visual representation of wrist movement, aiding players in understanding and comparing their motions. Additionally, studies in History have explored the potential of VR and audio games in enhancing learning experiences for individuals with visual impairments. VR tools, such as the Wii remote device, have been shown to enable individuals with visual impairments to learn subjects like history, geography, and physics independently by combining VR with speech synthesis [63]. Regarding studies in Music Education [64,65], Ref. [64] introduced a musical game designed for individuals with visual impairments, using 3D sound on tablets, but faced user challenges related to movement and orientation. However, the proposed enhancements include more intuitive interaction mechanisms like gyroscopes and enriched audio feedback to improve the user experience. Meanwhile, Ref. [65] explored the educational potential of an audio game named Kronos that combines music education with role-playing elements, proving its efficacy in making learning immersive through sonic symbols and suggesting future expansions for this innovative approach. Both studies underline efforts to enrich lives through targeted gaming experiences.

Lastly, studies have explored the use of haptic-enabled VR, head-mounted displays, and spatial AR to enhance accessibility for individuals with visual disabilities in art, museums, and educational settings. Ref. [66] developed a system called CIGI that allowed blind users to interact with virtual worlds through touch and audio. Ref. [67] found that head-mounted displays were effective for individuals with low vision seeking immersive experiences, while [19] emphasised the inclusivity of a prehistory game for the VI in a museum exhibition. Additionally, Ref. [58] demonstrated the efficiency of spatial AR in creating interactive audio-tactile drawings. These technologies have the potential to provide engaging and inclusive experiences for individuals with visual impairments in museums and art education.

Overall, research in various academic disciplines has demonstrated the potential of XR technologies, such as VR, AR, and tactile systems, in providing immersive and accessible learning experiences for individuals with visual impairments. Further advancements and feedback from individuals with disabilities are crucial to continue improving these tools and make education more inclusive for all learners.

3.2.8. Educational Maps

Educational maps are very important for the education of individuals with visual impairments. Educational maps provide a visual representation of spatial concepts that can be essential for the learning and understanding of individuals with visual impairments. By providing tactile or auditory representations of maps, educational maps empower individuals with visual impairments to access the same spatial information as their sighted peers. Recent research has focused on utilising spatial AR to develop interactive and accessible educational maps for individuals with visual impairments. The researchers [57,58,68] explored the creation of prototypes that allowed VI users to interact with maps using audio descriptions, quizzes, and tactile elements. These studies emphasised the importance of involving the target population in the design process to ensure the accessibility and adoption of the technology. User testing showed that the technology was engaging and beneficial for individuals with varying levels of mental representation skills. Overall, the research demonstrated the potential of spatial AR in enhancing educational materials and promoting autonomy for VI students.

3.2.9. Spatialized Audio

Spatialized audio is a term used to describe audio encoded and played back in a way that offers the listener a sense of three-dimensional space. This is accomplished by manipulating various factors, such as the direction, location, and movement of sound sources, as well as utilizing techniques such as stereo panning, binaural recording, and surround sound. The result is an immersive audio experience that enhances the perception of a sound's depth, distance, and directionality. Ref. [38] developed an extensive auditory orientation system named AOTS, designed for individuals with visual impairments. This system encompasses virtual training settings equipped with auditory cues, barriers, pathways, and significant locations to aid in navigation. AOTS features a wide array of soundscapes along with environmental noises; the barriers serve the purpose of enhancing obstacle awareness through the modulation of sound waves, which diminish as one approaches within two meters to simulate physical walls. This platform facilitates instructors in crafting customised virtual environments utilising XML coding. In related research conducted by [44], an innovative audio-based training game titled "Flying a Quadcopter" was examined for its efficacy in teaching spatialized audio cues to VI users. Participants' feedback contributed significantly towards refining both the acoustic fidelity and functionality regarding auditory localization exercises within this application setting, which indicates promising advances in educational methodologies focusing on visual impairment challenges, although it emphasises the necessity for more comprehensive evaluations, particularly those involving multiplayer scenarios with VI participants, before it can be deemed fully effective or ready for broad deployment.

3.2.10. Multi-User Extended Realities and Group Work

Research studies by [68–70] highlight the importance of multi-user XR and group work in educational settings, particularly for individuals with visual impairments. Ref. [68] introduced Nectar, a multi-user spatial AR tool, focusing on inclusivity for VI students with residual vision. The study explored the Interactive Botanical Atlas concept, demonstrating the potential of interactive technology to provide visual and tactile support in educational contexts. Ref. [69] examined haptic feedback's role in promoting collaboration between VI and sighted students, emphasising the benefits of shared haptic virtual environments in group work. Ref. [70] studied the use of spatial audio in audio AR experiences, showcasing how technologies like Bose "Frames" enhance collaboration in multiplayer settings. These studies emphasise the positive impact of interactive technologies on collaboration, inclusion, and learning outcomes for VI students, calling for further research to fully explore their potential in education. These studies demonstrate the importance of interactive and inclusive technologies in education. They provide valuable insights into the potential benefits of technologies like multi-user spatial AR.

3.2.11. Design Guidelines

Numerous scholarly articles have explored the critical need to develop design frameworks tailored to the creation of XR environments conducive to the learning needs of VI students. The work by [45] delineates the crucial nature of gesture-based interfaces for this demographic, highlighting how well-crafted gestures coupled with auditory feedback can bridge the sensory gap created by visual impairments. Their findings shed light on how haptic feedback and tactile maps significantly contribute to improved educational outcomes and navigational skills. To surmount existing obstacles, it is imperative that usability testing be customized to cater to distinct interaction modalities present in virtual realms, employing innovative tools such as gaming software, physiological monitoring devices, and bespoke audio cues. Such testing protocols necessitate several iterations informed by user input, assessing efficiency via task fulfilment rates alongside behavioural analysis logs. Neurological studies hint at potential neuroadaptive advantages accruing from immersive engagement for individuals with sight loss.

The research presented by [71] focused on immersive VR's capacity to foster experiential learning through enhancing spatial understanding from varying vantage points. Ref. [43] presents VR solutions aimed at navigation challenges, which underscore the emphasis on collective endeavours, custom-tailored auditory guidance systems, and ongoing participatory evaluation mechanisms. Ref. [72] delves into crafting tangible interactive audiological games, while [73] advocated the design of responsive voice–user interfaces presented within the same timeframe. Ref. [74] makes academic contributions concerning audible-haptic mapping considerations, which underwent equal scrutiny to previous studies. The more recent investigations of [75] centred around contriving AR application directives focused on accessible architectures, underpinning their discussion on the recurrent theme of embedded inclusivity targeting VI audience segments.

Overall, the literature highlighted the importance of using advanced technologies, such as gesture-controlled sound systems, interactive maps, and immersive digital environments, to enhance educational experiences. It focuses on supporting learners with visual impairments through innovative approaches like simulation platforms and bio-responsive devices that tailor education to individual needs. Studies into user behaviour and brain adaptability help to refine these tools for broader applicability. The ongoing goal is to develop effective methods and technologies that ensure inclusive education for all students, especially those facing vision challenges.

3.3. What Challenges and Limitations Exist in Implementing XR in the Education of Individuals Who Are Blind or Have Visual Impairments?

This review offers a thorough analysis of the challenges and limitations involved in utilising XR for educating VI and blind students. The challenges and limitations include general constraints that were faced by most of the reviewed research, as well as specific challenges that were more applicable to particular fields. General limitations in the research include small sample sizes, which limit the generalizability and statistical power of studies (e.g., Ref. [24,36]). Moreover, the reliance on existing literature may hinder the exploration of new ideas and approaches due to a dependence on past studies. This issue becomes evident when we notice the amount of repetition in this field of research. Additionally, incomplete reporting is another challenge, as some studies lack information on their limitations, hindering a full understanding of the challenges at hand [70,76].

The specific challenges were found to be related to specific research fields, such as the use of haptic devices for O&M education, which faced limitations in the interaction points on PHANTOM devices [69]. Difficulties also arise in perceiving angles and intersections in graphs and navigating virtual environments due to the absence of auditory cues [69]. Furthermore, there are challenges related to O&M education, such as finding the optimal walking simulation pose [42] and a potential bias toward partially sighted students due to visual elements [31]. Environmental limitations also play a role, including interference from light sources and difficulties in detecting and navigating complex environments [18]. In addition, GPS limitations are present, such as indoor usability and accuracy issues with GPS tracking [31]. It should be noted that XR environments cannot replace basic O&M training or completely replace real-environment O&M training [31].

Many of the limitations and challenges related to the use of XR technologies in VI education stem from the early stage of research and development [16,56]. Technological limitations, such as difficulties with object identification, accuracy, variations among users, and a lack of depth perception in XR systems, contribute to these challenges [16,56]. Gesture recognition accuracy, sound-recording limitations, and the lack of specific data analysis methods for these research data sources also need improvement [44,77,78]. Another technological limitation is related to the development of prototypes, including delays and limitations in creating accessible and engaging prototypes, as well as the scarcity of well-researched resources and materials [72]. Lastly, the high cost of XR technology can act as a barrier to its adoption [38].

Numerous challenges and limitations are associated with various aspects of inclusivity and inclusion. One major issue is the lack of accessible tools for map creation and other tasks, which hinders the participation of individuals with disabilities [57]. Additionally, striking a balance between accessibility and engagement is crucial for both blind and sighted students, as both groups have different needs [31]. Moreover, the cultural background of users plays a significant role in how they perceive and interact with XR technologies, emphasising the impact of cultural differences [55].

Overall, the implementation of XR in education for VI students holds immense potential. However, it is crucial to address and overcome the significant challenges and limitations associated with it. Further research and development are necessary to ensure that XR technologies are inclusive, accessible, and effective in this context. The specific challenges range from limitations in haptic devices for O&M education to technological constraints, such as difficulties with object identification and accuracy. There are also concerns regarding the balance between accessibility and engagement, as well as the influence of cultural backgrounds on the perception of and interaction with XR technologies. It is important to address these challenges and continue exploring and advancing XR technologies to ensure their effectiveness and inclusivity for VI students.

3.4. RQ03: What Recommendations Can Be Made for Future Research on the Use of XR in the Education of Individuals Who Are Blind or Have Visual Impairments?

XR has shown great potential in enhancing the educational experience for VI students. However, there is still much to explore and understand about the effective implementation of XR in VI education. This systematic literature review delves into the main recommendations for future research in this field to provide valuable insights that can inform the development of inclusive XR-based learning environments for VI students. When designing for accessibility, inclusivity should be a top priority for researchers. This means conducting research that considers the diverse needs and preferences of individuals with visual impairments across different ages, skill levels, and personal preferences [47,56,75]. Additionally, researchers should focus on usability and thoroughly evaluate the user experience. By integrating accessibility features, the technology can remain easily accessible and impactful for all users [47].

Regarding assessments and research focused on user experience, it may be beneficial to explore the educational effectiveness of VR/AR technology through user studies that quantitatively measure its impact [70,79]. Additionally, it would be important to consider the various dimensions of user experience, including not only usability but also factors such as skill development, engagement, and knowledge retention [71]. For the advancement of technology and accessibility, future research must prioritise partnerships and collaboration among researchers, developers, educators, and individuals with visual impairments. This will ensure continuous feedback and the continuous improvement of technologies, as recommended by [24,58]. Additionally, sharing research findings and openly developing technologies is key to promoting wider adoption and accessibility, as highlighted by [38,58].

When it comes to targeted research, VR game design must align gameplay with real-world skills and ensure that VR games enhance crucial daily living skills for individuals with visual impairments [32]. It is imperative to keep track of progress and personalise learning experiences by implementing monitoring systems and allowing for customised learning experiences [32]. Moreover, researchers should investigate in-home practice options and evaluate their effectiveness in various educational settings [32]. For location-based games, cutting-edge tracking technologies like Bluetooth beacons and NFC tags can be utilised to create more interactive and captivating experiences [31]. Additionally, regularly updating applications based on user feedback and testing, as well as exploring various subject matters, are crucial [31,38].

For immersive audio games, researchers can design VR experiences that promote active participation, knowledge transfer, and skill development [71]. Partnering with industry experts is also recommended to ensure technical feasibility, usability, and engaging narratives [19]. Moreover, research discoveries should be applied to produce practical assistive devices for individuals with visual impairments [36]. The creation of tangible tools and handheld devices to facilitate game design by individuals who are blind should also be explored [39,72]. Online platforms should be developed to encourage knowledge-sharing and collaboration among game designers and users [72]. The ongoing research on XR in VI education aims to develop reliable assessment tools for measuring user experience in Audio AR (AAR) applications [78]. It is recommended that these technologies undergo real-world testing to evaluate their practical impact on educational settings [20]. To ensure accessibility for all users, accessibility features such as gesture recognition and tactile map design should be improved [77]. Additionally, researchers should explore innovative solutions for distance education and training that utilise multimodal materials to promote inclusivity in remote learning environments [41]. Finally, it is essential to investigate the impact of VR/AR technologies on individuals with diverse physical and psychological needs to ensure inclusivity and address potential challenges [24].

Regarding haptic and audio technologies, future research should focus on refining haptic feedback by improving accuracy and exploring different types of haptic feedback for more immersive sensory experiences [56]. Additionally, it is crucial to enhance audio immersion by integrating 3D sounds and personalised audio responses to provide more engaging and informative feedback [43]. Furthermore, research should concentrate on developing accessible design methodologies to create VR products that successfully use haptic technology [66]. Solutions that can overcome the limitations in environmental detection and audio quality should also be explored to ensure the accurate delivery of information [18].

As researchers delve into the realm of XR technologies, it is paramount that they remain cognizant of ethical considerations. This entails upholding ethical guidelines and regulations regarding data privacy and security when collecting and utilising user data. Informed consent procedures must be inclusive and accessible to ensure that all participants understand the research process and their rights. To ensure that all participants are represented fairly and equitably, researchers need to examine and mitigate potential biases in research design, data collection, and analysis. Moreover, emerging technologies and trends warranting comprehensive user studies include brain–computer interfaces (BCIs) that enhance user interaction and control in XR environments, artificial intelligence (AI) that personalises learning experiences and provides real-time feedback in XR educational applications, and sensory substitution technologies that provide alternative ways to perceive and interact with the world, beyond vision. Future research on XR in VI education should focus on the long-term impact of immersive technology on learning outcomes. Additionally, there is a need to explore the effectiveness of different types of XR, such as VR and VR, in meeting the diverse needs of VI students. Furthermore, investigating the potential barriers to implementing XR in educational settings for the VI and finding solutions that can address these challenges is crucial. Lastly, studying the cost-effectiveness and sustainability of integrating XR into VI education programs will be essential for the scalability of such interventions.

Table 1 presents an overview of the study findings, presenting readers with an overall picture of the review findings.

Table 1. Overview of the findings.

Research Question	Themes	Subcategories
RQ01: What are the prevalent trends and themes surrounding the use of XR in the education of individuals who are blind or have visual impairments?	Educational Assistive Technology and Inclusive Education.	XR as an assistive tool
		XR for museum accessibility
		XR as assistant educational systems
		Indoor and outdoor navigation systems
		Enhancing various skills, promoting inclusion
	Orientation and Mobility Education (O&M)	O&M training
		Interactive and cost-effective O&M
		XR for white cane training
		Multimodal cues for cognitive spatial maps
		Spatial learning and navigation skills
	Spatial Cognition	Sensory augmentation and substitution techniques
	Educational Games and Gamification	Sound design
		Inclusive gamming
		Multimodal training
		Audio games
		Multisensory realities
	Multisensory Realities and Sensory Substitution	Sensory Substitution Devices (SSDs)
		Audio–tactile content
		Spatial representations with multimedia annotations
	Authoring Tools for Educational Purposes	Teacher and student authoring
		The involvement of the target population and stakeholders in the design process
	Academic Discipline	Mathematics
		Sport education
		History
		Chemistry
		STEM
		Geography
		Physics
		Music
	Educational Maps	Mental representation skills
		Three-dimensional space
	Spatialized Audio	Auditory orientation system
	Multi-User Extended Realities and Group Work	Multi-user Spatial XR
		Group work
		Collaboration in multiplayer settings
	Design Guidelines	Bespoke design
		Embedded inclusivity targeting VI
		Gestures coupled with auditory feedback can bridge the sensory gap created by visual impairments

Table 1. *Cont.*

Research Question	Themes	Subcategories
RQ02: What challenges and limitations exist in implementing XR in the education of VI students?	General Limitations	Small sample sizes
		Repetition in this field of research
		Incomplete reporting
		Studies lack information on limitations
	Specific challenges	
RQ03: What recommendations can be made for future research on the use of XR in this field?	Designing for accessibility	
	Assessment and research	
	Partnerships and collaboration among researchers, developers, educators, and individuals with visual impairments	
	VR game design	
	Personalise learning experiences	
	Develop reliable assessment tools	
	Haptic and audio technologies	
	Ethical considerations	
	Long-term impact of immersive technology on learning outcomes	
	explore the effectiveness of different types of XR, in meeting the diverse needs of VI students	
	The potential barriers to implementing XR for VI Education	
	Studying the cost-effectiveness and sustainability of integrating XR into VI education.	

4. Conclusions

XR holds immense potential to revolutionise education for the VI by providing immersive, engaging, and accessible learning experiences. While challenges remain regarding cost, technology, and pedagogy, ongoing research, collaboration, and ethical considerations are paving the way for its responsible and beneficial integration in diverse educational settings. Ultimately, XR can empower learners with visual impairments to explore and interact with previously inaccessible subjects, fostering inclusivity and expanding educational opportunities. This systematic review aimed to analyse the use of extended realities in the education of individuals with visual impairments, focusing on trends, effectiveness, impact on inclusion, challenges, limitations, and recommendations for future research. The review followed the PRISMA guidelines, ensuring a clear and methodical approach to the search and analysis of relevant studies. The challenges and limitations of utilising XR to educate VI students were thoroughly analysed. Overall, this systematic review provides valuable insights into the potential and the impact of extended realities in improving learning outcomes and promoting inclusion for the VI in educational settings.

5. Limitations and Future Research

We conducted this review using the PRISMA methodology, making every effort to identify all eligible studies. We expanded our search terms and databases and resolved any discrepancies through active discussion. To ensure the quality and rigor of our review, we limited our search to five databases recognized for their contribution to education. While this allowed us to prioritise the quality of the included studies, it also resulted in the selection of only 71 papers from 23 countries. We acknowledge that including additional databases might have yielded more studies from a wider range of countries. Additionally, we only considered studies written in English, which excluded many publications that could have made a significant contribution to our review. The studies we identified for screening came from various fields, including education, computer science, rehabilitation, medicine, special needs, and game design. These studies employed different research approaches, which made it challenging for our researchers to conduct this systematic literature review. Overall, the limitations of our review include the search being restricted to a limited number of databases, and potential language and geographical bias.

One of the major findings of this study is that XR has great potential in the field of education for people with visual impairments. Based on the limitations of our review, there are several implications for future research. First, future studies should consider expanding the search to include additional databases, beyond those recognized for their contribution to education. This would increase the likelihood of including a wider range of studies from different countries, thus reducing any potential geographical bias. Additionally, future research should also consider including studies written in languages other than English, as excluding non-English publications may lead to a language bias and limit the overall scope of the review. Moreover, given that the studies included in our review came from various fields and employed different research approaches, future research should aim to further explore the impact of these interdisciplinary approaches on the topic under investigation. This could potentially provide a more comprehensive understanding of the research landscape and encourage collaboration across disciplines. Lastly, to address the challenges faced during this systematic literature review, future studies should consider employing more specific inclusion and exclusion criteria to ensure a more focused and targeted search. This could help to improve the overall rigor of the review.

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Appendix A

Table A1. Search terms.

Database	Keywords	Rules
Scopus	TITLE-ABS-KEY ((“Virtual Reality” OR “Augmented reality” OR “ Mixed realities “ OR “Mixed reality” OR “Extended Reality”) AND (“Visually Impaired” OR “Blind” OR “low vision”) AND (“education” OR “education*” OR “school”)) AND PUBYEAR > 2012	Years = 2013–2023 Articles + Conference papers + Reviews English Only
	TITLE-ABS-KEY (“audio-games” OR “audio games” OR “tactile games” OR “tactile-games”)	
Science Direct	((“Virtual Reality” OR “Augmented reality” OR “Mixed Reality” OR “Extended Reality”) AND (“Visually Impaired” OR “Blind” OR “low vision”) AND (“education” OR “school”))	Years = 2013–2023 Articles + Conference papers + Reviews English Only
	“audio-games” OR “audio games” OR “tactile games” OR “tactile-games”	

Table A1. *Cont.*

Database	Keywords	Rules
ERIC	abstract: OR title: (“Virtual Reality” OR “Augmented reality” OR “ Mixed realities “ OR “Mixed reality” OR “Extended Reality”) AND (“Visually Impaired” OR “Blind” OR “low vision”)	Years = 2013–2023 Articles + Conference papers + Reviews English Only
	“audio-games” OR “audio games” OR “tactile games” OR “tactile-games”	
JSTOR	(“Virtual Reality” OR “Augmented reality” OR “Mixed Reality” OR “Extended Reality”) AND (“Visually Impaired” OR “Blind” OR “low vision”) AND (“education” OR “school”))	Years = 2013–2023 Articles + Conference papers + Reviews English Only
	“audio-games” OR “audio games” OR “tactile games” OR “tactile-games”	
Taylor and Francic online	[[Abstract: “virtual reality”] OR [Abstract: “augmented reality”] OR [Abstract: “mixed reality”] OR [Abstract: “extended reality”]] AND [[Abstract: “visually impaired”] OR [Abstract: “blind”] OR [Abstract: “low vision”]] AND [[Abstract: “education”] OR [Abstract: “school”]] AND [Publication Date: (01/01/2013 TO 12/31/2023)]	Years = 2013–2023 Articles + Conference papers + Reviews English Only
	[All: “audio-games”] OR [All: “audio games”] OR [All: “tactile games”] OR [All: “tactile-games”] AND [Publication Date: (01/01/2013 TO 12/31/2023)]	

Appendix B

Table A2. The quality assessment tools.

Item	Assessment Criteria	Description of Checklist
1	Does the article evidently define the study’s aim?	- No, the aim is not described. (0) - Partially, the aim is not clearly described. (1) - Yes, the aim is well described and clear. (2)
2	Are the research questions and/or objectives clearly defined?	- No, research questions and/or objectives are not clearly stated. (0) - Partially, research questions and/or objectives are present but unclear. (1) - Yes, the research questions and/or objectives are well described and clear. (2)
3	The paper effectively presents a clear research method that is clear and replicable.	- No, no methodology is stated. (0) - Partially, the methodology is present but unclear. (1) - Yes, it does. (2)
4	The presentation of the results is clear and unambiguous.	- No, the details are not fully described. (0) - Partially, but the details are unclear and must be determined from the references. (1) - Yes, the results and Findings can be used. (2)
5	The study shares clear and relevant conclusions.	- No, the Conclusions are not fully described. (0) - Partially, but the conclusions are unclear. (1) - Yes, the conclusions are clearly presented and relevant. (2)

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