Accessibility in Extended Reality: A Systematic Review of Accessibility Research on Extended Reality Published in the ACM Digital Library From 2000 to 2025

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Abstract

Extended Reality (XR), including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has become a powerful paradigm for human–computer interaction, offering new opportunities to support accessibility for people with disabilities and older adults. However, the rapidly growing body of XR accessibility research remains fragmented across communities, technologies, and methodological approaches, limiting a holistic understanding of the field. In this paper, we present a systematic review of 245 publications from the ACM Digital Library spanning 2000–2025. We develop a structured coding framework to analyze descriptive trends, research methods, communities studied, accessibility challenges addressed, technologies employed, and contribution types. Our findings reveal several key patterns. First, both research and progress are unevenly distributed across communities, with a strong focus on blind and low vision (BLV) users, older adults, and motor/physical disabilities and comparatively limited attention to other disability populations, such as intellectual or developmental disabilities (IDD) and people with multiple disabilities. Second, accessibility challenges are often framed within narrow functional domains, such as navigation or rehabilitation. Finally, studies frequently rely on small-scale, lab-based methods, with limited longitudinal and real-world evaluations. We further discuss emerging design implications and opportunities and directions for advancing more inclusive, robust, and ecologically valid XR accessibility research.

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1 Introduction

Extended Reality (XR), encompassing Virtual Reality (VR) [150], Augmented Reality (AR) [41], and Mixed Reality (MR) [239], has rapidly become a major direction in human–computer interaction research. By enabling immersive [275], embodied [226, 294], and multimodal [222] experiences, XR technologies offer new opportunities to rethink how users perceive, interact with, and benefit from digital systems. For people with disabilities and older adults, these technologies offer promise in navigation [47, 135, 158, 298], rehabilitation [25, 32, 43, 274], communication [88, 195, 233, 288], and social engagement [17, 84, 121]. At the same time, the sensory [61, 189, 310], cognitive [69, 85, 98], and physical [62, 196] demands of XR introduce accessibility challenges beyond traditional screen-based interfaces.

In response, a growing body of HCI research has explored accessibility in XR across diverse populations [96, 155], technologies [61, 62, 69], and application domains [31, 66, 228]. However, this rapidly expanding literature remains fragmented. Existing work often focuses on specific communities, technologies, or use cases, limiting a holistic understanding of how accessibility is addressed in XR. In particular, there is a limited perspective across key dimensions, including communities, challenges, technologies, contributions, and methods.

To provide a systematic overview, we reviewed publications from the ACM Digital Library (ACM DL) [23] spanning 2000 to 2025, resulting in a corpus of 245 papers. No relevant publications were identified between 2000 and 2007. We then developed a structured coding framework to analyze each study across multiple dimensions, including (i) descriptive trends (e.g., temporal distribution, venues, communities, technologies, and contribution types), (ii) research methods (formative and core studies), and (iii) population-specific challenges and contributions across disability and aging groups.

Our analysis reveals several key patterns. First, research is unevenly distributed across communities, with a strong concentration on certain groups (e.g., blind and low vision users, older adults, and motor/physical disabilities) and comparatively limited attention to others (e.g., intellectual or developmental disabilities, multiple disabilities, etc.). Second, accessibility challenges are frequently framed within specific functional domains (e.g., navigation, rehabilitation, or input methods), suggesting opportunities to broaden the scope toward more holistic and experiential dimensions. Finally, methodological practices tend toward small-scale, lab-based studies, with increasing but still limited adoption of longitudinal and in-the-wild approaches.

Our key contributions are:

(1) A systematic review of XR accessibility research in the ACM DL from 2000 to 2025.
(2) A structured analysis of research trends, including temporal trends, addressed challenges, technologies used, contribution types, research methods, and studied communities.
(3) An explanatory cross-community synthesis of XR accessibility research to date. We examine how research framing, platform ecosystems, evaluation norms, and community representation co-occur and reinforce one another, and discuss implications for advancing more inclusive, robust, and ecologically valid XR accessibility research.

2 Background and Related Work

2.1 Accessibility Research in HCI

Accessibility has long been a central concern in HCI, focusing on enabling equitable access to digital systems for people with diverse abilities [53, 141, 257]. Prior work in this area has emphasized assistive technologies [60, 217], inclusive design practices [91, 125], and user-centered approaches [70, 209] that account for a wide range of sensory, motor, and cognitive needs. Moreover, accessibility research in HCI often involves the development and evaluation of prototypes through user studies, participatory design, and qualitative inquiry grounded in users' lived experiences. These approaches aim to ensure that design decisions are informed by real-world contexts and user perspectives rather than abstract assumptions [203, 213, 243].

At the same time, existing literature has identified several recurring challenges. Accessibility is often framed in terms of functional limitations, with an emphasis on compensation or remediation rather than broader experiential goals [105, 141]. In addition, the representation of disability communities remains uneven, with certain groups receiving disproportionate attention [53, 175, 257]. Furthermore, there is also a tendency toward short-term or laboratory-based evaluations, which may limit insight into long-term use and real-world adoption [147, 203, 213]. These patterns shape how accessibility is conceptualized and assessed and provide important context for understanding how such approaches extend into emerging domains such as XR.

2.2 XR Technologies and Accessibility

XR encompasses a range of immersive technologies [188], including VR [150], AR [41], and MR [239], which differ in how they integrate digital and physical environments. VR creates fully immersive, computer-generated worlds that replace physical surroundings [97], typically via head-mounted displays (HMDs). In contrast, AR overlays digital content onto the real world [19], while MR enables dynamic interaction between virtual and physical elements through spatial mapping and real-time environmental understanding [227].

These technologies introduce fundamentally different modes of interaction compared to traditional screen-based systems. XR interactions are inherently embodied [226, 294], spatial [275], and multimodal [222]. These interactions require users to engage through head movements [114], gestures [295], gaze [254], and full-body actions [42] rather than discrete inputs such as touch or keyboard commands. Consequently, XR relies on multiple sensory channels, including vision, audition, and proprioception. While these features enable immersive experiences, they also introduce accessibility challenges, particularly for people with sensory, motor, or cognitive differences.

The relevance of XR to accessibility lies in this dual nature. On one hand, XR can enhance accessibility through alternative modalities such as spatial audio [59], haptic feedback [266], and adaptive visualizations [142], enabling new forms of interaction and representation. On the other hand, its embodied and immersive nature can reinforce existing barriers [95], as many systems rely on normative assumptions about sensory [61, 189, 310], mobility [62, 196], and cognitive [69, 85, 98] abilities. Unlike traditional interfaces, where accessibility can often be addressed through interface-level adaptations, XR requires more fundamental changes to interaction design [134, 222, 248], including how users perceive [309], navigate [16, 224], and engage [62, 107, 264] with digital environments.

As a result, XR represents a distinct and evolving space for accessibility research, where challenges and opportunities extend beyond conventional assistive technologies. Understanding how accessibility is conceptualized and addressed in XR is critical for developing inclusive research, design, and development practices that reflect diverse user capabilities and experiences.

2.3 Prior Surveys and Reviews of XR

A growing body of survey and review work has examined XR across technological [41, 265, 285], interactional [193, 316], and application perspectives [41, 187]. These works have explored immersive interaction, spatial computing, and the use of XR in domains such as healthcare [1, 11], education [129, 132], entertainment [5, 136, 255], and training [27].

More recent reviews have begun to examine XR in the context of disability and accessibility. However, these efforts are typically scoped to specific populations [96, 155] or application domains, such as communication support [31], rehabilitation [228], health [66], or education [74], often focusing on a single technology or use case. As a result, the literature remains fragmented across disability groups and contexts. Consequently, there is limited synthesis of cross-cutting patterns across communities, challenges addressed, technologies used, research methods, and contributions. Our work instead offers an integrative analysis of XR accessibility research, supporting a more holistic understanding of the field.

3 Method

To examine the state of XR research in accessibility and HCI for people with disabilities and older adults, we surveyed conference and journal publications available through the ACM DL. This search initially produced 3,489 records published between 2000 and 2025. After screening, 245 publications were selected for inclusion in the final dataset. In this section, we explain how the dataset was compiled and how the coding procedure was carried out.

3.1 Dataset Creation

3.1.1 Keyword Selection and Developing Search Query. We developed our search terms through an iterative process informed by prior review and mapping studies in this area [13, 175, 229]. Our goal was to capture a broad range of work at the intersection of XR, accessibility, and aging, including research involving people with disabilities and older adults. To support this aim, we identified the following keywords: *assistive tech*, disab*, access*, impair*, older adul*, older pe*, senio*, elder*, augmented reality, AR, virtual reality, VR, mixed reality, MR, extended reality, and XR.*

The ACM DL advanced search supports the use of the asterisk (*) as a wildcard representing any number of unknown characters [13]. This allowed us to capture multiple lexical variations of a term. For instance, the keyword *disab** could retrieve terms such as *disable, disabled, disability,* and *disabilities.* We intentionally did not include highly specific disability-related terms, such as blind, low vision, deaf, motor disability, etc. This decision was informed by prior work and our experience, suggesting that predefined disability categories can bias datasets toward well-represented groups while overlooking emerging areas [175].

Because our review targeted XR research involving people with disabilities or older adults, individual keywords produced many false positives. To improve precision, we constructed a combined Boolean search string designed to better reflect the scope of the review: *("assistive tech*" OR "disab*" OR "access*" OR "impair*" OR "older adul*" OR "older pe*" OR "senio*" OR "elder*") AND ("augmented reality" OR "AR" OR "virtual reality" OR "VR" OR "mixed reality" OR "MR" OR "extended reality" OR "XR")*

We used this query to search for short and long papers published between 2000 and 2025. We chose the year 2000 as a lower bound to capture the period in which XR and related accessibility research became more consistently represented in the broader HCI literature [52, 175, 241, 242]. The search was applied to titles, abstracts, and author-specified keywords. We did not search the full text of papers, as this approach yielded a large number of irrelevant results, consistent with observations reported in prior work [175].

3.1.2 Inclusion/Exclusion Criteria. A fundamental inclusion criterion was that each article had to be published in the ACM DL, situated within the field of HCI, published between 2000 and 2025, and written in English. We focused on the ACM DL due to its consistent indexing and structured use of Computing Classification System (CCS) concepts, which supported the systematic identification of relevant HCI publications [13, 175]. We acknowledge that relevant studies also appear in other venues; however, limiting the scope allowed us to assemble a coherent and manageable corpus for analysis rather than pursue an exhaustive review.

Furthermore, we included publications in which participants with disabilities either directly interacted with an XR system or reflected on their lived XR experiences during the "core study" phase. We define the "core study" phase as the primary empirical stage evaluating the feasibility, usability, effectiveness, or experiential qualities of a system.

This criterion aligns with HCI's emphasis on human-centered evaluation and the need to ground design knowledge in users' experiences. It is particularly important for XR, as its embodied, sensory, and interactive nature cannot be reliably assessed through proxy participants or expert review alone. Consequently, findings based solely on non-disabled participants or indirect evaluations have limited validity for disabled populations. We therefore required direct participation by people with disabilities—or studies centered on their lived XR experiences—for inclusion.

In contrast, we excluded studies that involved target populations only in "formative study" phase, such as identifying user needs, preferences, and challenges, without their participation in core study evaluations. Although such studies are valuable for informing design, they do not provide empirical evidence about how disabled users actually engage with, experience, or assess a concrete XR system. Accordingly, we excluded papers that proposed XR systems for disabled users but did not include an empirical study involving those populations.

Moreover, the article had to report a complete HCI research study. Papers that described only a system or prototype without any human interaction, user involvement, or empirical evaluation were excluded. We also excluded articles that discussed XR or accessibility only as potential directions for future work.

In addition, the article had to be a full peer-reviewed short or long paper reporting original findings. We excluded work-in-progress papers, posters, doctoral consortium papers, demos, workshop papers, position papers, white papers, theses, and review articles. These publication types typically report early-stage ideas, preliminary findings, incomplete datasets, or overviews of prior work rather than presenting novel empirical evidence.

3.1.3 Corpus Creation. We conducted our search in the ACM DL using the defined query string to retrieve long and short research articles published between 2000 and 2025. Using the "Advanced Search" option, we limited the search scope to titles, abstracts, and author-specified keywords. To ensure comprehensive coverage while managing the volume of results, we divided the search into three time periods: 2000–2015, 2016–2020, and 2021–2025. Due to the substantial increase in publication volume over the last decade (2016–2025), we used shorter time windows (e.g., 2016–2020, and 2021–2025) to ensure stable query execution and avoid truncation of results. This process yielded a total of 3,489 records, which were imported into Zotero for further screening.

Within Zotero, we first removed duplicate and retracted records, resulting in 3,211 articles. We then conducted an initial screening based on titles and abstracts, excluding 2,560 articles that were not related to accessibility. In addition, 226 articles were identified as review papers (e.g., meta-reviews, scoping reviews, surveys, and systematic reviews) and were excluded in line with our inclusion criteria. Among the remaining articles, two were not written in English, leaving a total of 423 articles for full-text review.

The first (N = 323, 76.36%) and second (N = 100, 23.64%) authors then conducted a full-text screening to assess eligibility against the inclusion criteria. During this stage, several article categories were excluded. Specifically, 46 articles (10.87%) described systems or prototypes without conducting empirical evaluations involving people with disabilities or older adults. 40 articles (9.46%) did not involve direct interaction with XR or were not grounded in participants' lived experiences. Additionally, 36 articles (8.51%) did not involve participants with disabilities or older adults. 27 articles (6.38%) included people with disabilities or older adults only in formative studies, and another 17 (4.02%) involved only secondary stakeholders (e.g., caregivers or specialists) rather than the target populations. 6 articles (1.42%) relied on simulated disabilities or aging conditions without including actual participants. 4 articles (0.95%) lacked sufficient detail regarding participants, study methods, or findings. Finally, 2 articles (0.47%) focused on situationally induced impairments and disabilities (SIID) and were excluded because they fell outside the scope of this review.

After applying all inclusion and exclusion criteria, a final set of 245 (57.92%) articles was retained for analysis. Figure 1 represents our step-by-step screening procedure.

3.2 Coding Procedure and Analysis

We organized the final set of 245 articles in a Google spreadsheet for systematic analysis. Initially, the first (N = 195, 79.59%) and second (N = 50, 20.41%) authors conducted an initial round of coding, focusing on key dimensions including publication metadata (e.g., title and DOI), technologies used, contribution types, challenges addressed, study methods, and targeted populations. During this phase, we adopted a descriptive coding approach to broadly categorize the data. Each article was assigned a unique identifier (codename), and the coding process was distributed across six separate sheets, each corresponding to a specific coding dimension. To maintain consistency and traceability across sheets, a shared codename column was included in each, ensuring that all entries remained linked throughout the dataset. Following this initial phase, the first and second authors conducted two review meetings to align on coding strategies and refine the categorization process. Based on these discussions, we adopted and adapted coding practices from prior work [13, 175] to guide the subsequent, more structured coding process. After this, we systematically applied the coding rubric outlined in Table 1 to refine and standardize the dataset.

Each article was coded across multiple dimensions, including metadata, technologies used, contribution types, challenges addressed, study methods, and targeted populations. The rubric provided a structured schema with predefined categories and labels for each dimension, enabling consistent interpretation across coders. For categorical fields (e.g., technology used, contribution type, and challenges addressed), we employed a binary or multi-label coding scheme, allowing a single article to be associated with multiple codes where applicable. For example, articles could simultaneously address multiple challenges (e.g., communication, independence, etc.) or employ multiple technologies (e.g., VR, AR, and/or MR).

For study methods, we distinguished between formative and core studies and further categorized each based on standardized methodological types (e.g., usability testing, interviews, controlled experiments, workshops, etc.). Similarly, we differentiated between primary and secondary populations, capturing both the main target group (e.g., BLV, DHH, older adults) and any additional stakeholders (e.g., non-disabled participants, caregivers, specialists). Quantitative attributes, such as the number of participants, were recorded as numeric values to support subsequent descriptive analysis.

To ensure consistency and reliability, the first and second authors iteratively reviewed the coded data, resolving discrepancies through discussion and consensus. In cases where classification was ambiguous, articles were revisited and coded conservatively based on the dominant focus of the study. This coding process enabled both qualitative interpretation and quantitative aggregation, forming the basis for the analyses presented in the following sections.

4 Findings

4.1 Overall Descriptive Trends

4.1.1 Temporal Trends and Publication Venues. The earliest paper in our dataset appeared in 2008 [215]. Since then, publication activity has shown a consistent upward trajectory, indicating the rapid growth of this research area. From 2008 to 2014, the literature in our dataset remained sparse, with only one or two papers published annually. Research activity increases in subsequent years, coinciding with the emergence of commercial XR technologies, including devices such as Google Glass (2013), Microsoft HoloLens (2016), and the consumer release of the Oculus Rift (2016).

A notable increase in publication volume became evident from 2018 onward, with 12 papers (4.90%) published that year, rising to 25 by 2021. This growth peaked in 2024 with 49 publications (20%), driven in part by major venues such as CHI [1], which alone contributed 16 (6.53%) papers in that year. The trend continued into 2025, with 44 publications, underscoring the past five years as the most prolific period for XR accessibility research. Among publication venues, CHI and ASSETS emerged as the most prominent contributors, with 47 (19.18%) and 43 (17.55%) papers, respectively. In addition, research was disseminated across a wide range of other conferences and journals (e.g., ISS, AVI, UbiComp, IUI, CHI PLAY, TOCHI, OzCHI, etc.), which collectively accounted for 80 papers (32.65%). However, each of these venues individually contributed fewer than five publications over the 26-year period, indicating a highly distributed but uneven publication landscape. A complete list of venues categorized as "Other" is provided in Appendix B. An illustration of publication year and venues is presented in Figure 2.

4.1.2 Focus on Communities. Our analysis indicates that BLV populations constitute the most frequently studied primary group (N = 68, 27.76%). Other prominent groups include older adults (N = 42, 17.14%), people with motor/physical disabilities (N = 39, 15.92%), and those with ASD (N = 23, 9.39%), whereas IDD (N = 6, 2.45%) remain comparatively underrepresented. In addition, we identified studies focusing on multiple disabilities (N = 12, 4.90%), mixed disability groups (N = 11, 4.49%), and combined cohorts (N = 1, 0.41%). A smaller subset of studies (N = 10, 4.10%) examined other less commonly represented conditions, including color vision deficiency (CVD), invisible chronic conditions, and mental health

[1] Full names of abbreviated publication venues are provided in Appendix A.

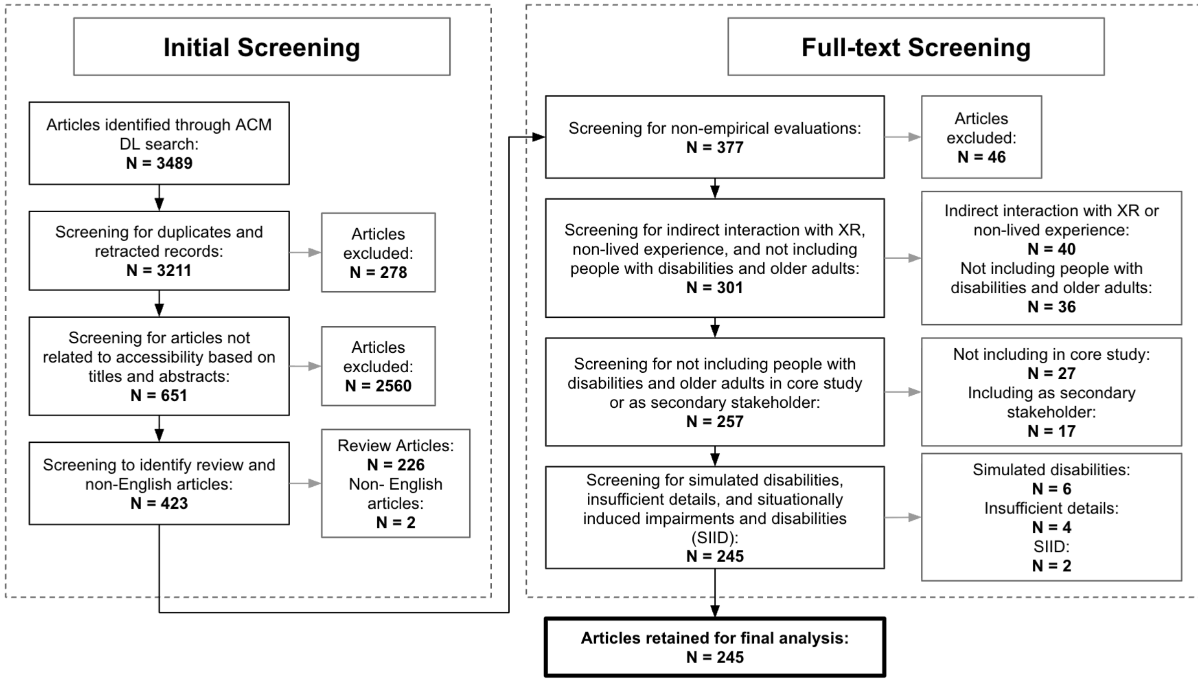


Figure 1: Our step-by-step screening procedure from initial 3489 articles to final 245 articles.

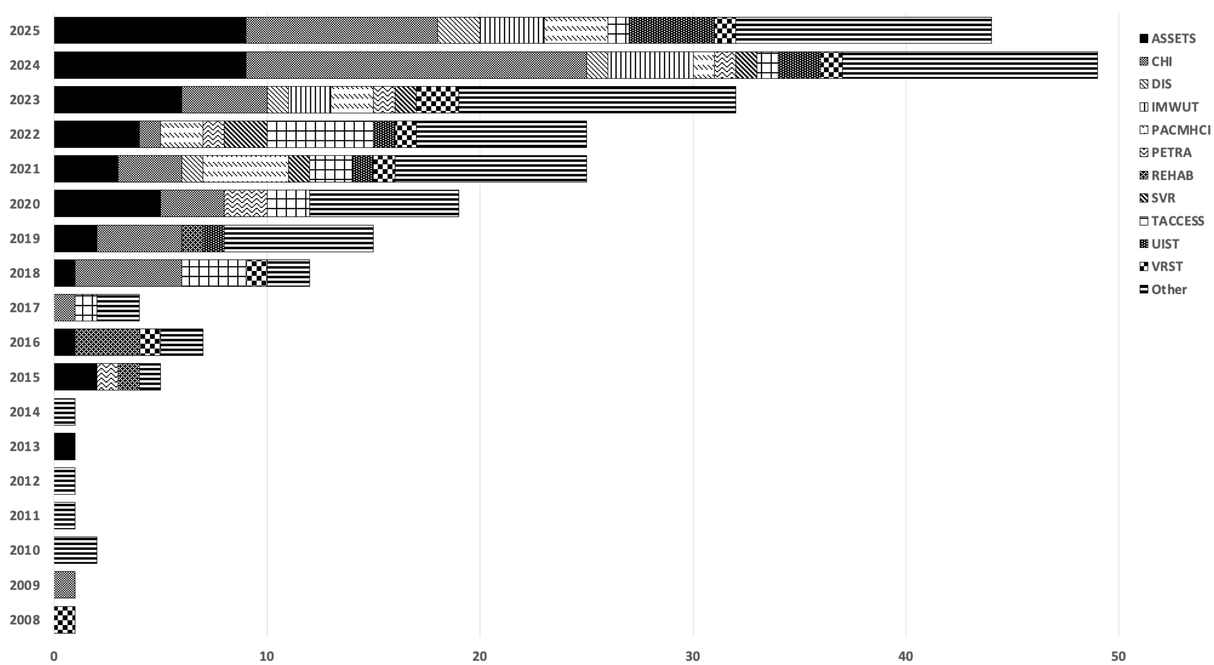


Figure 2: Published full papers on the topic of XR and accessibility (long and short) in ACM DL between 2000 and 2025.

conditions. Figure 3 provides an overview of the distribution of primary populations across the analyzed dataset.

With respect to secondary populations, the majority of studies (N = 142, 57.96%) did not include any additional participant groups, suggesting that much of the literature focuses on primary populations in isolation. When secondary participants were included, non-disabled people were the most common group (N = 55, 22.45%), followed by mixed groups (N = 20, 8.16%), which typically included

Table 1: Coding Framework Used for Data Extraction and Analysis.

Coding Aspects	Categories	Codes
Metadata	Title	publication title
	Year	published year
	Venue	publication venue
	Page Length	length of publication in pages
	DOI	DOI of publication
	Authors	authors of the publication
Used Technologies	AR VR MR XR Other	yes or no
Contribution Type	Primary Secondary Other	(1) empirical, (2) artifact, (3) methodological, (4) theoretical, (5) benchmark/dataset, (6) survey, and/or (7) opinion.
Challenges Addressed	Primary Secondary Other	(1) increase digital access/ease of use, (2) increase physical access, (3) increase independence, (4) increase understanding of users, (5) help with personal informatics and/or behavioral change, (6) support communication, and/or (7) other.
Study Method	Formative Study?	yes or no
	Formative Study Method	(1) controlled experiment, (2) survey, (3) usability testing, (4) interview, (5) case study, (6) focus group, (7) field study, (8) workshop/design, (9) other, and/or (10) N/A.
	Core Study Method (Primary) Core Study Method (Secondary) Core Study Method (Other)	(1) controlled experiment, (2) survey, (3) usability testing, (4) interview, (5) case study, (6) focus group, (7) field study, (8) workshop/design, and/or (9) other.
	Core Study Location (Primary) Core Study Location (Other)	(1) near/at researcher's lab, (2) participant's home, residence, or school, (3) neutral location, (4) online/remote, (5) other, and/or (6) unclear.
Targeted Population	Focused Population in Formative Study	(1) blind and low vision (BLV), (2) d/Deaf and hard of hearing (DHH), (3) motor/physical disabilities, (4) autism spectrum disorder (ASD), (5) intellectual or developmental disabilities (IDD), (6) cognitive disabilities, (7) older adults, (8) multiple disabilities, (9) people without disabilities, (10) specialists, (11) caregivers, (12) other, (13) unclear, and/or (14) N/A.
	Number of Participants in Formative Study	total number of participants in formative study
	Community of Focus in Core Study (Disabled or Older Adults)	(1) blind and low vision (BLV), (2) d/Deaf and hard of hearing (DHH), (3) motor/physical disabilities, (4) autism spectrum disorder (ASD), (5) intellectual and developmental disabilities (IDD) (6) cognitive disabilities, (7) older adults, (8) multiple disabilities, (9) other.
	Number of Participants in Core Study (Disabled or Older Adults)	total number of participants in core study who are people with disabilities or older adults
	Community of Focus in Core Study (Other)	(1) people without disabilities, (2) specialists, (3) caregivers, (4) other, (5) unclear, and/or (6) N/A.
	Number of Participants in Core Study (Other)	total number of participants in core study who are not people with disabilities or older adults

combinations of specialists, caregivers, and non-disabled participants, and specialists alone (N = 18, 7.35%).

4.1.3 Addressed Challenges. The analyzed research predominantly focused on increasing digital access and ease of use. This objective appeared in 94 studies (38.37%) targeting interaction, cognitive support, and usability challenges. Physical access (N = 42, 17.14%) and communication support (N = 39, 15.92%) are the next major focus areas. These address challenges in navigation, motor rehabilitation,

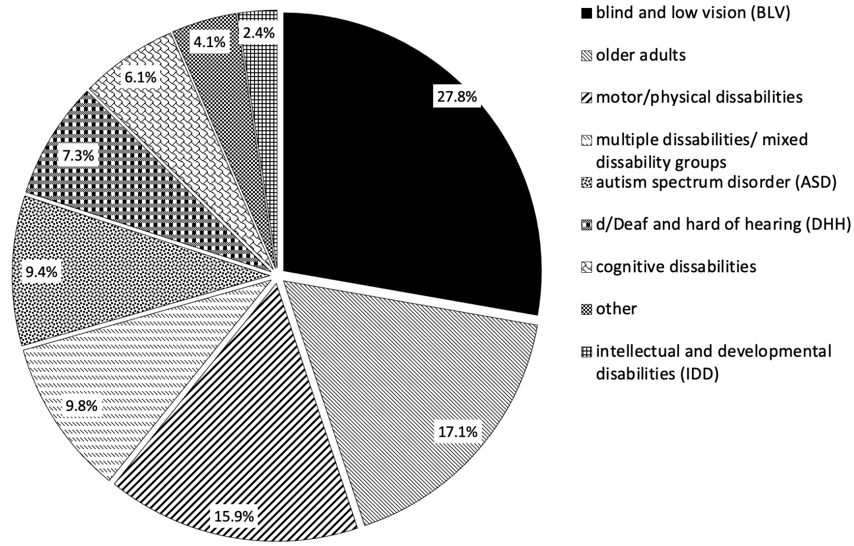


Figure 3: Primary population of focus across our analyzed dataset.

and social interaction through captioning and non-verbal cues. Additionally, studies focus on understanding users (N = 31, 12.65%) through perceptual and usability analyses, while personal informatics and behavioral change (N = 28, 11.43%) support therapeutic and self-regulatory outcomes. Although increasing independence is less frequently identified as a primary objective (N = 11, 4.49%), it remains an important underlying goal, especially for enabling autonomy in daily activities.

4.1.4 *Technology Used.*

VR is the most widely utilized immersive technology (N = 153, 62.45%) in our corpus, commonly implemented through commercial head-mounted displays (HMDs). Standalone devices such as the Meta Quest 2 and Meta Quest 3 are frequently used for simulation and training, while tethered systems like the Oculus Rift and HTC Vive support high-fidelity research. Devices such as the Pico Neo are often employed in geriatric and intergenerational contexts, and social VR platforms, particularly VRChat, are widely used to study interaction and disability disclosure. Lower-cost solutions, including Google Cardboard and smartphone-based setups, are also used to broaden accessibility and support applications such as exposure therapy. In parallel, AR (N = 91, 37.14%) and MR (N = 23, 9.39%) are prominently represented by devices such as the Microsoft HoloLens, enabling in-situ guidance, communication support, and spatial interaction. Emerging platforms such as the Apple Vision Pro and smart glasses (e.g., Google Glass, Vuzix Blade) further extend these capabilities. Additionally, Spatial-AR (SAR) leverages camera-projector systems to provide hands-free, in-situ interaction, offering an alternative to wearable devices.

To augment primary XR platforms, researchers integrated a range of adjacent hardware to support tracking, interaction, and feedback. Hand and body tracking were enabled through devices such as Leap Motion, Microsoft Kinect, and the Myo Armband, while eye-tracking technologies embedded in HMDs or used independently supported interaction for users with severe motor disabilities. Haptic and tactile feedback were widely employed through custom devices and wearables, alongside rehabilitation-focused systems such as robotic gait orthoses, multi-sensor platforms, and omnidirectional treadmills. Additional wearable sensors, including earables, EEG headbands, and biofeedback systems, provided real-time data for personalized interventions. These hardware systems were supported by software platforms such as Unity and increasingly integrated with Artificial Intelligence (AI). In particular, generative AI and large language models (e.g., GPT-4) were used to power virtual agents and real-time assistance, while machine learning and computer vision enabled tasks such as object detection, OCR, and spatial navigation. These systems were often complemented by traditional digital tools, such as Zoom and Slack, to support remote assistance and communication.

4.1.5 *Contribution Type.*

Research contributions are primarily characterized by artifacts (N = 122, 49.80%, as primary contributions) and empirical evaluations (N = 107, 43.67%, as primary, N = 121 as secondary). Most studies focus on developing novel systems, such as the HoloLearn application and the VRCaptions prototype, which are subsequently validated through feasibility studies, performance evaluations, and field observations. Empirical work also serves as a major primary contribution, employing methods such as diary studies, semi-structured interviews, and thematic analysis to examine user experiences and behaviors. Methodological contributions frequently appear as supplementary outputs (N = 51, 20.81%), providing design guidelines, taxonomies, and frameworks to inform future research and development. In contrast, theoretical contributions, benchmarks, and datasets (e.g., the DISCOVR VR image collection), and survey-based studies constitute a comparatively smaller portion of the literature. Figure 4 illustrates the distribution of contribution types among the analyzed articles.

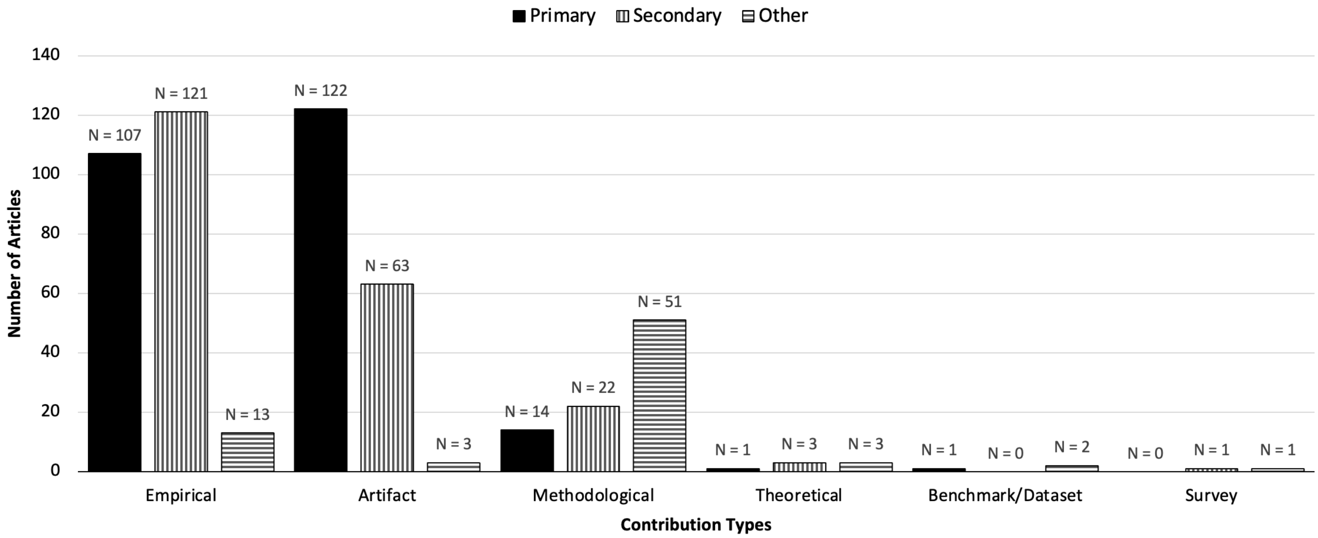


Figure 4: Distribution of Primary, Secondary, and Other Contribution Types in XR Accessibility Research.

4.2 Research Methods

We categorized the study methods employed in the reviewed works into two primary types: (i) formative studies and (ii) core studies. We define formative studies as those conducted to identify user needs, preferences, and challenges prior to the development or evaluation of a study's main contribution. In contrast, core studies refer to the central empirical phase of a project, in which the feasibility, usability, effectiveness, or experiential aspects of a proposed system, solution, or artifact are systematically examined.

4.2.1 Formative Study. Of the 245 articles analyzed, 174 (71.02%) incorporated a formative study. This reflects a growing emphasis on integrating user requirements and contextual constraints early in the design process, thereby enhancing ecological validity and reducing the likelihood of post-hoc accessibility adaptations. The formative methods employed were diverse, including collaborative and participatory design, inquiry and self-report techniques, evaluative and technical testing, observational and contextual research, and secondary analysis. Participatory approaches, such as workshops [231], iterative co-design sessions [218, 253], and design probes [83, 291], enabled the co-construction of knowledge and ensured that lived experiences of disability directly informed system design. Inquiry-based methods—including interviews [113, 250], surveys [93, 103], and diary studies [87]—were used to identify user needs and interaction challenges, while evaluative techniques such as pilot studies [224, 269] and usability testing supported early [310, 312]-stage system refinement. Observational methods, including in-the-wild and contextual studies [48, 82, 309], provided insights into real-world interactions, and secondary research (e.g., literature reviews [78, 304] and content analyses [109, 211, 293]) was often used to contextualize accessibility gaps and justify design interventions.

Among the studies reporting formative work, participant reporting varied considerably. 28 studies (11.43%) did not clearly specify participant numbers. Of those that did, most relied on small samples: 85 studies (34.69%) included 1–10 participants, reflecting a preference for intensive, high-resolution feedback in early-stage design. These smaller samples often supported exploratory or in-depth methods, such as single-participant optimization techniques [206] or autoethnographic [247] approaches. Additionally, 31 studies (12.65%) involved 11–20 participants, and 13 studies (5.31%) included 21–50 participants, which is consistent with common practices in participatory design and qualitative research [164, 288]. Larger sample sizes were less common, with only 2 studies (0.81%) including 51–100 participants and 5 studies (2.04%) exceeding 100 participants; these studies typically shifted toward broader validation and quantitative analysis [103, 186]. Across studies that reported participant counts, the mean number of participants was approximately 17.40, with a median of 8 and a mode of 6 participants, indicating a general tendency toward smaller, in-depth formative investigations.

More than half of the studies reporting formative methods (N = 97, 39.59%) included only a single participant population, most commonly specialists and caregivers (N = 34, 13.88%), BLV people (N = 33, 13.47%), people with motor or physical disabilities (N = 18, 7.35%), older adults (N = 17, 6.94%), ASD (N = 13, 5.31%), and non-disabled participants (N = 13, 5.31%). Less frequently represented groups included DHH people (N = 7, 2.86%), people with IDD (N = 7, 2.86%), and those with cognitive disabilities (N = 6, 2.45%), along with a small number of studies involving less commonly specified conditions such as mixed disabilities [82], general disabilities [17], hidden disabilities [218], dyslexia [104], CVD [317] and color blindness [250]. A comparable number of studies (N = 77, 31.43%) included multiple participant populations, where specialists and caregivers (N = 32, 13.06%) and non-disabled participants (N = 11, 4.49%) were most often incorporated as secondary groups alongside participants with disabilities, indicating a tendency to complement primary user input with supporting perspectives during formative design.

From our analysis, it is also evident that non-disabled participants were frequently included in formative studies, often serving as baseline comparison groups for investigations focused on disabled or older adult populations [43, 75, 315]. They were also involved in studies that simulated disability experiences, such as blindfolding sighted participants [157, 220, 259]; examined collaborative workflows with disabled or older adult populations, including caregivers [29, 92, 262, 315], therapists [92, 116, 195, 238, 256], trainers [33, 130], and teachers [284, 286, 300]; or aimed to promote empathy and awareness [9, 279].

4.2.2 Core Study. Nearly half of the analyzed articles (N = 119, 48.57%) employed multiple methods within their core studies, reflecting a strong tendency toward mixed-method approaches. As illustrated in Figure 5a, among primary methods, usability testing was most prevalent (N = 92, 37.55%), followed by controlled experiments (N = 83, 33.88%). Usability testing was typically implemented through task-driven and probe-based evaluations to assess system usability, spatial understanding, and functional performance [6, 126, 139, 152, 172, 221, 234, 297]. In contrast, controlled experiments commonly adopted comparative designs to benchmark novel or assistive interventions against traditional methods or baseline conditions [164, 170, 178, 206, 208, 235, 271, 276]. Field studies (N = 26, 10.61%) were also used as primary methods, primarily to examine sustained use [68, 108, 300], user adaptation [26, 38, 204], and real-world applicability [56, 180, 233] of XR systems over time.

Less frequently, studies employed interviews (N = 15, 6.12%), workshops or design sessions (N = 11, 4.49%), and case studies (N = 10, 4.08%) as primary methods, leveraging qualitative and participatory approaches to capture user experiences [9, 24, 158, 186, 304] and support iterative development [87, 123, 182]. Focus groups (N = 3, 1.22%) and surveys (N = 2, 0.82%) were rare, with the former used for collective evaluation [64, 86, 131] and the latter for assessing user perceptions and system acceptance [160, 267]. A small number of studies (N = 3, 1.22%) utilized alternative approaches, including diary studies [305], large-scale quantitative analyses [298], and physiological evaluations [128].

As secondary methods, interviews were most commonly used (N = 60, 24.49%), followed by surveys (N = 20, 8.16%) and usability testing (N = 17, 6.93%), highlighting their role in complementing primary evaluations and enriching interpretive insights. These secondary methods are primarily employed to complement primary evaluations by adding qualitative depth [10, 139, 162, 314], quantitative validation [26, 234, 267, 288], and experiential context [79, 145, 149], enabling researchers to triangulate findings and develop a more comprehensive understanding of user experience.

As shown in Figure 5b, study locations varied considerably across the analyzed articles. A substantial proportion of studies were conducted in researcher-controlled environments (N = 114, 46.53%), predominantly as primary settings (N = 111, 45.31%), including university campuses [115, 312, 313], dedicated experimental rooms [152, 297, 308, 309], and simulated environments such as recreated living rooms [269] or kitchens [261]. The next most common setting comprised clinical and specialized facilities (N = 55, 22.45%), primarily used as main study sites (N = 49, 20%), including psychiatric and geriatric hospitals [28, 68, 246, 280], rehabilitation centers [32, 268], and sheltered workshops [82, 108, 126]. Remote or online settings were also frequently utilized (N = 35, 14.29%), mainly as primary environments (N = 31, 12.65%), leveraging video conferencing platforms such as Zoom and Microsoft Teams [24, 25, 121, 157, 186, 304] or social virtual environments like VRChat [17, 305].

In addition, a number of studies were conducted in participants' personal or institutional environments, including homes, schools, and care facilities (N = 28, 11.43%), with examples such as private kitchens [116], classrooms [45, 117, 156, 253], and long-term care communities [131, 208, 262, 270]. Public or neutral spaces (N = 22, 8.98%) were also used to capture interaction in more naturalistic contexts, including libraries [76, 123], museums [8, 270], cafes [183, 233], and professional conferences [122, 179, 306]. A smaller subset of studies (N = 23, 9.39%) reported using multiple locations, while 14 (5.71%) articles did not clearly specify their study setting.

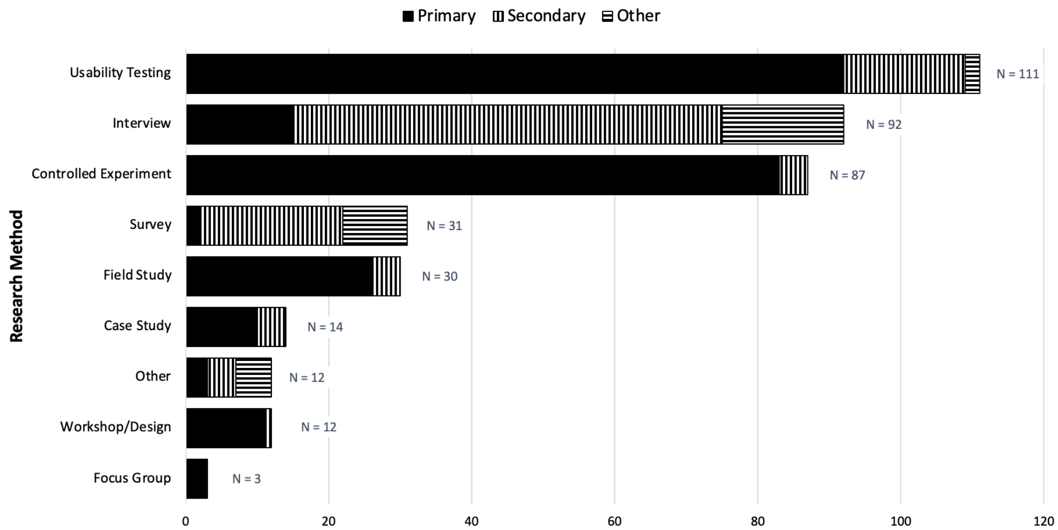
We also observed key differences in the orientations of lab-based and field studies. Lab-based work, largely consisting of usability tests and controlled experiments, typically evaluates system performance through objective metrics such as task completion time [146, 253], survey scales [90, 121, 298], and balance scores [72], with qualitative data [92, 145, 256] providing supplementary context. Field studies, in contrast, reveal how users adapt technologies within real-world constraints, such as how XR shapes social interaction [286], desensitizes phobias [99] over time, or how intergenerational connections develop through repeated shared sessions [300]. These patterns of adoption, adaptation, and sustained engagement are difficult to capture in controlled evaluations because they emerge primarily in everyday contexts.

We identified people with disabilities or older adults as the primary population across the analyzed studies. Participant sizes in these primary populations were generally small, with nearly half of the studies (N = 120, 48.98%) involving 10 or fewer participants. Although the mean number of participants was 34.66, this value is skewed by extreme outliers [298]; the median (11) and mode (10) more accurately reflect typical study sizes. This distribution reflects a strong emphasis on small-scale, in-depth investigations, including single-participant case studies [57, 183, 210] and studies involving very small groups [87]. Studies with 11–20 participants constituted the second most common category (N = 82, 33.47%), while larger cohorts were relatively rare (51–100 participants, N = 4, 1.63%; more than 100 participants, N = 1, 0.41%).

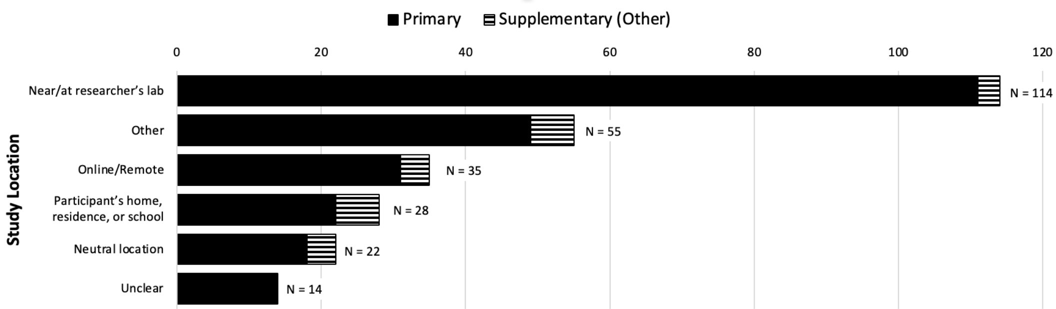
In addition to primary participants, many studies incorporated secondary populations (N = 98, 40%), most commonly non-disabled people (N = 55, 22.45%) and specialists (N = 18, 7.35%). Similar to primary populations, secondary participant sizes were also skewed toward smaller samples ($\leq$ 10 participants, N = 51, 20.81%; 11–20, N = 19, 7.76%; 21–50, N = 15, 6.12%), with a median of 9 and a mode of 6. Figure 6 provides a comprehensive overview of participant distributions in core studies.

4.3 Communities Studied

In this section, we present findings on individual populations in ascending order, followed by an overview of research on people with multiple disabilities, mixed disability groups, and other less frequently studied populations with disabilities. Specifically, we



(a) Research methods used in the core study.



(b) Locations used as primary or supplementary (other) space for the core study.

Figure 5: Overview of core study characteristics: (a) research methods and (b) study locations.

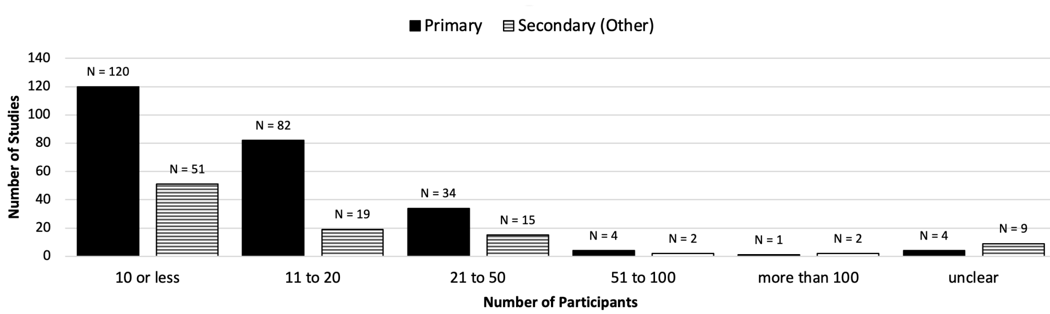


Figure 6: Number of participants in core studies, categorized as primary population (people with disabilities or older adults) and secondary population (non-target participants).

present findings on the challenges addressed and contributions made for each population.

4.3.1 Blind and Low Vision. Research on BLV populations primarily addressed challenges related to physical access, digital accessibility, and functional independence. A significant body of work focused on navigation tasks, including indoor wayfinding [313], stair traversal [312], and obstacle avoidance in complex environments [56, 235]. In parallel, studies aimed to improve access to visually intensive digital platforms, such as VR environments [83, 276], touchscreen interfaces [149, 220], and 360° media [122, 291], through non-visual or enhanced sensory modalities. Additional efforts targeted independence in daily activities, including cooking [152], dining [51], and parcel retrieval [102], as well as communication support by translating non-verbal cues (e.g., gaze and avatar behavior) into accessible auditory or haptic feedback [54, 121, 127].

The contributions of these studies spanned artifacts, empirical insights, and methodological frameworks. Artifact-based contributions were most prevalent, encompassing both hardware (e.g., haptic controllers [234, 309], wearable sensing devices [124]) and software solutions (e.g., AI-driven scene description systems [133] and mobile navigation tools [157, 298]). Empirical contributions provided evidence through performance evaluations [313], field observations [256], and participatory design studies [12], while methodological contributions included design guidelines [234, 311], taxonomies [109], and conceptual frameworks for accessible XR interactions [302]. In some cases, studies also contributed datasets and benchmarks to support accessibility-focused AI development [133, 261].

4.3.2 Older Adults. Research concerning the older adult population primarily focused on mitigating the effects of age-related physical and cognitive decline while fostering social connectedness. A central theme was the use of technology for cognitive assessment and rehabilitation, such as detecting early signs of dementia [118, 170, 208], assessing episodic memory [215], and stimulating spatial memory to mitigate mental decline [20, 30]. Physical health and safety were equally prominent, with studies addressing balance training and fall prevention through exergames [130, 163, 167, 225, 273, 296], promoting active aging [26, 47], and assisting with wayfinding in complex healthcare facilities [156]. Furthermore, research targeted social and emotional well-being by leveraging virtual environments to alleviate loneliness and isolation [100, 167, 221, 262, 292, 301] and strengthening intergenerational bonds through reminiscence and shared activities [162, 165, 300]. Finally, significant efforts were directed toward digital access, helping seniors learn complex smartphone features or navigate autonomous vehicles to maintain their independence [21, 123, 161].

The contributions of these studies were primarily categorized into artifacts and empirical findings. Artifacts constituted a major primary contribution, including the development of custom VR exergames [68, 130, 167], cognitive assessment batteries [170, 208], and specialized support tools for autonomous learning [123, 161]. Empirical contributions were equally significant, often serving as the primary output through longitudinal trials, feasibility studies, and experiments that compare age-related performance data [26, 156, 163, 205, 223, 273, 292]. Additionally, researchers provided methodological contributions by formulating design guidelines for intergenerational AR [165], proposing usability frameworks for VR game development [301], and identifying interaction challenges specific to elderly users [20, 279, 287]. Some studies also offered theoretical contributions by characterizing age-related cognitive map decay or providing design implications for age-appropriate physical training [30, 130].

4.3.3 Motor/Physical Disabilities. Research revolving around people with motor and physical disabilities primarily addressed barriers to digital access and ease of use [65, 79, 93, 148, 210, 258, 278, 293], focusing on inclusive interaction techniques such as adapting 3D inputs to comfortable motion ranges [278] and enabling one-handed interaction for complex tasks [293]. A significant body of work also targets physical access [25, 32, 58, 137, 178, 249, 268], particularly in motor rehabilitation and stability, including support for home-based therapy [58, 73, 179, 249], postural control [178], and upper-limb recovery [137, 192, 289]. Beyond accessibility, studies aim to enhance independence [79, 211, 219, 249, 290], promote behavioral change through gamified rehabilitation [73, 179, 219, 244, 306], and support communication via assistive devices [64]. Additionally, researchers emphasize understanding user-specific challenges, such as pain and fatigue associated with restrictive interaction techniques, to inform more inclusive design [18, 197, 216].

Furthermore, these studies provided a wide range of contributions to the field of assistive technology. Empirical contributions were the most frequent, providing user evaluation data, results from controlled studies on balance, and qualitative feedback from stroke survivors [73, 179, 185, 192] and disabled athletes [9]. Artifact contributions are also highly prevalent, featuring the development of novel feedback techniques [178], accessible VR game prototypes [9, 93, 244], mobile rehabilitation systems [25, 219], and custom haptic devices [22, 192]. Methodological contributions include new design frameworks like "Nearmi" [148], co-design techniques for people with language difficulties [64], and standardized test procedures for accessible computing [190]. Additionally, the sources highlight theoretical contributions that identify design considerations for inclusive freehand systems [216] and define new languages for "motion primitives" [278], as well as benchmark datasets for tracking rehabilitation progress [25].

4.3.4 Autism Spectrum Disorder. Research that included people with ASD focused heavily on supporting communication and social interaction. This included developing platforms for remote spelling-based training [67], fostering social initiation and engagement [84, 286], and improving effective communication through virtual letterboards or language-based alternatives for nonspeaking people [10, 201, 202]. Another priority was supporting independence and vocational success, including addressing employment barriers through simulated interview training [6], accessible job training [37], and activities of daily living such as toothbrushing [315]. Additionally, researchers seek to increase understanding of users by analyzing fine motor behaviors [168, 308], exploring highly variable sensory needs and regulation [35], and making "invisible" nonverbal social cues, such as proximity and volume, visible through immersive technology [36]. Behavioral challenges, such as managing stress triggers and improving social-emotional learning, are also central themes [2, 174, 186, 251].

The primary contributions of these studies were artifacts and empirical findings. Artifacts included novel training platforms like "CIRVR" [6] and "VR4VR" [37], assistive communication systems like "HoloGaze" [201] and "HoloBoard" [10], and therapeutic games such as "Foldiverse" [168] and "vrSocial" [36]. Empirical contributions were derived from feasibility studies [6, 201, 308, 315], field studies [173, 286], and user trials that evaluate sensory regulation, state anxiety, and social coordination [35, 84, 198]. Furthermore, many of the research works provided methodological contributions. These included establishing design principles for future VR systems [37], identifying design requirements for self-interventions [186], and evaluating engagement frameworks specifically for users with ASD [251].

4.3.5 *d/Deaf and Hard of Hearing.*

Research concerning the DHH population primarily focused on supporting communication by reducing barriers across social and digital contexts. Central objectives included enhancing access to auditory information in VR [288]; improving speech comprehension [212]; real-time captioning and sign language interpretation [49, 180, 269]; and improving accessibility by translating auditory cues into visual or haptic modalities [40, 119, 164, 166]. In addition, studies examined the accessibility of emerging spatial computing platforms [181], supported independent learning of visual languages [110], and addressed broader accessibility needs such as emergency alerts, web information access [153], and real-time translation services [103].

The contributions in this body of work were primarily categorized into artifacts and empirical evaluations. Artifact contributions encompassed a wide range of prototypes, including systems such as VRCaptions [288], SpeechBubbles for group communication [212], the Sign-to-911 translation system [103], and SoundHapticVR for spatial audio representation [44]. Empirical contributions were similarly prominent, drawing on exploratory studies, field deployments, and controlled experiments to assess factors such as recognition accuracy, usability, and user satisfaction [153, 180, 191, 269]. In addition, several studies offered methodological contributions, including design implications for shared AR environments [172], participatory design recommendations for MR-based communication [49], and conceptual frameworks that define design spaces for haptic interaction [119].

4.3.6 *Cognitive Disabilities.*

Research regarding people with cognitive disabilities primarily aimed to improve digital access and ease of use through cognitive assistance, including context-sensitive instructions [82, 126, 143] and intuitive authoring tools [33]. A major focus was placed on increasing independence, helping users learn everyday activities for autonomy [82, 126, 271] and fostering the inclusion of workers with disabilities into professional environments [33, 82]. Studies also addressed behavioral change and personal informatics, such as symptom management for agitation [182], psychological interventions to alleviate anxiety [160], and promoting safe engagement in physical exercise [71]. Furthermore, researchers seek to increase understanding of users by evaluating the perception of different error-feedback modalities [143], assessing perceived mental load [81], and exploring the mechanisms behind emotion recognition disability [272].

The contributions were primarily categorized as artifacts and empirical findings. Artifact contributions included novel applications like the "HoloLearn" virtual assistant [271], the "PARTAS" prototype for assembly tasks [126], social skill intervention systems like "MASI-VR" [272], and the "Memory Journalist" exergame [131]. Empirical contributions were derived from controlled studies, feasibility pilots, and observational interviews that evaluate system performance, likability, and effectiveness in reducing dementia progression or managing symptoms [71, 82, 120, 143, 246, 260, 271]. Furthermore, researchers provided methodological contributions by establishing design implications for error-feedback systems [143], providing healthcare deployment recommendations [246], and detailing iterative participatory design processes for specific cognitive disabilities [71, 131, 182].

4.3.7 *Intellectual or Developmental Disabilities.*

Research related to people with IDD primarily emphasized personal informatics and behavioral change, including interventions such as desensitization for phobias [99] and physiologically informed rehabilitation [72]. A key objective was also increasing independence, particularly by addressing mobility challenges [99] and supporting autonomous decision-making in everyday tasks [233]. In addition, studies focused on digital access and ease of use through step-by-step instructions [108], support for academic skill development [117], and identifying accessibility barriers [138]. Finally, research contributed to communication support by enabling non-verbal interaction and facilitating collaboration within heterogeneous groups [108, 233].

The contributions in this body of work can be categorized into artifacts, empirical findings, and methodological frameworks. Artifact contributions included the development of immersive therapeutic systems [99] and networked assistive assembly platforms [108]. Empirical contributions were particularly prominent, including longitudinal studies [99, 108], hardware evaluations [72], observational work [233], and thematic analyses of user challenges [138]. In addition, several studies provided methodological contributions, including pipelines for multimodal analysis based on biometric data [72] and iterative design processes for assistive workplace technologies [108].

4.3.8 *People With Multiple Disabilities and/or Groups With Mixed Disabilities.*

Among the studies categorized as involving multiple disabilities, mixed groups, and combined cohorts, we observed a strong emphasis on older adults and neurodiverse populations. Research on multiple disabilities primarily focused on geriatric populations with cognitive decline[4, 280], as well as people with Parkinson's disease [207] and post-stroke disabilities, including disorientation, hemiparesis, and speech deficits [4, 194]. Studies involving mixed disability groups often included heterogeneous cohorts of neurodiverse children and students with conditions such as ADHD [63, 92, 101], ASD [89, 92, 101, 171, 218], dyslexia [101], and anxiety [218]. These studies also encompassed broader populations with mobility disabilities [17, 305], chronic conditions [305], and sensory differences [17, 85, 304]. Additionally, several studies addressed the needs of individuals with specific motor and communication challenges, including those with Cortical Visual Impairment (CVI) [86], Severe Speech and Motor Impairment (SSMI) [146], non-speaking users in social virtual environments [46], and users of mobility aids such as wheelchairs and prosthetics [281].

Research on these diverse populations primarily addressed challenges related to independence, physical rehabilitation, and social inclusion. A key focus was on increasing independence, such as supporting daily activities through in-situ guidance [280], enabling interaction with assistive technologies [146], and preparing users for real-world scenarios like air travel [218]. Physical access and rehabilitation were also central, with efforts targeting home-based recovery [303], stroke rehabilitation [194], and fine motor skill development [80]. Additionally, studies aimed to support communication and digital access through inclusive avatars [17, 101], immersive storytelling [89], and strategies to manage sensory overload [86], while leveraging personal informatics to monitor conditions [207], capture user experiences [63], and promote engagement in activities such as exercise [38].

The contributions of these studies were multifaceted, spanning technical artifacts, empirical insights, and methodological frameworks. Artifact contributions included systems such as the"Wildcard" storytelling platform [89], "Innova Vive" therapy application [267], "cARe" AR framework [280], and "MRehab" rehabilitation system [274]. Empirical contributions are derived from multi-week longitudinal studies [38, 63, 92], diary studies and qualitative interviews [17, 281, 305], and case studies tracking cognitive and motor outcomes over time [194]. In addition, these works offer methodological and theoretical contributions, including design guidelines [86, 280], analytical models [85], mapping algorithms [207], and accessibility frameworks [4].

4.3.9 Other. Among less frequently represented groups in our dataset, people with CVD or color blindness were the most prominent, spanning general users, professionals, and gaming contexts [214, 245, 250, 299, 317]. Research also addressed individuals with mental health conditions, including patients with schizophrenia or personality disorders, as well as young adults seeking support for emotional regulation and rapport-building [204, 238]. Additionally, studies explored neurodivergent populations, focusing on children with dyslexia and adults with ADHD to support reading and real-time discourse management [104, 307]. Finally, some work examined professionals with "invisible" chronic conditions, such as migraines and fibromyalgia, emphasizing workplace communication and awareness strategies [88].

Research on these populations primarily addressed challenges related to digital access, personal independence, and social communication. For people with CVD, studies focused on mitigating color ambiguity in everyday tasks and identifying chromatic accessibility challenges in digital environments [214, 245, 250, 317]. Work involving mental health conditions emphasized personal informatics and behavioral change, including treatment adherence, physiological monitoring, and support for self-disclosure in therapeutic contexts [204, 238]. Research on dyslexic children aimed to promote independent reading without reliance on specialists [104], while studies on adults with ADHD focused on real-time discourse support [307]. Additionally, research addressing professionals with migraines or fibromyalgia explores strategies for workplace communication and awareness of "invisible" conditions [88].

The contributions in this body of work spanned artifacts, empirical findings, and methodological frameworks. Artifact contributions include software systems such as "Chroma" [250] and "Augmenta11y," [104] therapeutic platforms like "ARCADIA" [238] and "CounselAR," [204] and hardware prototypes such as computational glasses [245]. Empirical contributions are derived from laboratory studies, psychophysical experiments, longitudinal fieldwork, and qualitative analyses, including interviews and online data sources [88, 204, 238, 250, 307, 317]. In addition, researchers offer methodological and theoretical contributions, including design guidelines for workplace disclosure [88], frameworks for gamified MR systems [238], and approaches for integrating accessibility simulations into game design processes [214, 317].

5 Discussion

5.1 State of Research Progress

The body of XR accessibility research reflects substantial technical and methodological progress across disability communities, although the maturity of this progress varies. Research for BLV users has advanced the furthest, establishing spatial audio [312, 313], haptic feedback [234, 309], and multimodal sensory substitution [121, 127] as core accessibility techniques. It has also expanded beyond navigation into communication [54], daily living [51, 152], and immersive media [122, 291], while producing reusable design guidelines [234, 311], conceptual frameworks [302], and benchmark datasets [133, 261]. Older adult research has distinguished itself through longitudinal and clinically grounded evaluations of exergames, fall prevention [130, 163, 167, 273], dementia screening [20, 118, 170, 208], and memory rehabilitation [20, 118, 170, 208] while also addressing social isolation [262, 292, 301], intergenerational connection [165, 300], and digital independence [123, 161].

Furthermore, research on motor disabilities has simultaneously expanded accessible interaction techniques [9, 93, 278, 293] and rehabilitation applications [73, 179, 192], progressing from adapted input methods to comparative clinical evaluations [18, 197, 216] while recognizing pain and fatigue as critical long-term accessibility concerns. Similarly, ASD research has evolved from demonstrating social-skill training [6, 37, 84, 286] to developing community-responsive design principles [35, 36], engagement frameworks [251], and sensory-aware systems [37, 186] that leverage XR's unique ability to scaffold social interaction.

Other communities demonstrate meaningful but comparatively earlier stages of progression. For example, DHH research has established multimodal communication support through visual, haptic [44, 119, 164, 166], captioning, and sign-language systems [49, 180, 269, 288] while increasingly adopting participatory methods [49] that embed community communication preferences into design. Cognitive disability research has shown XR's potential to provide structured, context-aware support for everyday tasks [82, 126, 271] while contributing broader insights into cognitive load [81], feedback [143], and participatory design [71, 131, 182].

Although research involving people with IDD and multiple or mixed disability groups remains relatively limited, these communities have introduced longitudinal [38, 63, 92, 99, 108], diary [17, 281, 305], and naturalistic evaluations [194, 233] that demonstrate XR's potential for supporting autonomy [233], collaboration [108], and intersectional accessibility [63, 92, 101] while advancing inclusive frameworks [4, 280] and design guidelines [86, 280]. Collectively, these studies illustrate a broader transition from isolated proof-of-concept systems toward community-informed, ecologically grounded, and more generalizable accessibility design knowledge across XR.

5.2 Framing of Accessibility Research in XR

Our surveyed body of work reflects a field in productive motion; however, when examined collectively, the landscape of addressed challenges revealed a striking consistency. Research is predominantly organized around functional limitations, focusing on what disabled users are perceived as unable to do and aiming to restore or compensate for these constraints, a pattern also reflected in prior work [94, 111, 175, 176]. While this framing has enabled the development of effective solutions for specific challenges, it also produces a systematically incomplete view of disabled people as users, leaving broader dimensions of human experience underexplored.

This tendency is evident across nearly all disability communities in our review. Research questions consistently converge on a narrow set of functional domains. For example, navigation [253, 309, 312] and daily task completion [133, 250, 310] for BLV users, fall prevention [167, 273] and cognitive monitoring [30, 170, 208] for older adults, rehabilitation [137, 249, 268] for people with motor disabilities, communication for users with ASD [67, 84, 286] and DHH populations [212, 269, 288], etc. These priorities are further reinforced by how contributions are structured, with artifacts designed to address discrete problems and evaluated primarily through task performance or symptom reduction. As a result, relatively little attention is given to whether these interventions hold sustained meaning for users or how they shape everyday experiences beyond task completion.

Collectively, the framing of accessibility as functional correction and the reliance on short-term evaluation shape what is studied—and, importantly, what remains unexamined. One notable gap is the limited attention to disability as a dimension of identity. Similar to prior work [175, 184, 240], XR research on users with ASD often emphasizes alignment with neurotypical social norms, while DHH research focuses on improving access to hearing-centric communication. In both cases, there is comparatively little exploration of how XR systems might support identity-affirming interactions or reflect diverse cultural and communicative practices.

Similarly, creativity and leisure are rarely treated as primary objectives. When present, interactive systems—particularly games—are typically framed as therapeutic tools, such as exergames for rehabilitation [72, 163, 249] or platforms for behavioral training [130, 131, 167]. The possibility of engagement driven by enjoyment, exploration, or self-expression remains largely absent. This emphasis risks producing systems oriented toward compliance and intervention rather than intrinsic motivation or user-driven experiences.

While some studies address social interaction, particularly for older adults [167, 262, 292] and users with ASD [84, 174, 286], these efforts are often framed around reducing isolation or improving social competence. Consequently, the broader concept of belonging remains underexplored. Belonging extends beyond access, requiring XR environments to anticipate and value users' presence rather than accommodate it post hoc. For example, research on users with motor disabilities often emphasizes rehabilitation [25, 43, 244] and accessibility [93, 178, 210], yet rarely considers how XR social spaces can support inclusive participation and shared experiences. These patterns suggest an opportunity to expand XR accessibility beyond functional limitations toward a more holistic perspective encompassing identity, engagement, and belonging.

5.3 Community Representation

The distribution of XR accessibility research across disability communities is notably uneven, a pattern also observed in prior reviews [53, 175]. BLV users, older adults, and motor/physical disabilities dominate more than 60% of our literature combined, while populations such as people with IDD and those with mixed or multiple disabilities remain under-represented. This imbalance reflects broader structural dynamics in how accessibility research is initiated, funded, and evaluated [34, 39, 55, 175]. These dynamics directly influence who benefits from advances in XR technologies.

Several factors likely contribute to this concentration. First, BLV and older adult populations align with established assistive technology paradigms, such as screen readers [203], rehabilitation systems [154], and navigation aids [147], providing clear foundations for extending research into XR. Second, older adults receive sustained attention due to demographic trends [263, 283], as aging populations are a growing priority in healthcare [105, 252] and HCI [140, 141], particularly in the global West [105]. Third, BLV communities have established strong advocacy networks [199, 282] and research partnerships [14, 257], increasing visibility and easing participant recruitment for XR technologies. Fourth, motor/physical disability research benefits from established clinical rehabilitation paradigms, such as stroke recovery [249, 268], spinal cord injury, and neuromotor rehabilitation, where existing evidence, institutional infrastructure, outcome measures, protocols, and recruitment pathways make XR-based rehabilitation studies more feasible [15, 237, 277]. In contrast, populations such as people with IDD, multiple disabilities, or less visible conditions (e.g., ADHD, fibromyalgia, or CVD) present greater challenges in recruitment, consent, and evaluation design, which may discourage research under typical constraints.

Beyond differences in quantity, disparities also appear in the nature of research. Underrepresented communities are not only studied less frequently, but are also often examined through narrow and distinct problem framings. For example, in studies involving people with IDD, the focus is often on behavioral training or task-oriented outcomes, such as reducing fear of stairs [99], supporting vocabulary acquisition [117], or improving completion of predefined activities [108]. By contrast, studies involving people with multiple disabilities are more often organized around specific clinical cohorts or combinations of impairments, such as older adults with cognitive impairments [280] or stroke survivors with motor and cognitive disabilities [194]. These patterns reflect distinct forms of narrowing, such as framing users primarily through skills to be trained, behaviors to be improved, or diagnostic and clinical groupings. Although the mechanisms differ, both forms of narrowing leave broader lived experiences, everyday contexts, and self-determined needs underexplored. As a result, the scope of inquiry remains constrained and may reinforce the deficit-oriented perspectives identified earlier.

This narrow scope has important implications. For people with intersecting disabilities, insights from single-disability research are often insufficient. The lack of tailored XR research creates gaps that cannot be addressed through incremental extensions of existing work.

5.4 Structural Factors in Current Research Approaches

XR accessibility research is shaped by the commercial ecosystems in which it develops. Much of the literature clusters around a small set of widely available platforms. For example, VR studies rely on consumer headsets such as Meta Quest 2 and 3, Oculus Rift, and HTC Vive, and AR work largely centered on the Microsoft HoloLens. While this concentration lowers barriers to entry and supports reproducibility, it also ties research outcomes to the affordances and limitations of devices not designed with accessibility in mind [95, 106, 197]. As a result, interaction paradigms based on hand tracking, bilateral controllers, and visually dominant interfaces become normalized, potentially excluding users for whom these modalities are inaccessible.

Furthermore, across communities, the inclusion of secondary populations, such as non-disabled participants, specialists, and caregivers, in formative and core studies follows a consistent rationale. Examples include non-disabled users providing comparative baselines [115, 218, 288], specialists contributing domain expertise [256, 307, 309], and caregivers supporting ecological validity [64, 174, 286]. While these roles are valuable, they also reveal implicit assumptions about the intended audience and evaluative priorities of research. For example, when non-disabled participants evaluate empathy simulations, the focus often shifts toward improving their understanding rather than supporting disabled users. Similarly, when caregivers dominate formative design phases, systems may reflect caregiver workflows over disabled users' lived experiences. These patterns highlight the need to distinguish designing for disabled communities from designing about them, and to treat secondary participants as complementary.

Moreover, our corpus shows a strong preference for controlled, researcher-managed environments, with over 45% of studies conducted in laboratory or simulated settings. Usability testing and controlled experiments are the most common core methods, as they enable variable isolation and causal inference [151, 177]. However, this emphasis also introduces a gap between evaluation and real-world use. Systems that perform well under controlled conditions may not account for the variability and constraints of everyday life with a disability [112, 213, 243]. In contrast, field studies, which are better suited to capturing sustained use, contextual factors, and emergent barriers, remain relatively limited (Section 4.2.2). Consequently, the literature emphasizes ideal-condition performance over real-world adoption and sustained use. The limited field deployments in our corpus show that naturalistic studies reveal barriers that laboratory evaluations often cannot capture, such as post-study abandonment [38, 233], context-dependent changes in use [3, 195, 300], and social dynamics that emerge through sustained engagement [99, 173, 204]. In contrast, the broader literature often privileges controlled performance over real-world adoption, leaving unresolved whether XR accessibility systems retain value beyond the research setting.

5.5 Design Implications

Our analysis point toward a set of design implications for how XR systems should be built to be genuinely accessible. We further identify cross-cutting principles grounded in what the literature has collectively revealed about the relationship between XR design and disability.

5.5.1 Decouple Interaction from Normative Body Assumptions. Across motor, sensory, and cognitive disabilities, dominant XR interaction paradigms, including bilateral hand tracking, visually anchored interfaces, and spatial audio, create systematic barriers because they assume a normative body [197, 216, 278, 293]. Work on motion-range adaptation [278], one-handed interaction [293], and gaze- and switch-based input demonstrates that XR interactions can be redesigned, but these efforts remain fragmented. Future XR systems should support flexible, interchangeable interaction modalities, allowing users to engage through whichever motor, sensory, and cognitive resources are available without requiring disability-specific adaptations.

5.5.2 Build Multimodal Redundancy Into Core System Architecture. Across BLV, DHH, and motor disability research, the dominant accessibility strategy has been sensory substitution — replacing one modality with another [119, 121, 127, 164, 166]. While effective for specific communities, substitution-based design often remains inaccessible to users with multiple or intersecting disabilities. A stronger design principle could be multimodal redundancy, making information and interactions available through visual, auditory, haptic, and spatial channels so users can engage through their preferred modalities. Treating multimodal interaction as an architectural requirement would broaden XR accessibility across communities.

5.5.3 Design Feedback Systems for Cognitive and Sensory Diversity. Across cognitive disability, ASD, and IDD research, the design of feedback, how systems communicate state, error, progress, and instruction, emerges as a critical and undertheorized dimension of XR accessibility. Research on error feedback [143], mental load [81], and sensory regulation [35] shows that feedback effective for neurotypical users can overwhelm or confuse users with cognitive or sensory differences. XR systems can deliver feedback through multiple modalities, timing, and intensity levels, yet this flexibility is rarely used to improve accessibility. Feedback systems in future should support customizable modality, timing, and intensity, and be evaluated with cognitively and sensorially diverse users.

5.5.4 Leverage XR's Unique Affordances for Social Accessibility. Several notable studies use XR to restructure social environments rather than simply simulate the physical world. XR can make social cues perceptible [36], support non-speaking users [46], enable real-time sign language interpretation [49, 180], and provide inclusive avatars [17, 101], capabilities with few physical or screen-based equivalents. Yet they remain underdeveloped relative to the volume of work focused on task performance and rehabilitation. Future XR designs should leverage the medium to reshape social presence, embodiment, and communication around disabled users' needs rather than retrofitting accessibility.

5.6 Opportunities for Future Research

Based on our findings, future research should expand XR accessibility beyond deficit-oriented, task-completion models toward richer accounts of human experience. This means designing and evaluating XR systems that foreground identity expression, cultural belonging, and leisure as legitimate research objectives in their own right, not merely as secondary benefits of functional interventions. For disabled users across all communities, this requires developing evaluation frameworks that move beyond symptom reduction and task performance to capture meaning, sustained engagement, and self-directed use. Longitudinal, community-embedded studies would be particularly valuable for understanding how XR shapes identity and social belonging over time, rather than measuring discrete outcomes in controlled sessions.

Furthermore, future research should address imbalances in community representation by focusing on underrepresented populations, including people with IDD, multiple disabilities, and less-visible conditions such as ADHD and chronic pain. This requires developing ethical recruitment strategies, accessible consent processes, and evaluation frameworks appropriate for these groups, rather than defaulting to populations that are simply easier to recruit. Critically, supporting this shift requires investment in participatory and longitudinal approaches, along with evaluation criteria that value community diversity and real-world relevance over controlled performance metrics.

In addition, addressing structural constraints requires diversifying platforms and methods in XR accessibility research. Studies should engage with a broader range of hardware, including emerging and low-cost devices, and critically examine how dominant platform affordances constrain the accessibility questions researchers are able to ask. Methodologically, greater investment in field studies, in-situ deployments, and longitudinal designs would improve ecological validity and surface real-world barriers invisible to laboratory evaluation. Equally important is recentering disabled users as primary participants in both formative and evaluative phases, treating secondary participants as genuinely complementary rather than as proxies for disabled perspectives.

5.7 Limitations of Our Research Process

While our findings offer important insights, they should be interpreted within the context of several limitations. First, our literature search was limited to publications indexed in the ACM DL. While ACM DL is a primary venue for HCI research, this scope may exclude relevant work published in adjacent fields such as healthcare, rehabilitation, psychology, or computer vision. As a result, our analysis primarily reflects trends within HCI-oriented XR accessibility research rather than the broader interdisciplinary landscape.

Second, we restricted our corpus to full peer-reviewed papers (long and short formats), excluding posters, workshop papers, doctoral consortium, and other forms of emerging work. Although this decision ensures a focus on mature and complete contributions, it may omit early-stage innovations and exploratory ideas that often appear in these formats, potentially underrepresenting emerging directions in the field.

Third, the coding process was conducted by researchers who are non-disabled and within a limited age range (25–55). While we followed structured coding procedures and iterative discussions to improve consistency, our perspectives may introduce interpretive bias, particularly when analyzing research involving lived experiences of disability. This limitation underscores the importance of including diverse perspectives, including those of people with disabilities, in future analyses.

In short, these limitations highlight the scope and boundaries of our review and suggest opportunities for future work to expand across databases, publication types, and researcher perspectives.

6 Conclusion

This paper presented a systematic review of accessibility research in XR published in ACM DL spanning 2000–2025, analyzing findings across 245 publications. By examining targeted communities, addressed challenges, used technologies, contributions, and research methods, we provide a holistic view of how accessibility is conceptualized and operationalized in XR research. Our analysis reveals key patterns: uneven representation, functional framing, and reliance on small, lab-based studies. Our findings suggest that, despite progress in developing XR accessibility systems and interaction techniques, there remains significant scope for expansion. Future work should broaden community representation, extend accessibility beyond functional tasks to social and experiential dimensions, and adopt longitudinal, real-world methodologies to capture sustained use. Additionally, integrating cross-community insights and improving methodological consistency may support more generalizable and transferable design knowledge. By providing a structured overview, our work advances understanding of XR accessibility and informs the design of more inclusive, robust, and context-aware systems. This review provides a foundation for future research to advance XR accessibility in more holistic and impactful ways.

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A Publication Venue Abbreviations and Full Names

- ACIT = Applied Computing and Information Technology

- ASSETS = ACM SIGACCESS Conference on Computers and Accessibility
- AVI = Advanced Visual Interfaces
- CHI = Conference on Human Factors in Computing Systems
- CHCHI = Chinese CHI
- CHItaly = Conference of the Italian SIGCHI Chapter
- CHI PLAY = Computer-Human Interaction in Play
- DIS = Designing Interactive Systems
- DSAI = Digital Society and Artificial Intelligence
- ECCE = European Conference on Cognitive Ergonomics
- EICS = Engineering Interactive Computing Systems
- ETRA = Eye Tracking Research and Applications
- GoodIT = Information Technology for Social Good
- HAI = Human-Agent Interaction
- HEALTH = ACM Transactions on Computing for Healthcare
- i-CREATe = Rehabilitation Engineering & Assistive Technology
- ICBBT = International Conference on Bioinformatics and Biomedical Technology
- ICBRA = International Conference on Bioinformatics Research and Applications
- ICETC = International Conference on Education Technology and Computers
- ICIET = Information and Education Technology
- ICMHI = International Conference on Medical and Health Informatics
- ICMI-MLMI = Multimodal Interfaces and Machine Learning for Multimodal Interaction
- IDC = Interaction Design and Children
- IECC = International Electronics Communication Conference
- IHC = Brazilian Symposium on Human Factors in Computing Systems
- IMWUT = Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies
- IMX = Interactive Media Experiences
- Interacción = International Conference on Human Computer Interaction
- ISS = Interactive Surfaces and Spaces
- ISWC = International Symposium on Wearable Computers
- IUI = Intelligent User Interfaces
- IVA = Intelligent Virtual Agents
- JOCCH = Journal on Computing and Cultural Heritage
- Mindtrek = Entertainment and Media in the Ubiquitous Era
- MM = International Multimedia Conference
- MobiCom = Mobile Computing
- MundC = Mensch und Computer
- MUM = Mobile and Ubiquitous Multimedia
- OzCHI = Australian Conference on Human-Computer Interaction
- PACMHCI = Proceedings of the ACM on Human-Computer Interaction
- PETRA = Pervasive Technologies Related to Assistive Environments
- REHAB = Rehabilitation Research Techniques
- SIGGRAPH-ASIA = Computer Graphics and Interactive Techniques-Asia
- SUI = Spatial User Interaction
- SVR = Symposium on Virtual and Augmented Reality
- TACCESS = ACM Transactions on Accessible Computing
- TAP = ACM Transactions on Applied Perception
- TechMindSociety = Technology, Mind, and Society
- TIIS = ACM Transactions on Interactive Intelligent Systems
- TOCHI = ACM Transactions on Computer-Human Interaction
- TOMM = ACM Transactions on Multimedia Computing, Communications, and Applications
- UbiComp = Ubiquitous Computing
- UIST = User Interface Software and Technology
- UMAP = User Modeling, Adaptation and Personalization
- VINCI = Visual Information Communication - International Symposium
- VRCAI = Virtual Reality Continuum and its Applications in Industry
- VRIC = Virtual Reality International Conference
- VRISP = Virtual Reality, Image and Signal Processing
- VRST = Virtual Reality Software and Technology
- W4A = Web Accessibility

B Publication Venues Categorized as "Other"

Table 2: Publication venues categorized as "Other" by year, including associated references and number of publications each year from 2008 to 2025.

Year	Venues with Reference to the Publication	Number of Publications
2010	VRCAI [156], iCREATe [137]	2
2011	ACM SIGACCESS Accessibility and Computing [306]	1
2012	VRIC [191]	1
2014	UbiComp [250]	1
2015	VINCI [185]	1
2016	AVI [89], TOCHI [231]	2
2017	ICMI [218], CHItaly [20]	2
2018	TechMindSociety [29], VRCAI [301]	2
2019	MUM [33, 280], IDC [35], ACIT [110], VRCAI [251], ETRA [190], ICIET [296]	7
2020	AVI [267, 271], HEALTH [72], ICBRA [26], ICMI [56], ICIET [206], MuC [100]	7
2021	OzCHI [104], MuC [144], ISWC [207], Interacción [84], IHC [65], W4A [7, 51], GoodIT [2], ICMI [119]	9
2022	ISS [286], MuC [118], UMAP [182], IUI [158], TOCHI [245], ECCE [236], ICMHI [192], HAI [198]	8
2023	ISS [297], MuC [221], SA [115], IUI [261], ICETC [45], IMX [270], OzCHI [233], ICBBT [303], MobiCom [103], SUI [205], ISS [260], IECC [159], ICMI [244]	13
2024	W4A [113], TOCHI [78], ETRA [50], CHCHI [169], IHC [75], CHI PLAY [168], ICETC [284], DSAI [117], Mindtrek [76], ICBRA [80], IMX [77], SUI [232]	12
2025	SUI [256], IMX [99], GoodIT [268], TAP [230], VRISP [273], MUM [9], MM [161], TOMM [160], JOCCH [90], TIIS [200], IVA [153], TAP [120]	12