Mondragon Unibertsitatea Biblioteka Biblioteca

biblioteka@mondragon.edu

Etxabe-Antia, A., Beitia-Amondarain, A., González de Heredia-López de Sabando, A. *et al.* Characterisation of accessibility guidelines for digital technologies. *Univ Access Inf Soc* (2025). https://doi.org/10.1007/s10209-025-01214-6

This version of the article has been accepted for publication, after peer review (when applicable) and is subject to Springer Nature's AM terms of use, but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at:

https://doi.org/10.1007/s10209-025-01214-6

Characterisation of accessibility guidelines for digital technologies

Amaia Etxabe Antia[1*[0000-0001-7843-2274]], Amaia Beitia Amondarain[1[0000-0002-0787-5411]], Arantxa González De Heredia López de Sabando[1[0000-0003-4114-5700]], Daniel Justel Lozano[1[0000-0002-8302-4862]]

[1] Mondragon Unibertsitatea: Design Innovation Center (DBZ) - Faculty of Engineering Loramendi, 4; 20500 Arrasate - Mondragón (Gipuzkoa), Spain.

*Corresponding author(s). E-mail(s): aetxabea@mondragon.edu; Contributing authors: abeitiaa@mondragon.edu; agonzalezh@mondragon.edu; djustel@mondragon.edu

Abstract. In contemporary society, technological advances play a crucial role in daily life. Digital inclusion is essential to ensure that the maximum number of people benefit from the opportunities these technologies offer. However, this inclusion is not universally guaranteed, as technology can either act as a barrier or a facilitator depending on its design. This study aims to identify the characteristics of accessibility recommendations for digital technologies through a systematic literature review (SLR). Analysing 32 peer-reviewed articles, we identified 596 accessibility guidelines across various technologies, including ICT, Web/apps, immersive, robotics, and artificial intelligence. The findings highlight significant differences in accessibility recommendations between established and emerging technologies. Established technologies, such as ICT and Web/apps, often rely on widely recognized guidelines like WCAG, ADA, and Section 508, while emerging technologies tend to adopt user-centred design approaches. This difference underscores the need for more robust and specific accessibility guidelines tailored to the unique challenges posed by each technology. The results identify research gaps and propose future lines of study to enhance accessibility in the rapidly evolving technological landscape. We anticipate that this contribution will lead to the development of more accessible technological solutions, thereby promoting digital inclusion for everyone.

Keywords: accessibility guidelines, inclusive design, digital technologies, systematic literature review (SLR), digital inclusion, user-centred design.

1 Introduction

In the current digital era, the need for digital inclusion is evident, as the swift adoption of technological advancements has become crucial in daily life [1, 2]. Digital inclusion ensures that a wider population can gain access and the skills to use Information and Communication Technologies (ICT) effectively, safely, and meaningfully, to enable their full participation in the digital society [3–7]. The European Union has launched a Europe-wide initiative to guarantee that everyone can contribute to and benefit from the digital world [1].

Digital inclusion has positively impacted the quality of life and well-being of individuals [8–10]. This positive impact is reflected across various areas, including communication, the workplace, education, health, and personal finance:

- In the realm of communication, ICT plays a critical role in bridging distances [11] and strengthening social contact [12]. This helps reduce the risks associated with depression, loneliness, and social exclusion [13–16], which is especially important for individuals facing challenges in leaving their homes;
- In the employment sector, online work has led to improved job opportunities, which in turn expands learning and training opportunities [17];
- In the educational sphere, technology, such as tablets, has been shown to improve reading outcomes in students with intellectual disabilities, as well as reading comprehension and vocabulary in individuals with attention disorders [18]. Furthermore, it offers greater freedom to explore content independently [19];
- Within the healthcare sector, ICT offers greater accessibility and efficiency in health services [10], allowing monitoring of health issues such as diabetes, asthma, and weight control. A positive impact on mental health improvement has also been observed with the use of ICT [15], which is associated with a reduction in dementia and enhances cognition and functional ability. In the case of Alzheimer, the use of technologies has been positively linked with preventive behaviours against the disease [20];
- As for personal finance, digital inclusion facilitates better tracking of income and expenses [21].

However, it is important to note that not everyone can fully leverage the benefits of digital resources [8, 22]. In fact, certain people risk being isolated from the digital society if they do not develop the skills that allow them to take advantage of technological advancements [16]. As a result, the concept of the digital divide emerges, which can limit opportunities and participation for individuals based on their differences, thereby increasing marginalisation and inequality among groups [23–25]. Therefore, addressing the digital divide is key to removing one of the main obstacles to full and effective inclusion.

1.1 The digital divide

The digital divide is a complex, dynamic, and evolving multidimensional phenomenon [6, 26]. Although the term initially referred to ICT, this concept can be extended to other emerging technologies and their impact on society. Currently, it is conceived as the inequality between individuals, communities, or countries in terms of access or the ability to leverage the benefits that technological evolution can offer [9, 27, 28]. As technology and society progress, three levels of the digital divide have been defined, shown in the Figure 1, illustrating: access to technologies at the first level, their use at the second level, and the outcomes achieved at the third level [29].

At the first level - technology access - the digital divide refers to the "gap between those who have and those who do not have access to technologies" [6]. This level can be influenced by factors such as infrastructure, the availability of devices, cost, user cultural and social context, and even the legal and policy frameworks in place [4, 6, 30]. As access to digital resources becomes more widespread, the definition of the digital divide has expanded to include factors such as content accessibility, user knowledge and skills, interface design, user experience and digital literacy [31, 32]. This has given rise to the second-level digital divide, which concerns individual skills and effective utilization of technologies [31, 33]. However, it is now acknowledged that merely having access and using technologies is insufficient to leverage their full potential [34]. Consequently, a third level of the digital divide has been defined, which considers the outcomes and consequences of using digital technology [25, 35, 36]. This third level considers the extent to which individuals can meaningfully integrate technology into their daily lives to fully benefit from it. Key factors influencing this level include the depth and breadth of use, user engagement, community support, and other aspects of sustained interaction with digital resources [7, 34].

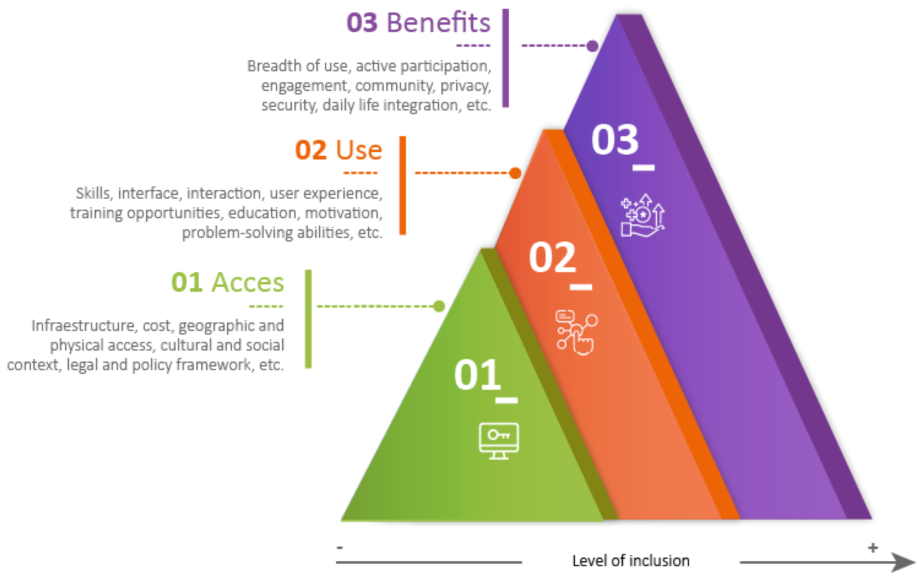


Fig. 1 Levels of the digital divide

For most individuals, technology simplifies life. However, for people with disabilities, accessible technology enables possibilities that were otherwise unattainable [8]. This underscores the critical importance of the digital divide for individuals with disabilities, as it can deprive them of independence and opportunities in education, employment, social networking, and mobility [9, 37]. Conversely, accessible technology can enhance their quality of life and mitigate the severity of their disabilities. In certain contexts, particularly within the workplace, technology serves as an equalizer, offering individuals with disabilities equitable conditions for competition [38]. For those with developmental disabilities, technology provides a safe, controlled, and predictable learning environment [39]. Therefore, for many individuals with disabilities, access to technology is not merely a convenience but an essential means to perform critical tasks [40]. Despite having access to technological tools, these individuals often encounter the second level of the digital divide, where they are unable to fully utilize the available technologies [33, 41].

Similarly, older adults represent a vulnerable group that could be deprived of the benefits of digital inclusion [42, 43]. Access to technology not only promotes the well-being of older adults but also compensates for the losses - physical, emotional, or social - associated with the aging process [44]. This has a negative impact on independent living and aging actively and with dignity [12, 45–48]. Therefore, the lack of digital inclusion is creating a health divide that has become one of the social determinants of health in older adults [45].

1.2 Digital technologies

Although the digital divide is a reality for millions of people, technologies hold the potential for inclusion [49]. The rapid evolution of technology is transforming tools for older adults and individuals with disabilities from assistive technologies to augmentative technologies, enhancing cognitive, physical, social, and aesthetic aspects of life [50]. Gandy et al. [50] question whether disabilities will continue to be viewed as specific limitations or if we will begin to recognize that every individual has characteristics they seek to improve or modify through technology.

However, technologies are not always accessible. Immersive experiences, such as augmented reality (AR) and virtual reality (VR), present a significant risk of exclusion due to their immersive nature [51]. These technologies often assume the ability to perform gestures, use both hands simultaneously, rotate the head and torso, or point at objects within a scene [52]. Additionally, it has been observed that VR glasses, for example, do not fit children properly [53]. Subtitles that are understandable on rectangular 2D screens can also pose challenges in an immersive environment [51].

Ensuring that immersive experiences are inclusive is as crucial as making the physical environment accessible to everyone [54, 55]. These technologies can serve as tools for empathy, highlighting deficiencies and fostering a better understanding of the challenges faced by individuals [56]. Inclusive virtual worlds reinforce a sense of community among participants, regardless of their abilities [57]. Achieving this requires a reconsideration of existing accessibility features for immersive formats from the early stages of design to develop barrier-free immersive environment [55].

Artificial intelligence (AI) is another emerging technology that can either reduce or exacerbate disparities and inequalities depending on its application. Microsoft highlights the role of AI in narrowing the digital divide for all people, provided that accessibility is addressed from the design phase [58]. However, Microsoft acknowledges that the inclusiveness of AI largely depends on the diversity and representativeness of the data it is trained on.

Addressing the limitations inherent in training data is crucial not only in AI but also other technologies, especially when this data lacks diversity and does not represent vulnerable populations. According to the Washington Group on Disability Statistics, data related to vulnerable populations, such as people with disabilities, is often scarce and inconsistently collected across countries [59]. This inconsistency complicates the comparison and integration of data, hindering efforts to develop inclusive systems. Given that digital technologies rely on large datasets, it tends to reproduce and even amplify existing biases if methods to mitigate the lack of inclusive data are not implemented. To address this, promoting collaborations with specialized organizations, such as the Washington Group on Disability Statistics, could support this goal by providing expertise on inclusive data practices. Techniques like data augmentation could also be employed to simulate diverse populations, compensating for the lack of representative data when necessary [60]. Until data collection practices become more inclusive and diversity is naturally embedded in datasets, it is essential for designers to be particularly aware of these issues. They should have access to tools, guidelines, and best practices to address inclusivity from the initial stages of digital system design.

Other emerging technologies, such as smart homes, wearables, and robots, are also expanding and are expected to continue growing, particularly in light of the aging population [61]. To ensure their accessibility, these technologies must be designed with Inclusive Design principles from the earliest stages [62]. This approach will transform technologies from being merely assistive to becoming augmentative, benefiting everyone.

1.3 Inclusive Design

Fortunately, the digital divide is increasingly preventable, as solutions designed with consideration of the needs of people can bolster digital inclusion [49]. As the World Health Organization states, systems need to be designed from a Universal Design philosophy [63] and it might also be beneficial to apply gerontological design principles [64]. In this sense, the digital divide can be partially addressed through Inclusive Design [65]. According to the standard BS 7000-6:2005 [66], Inclusive Design is the design of products, services, and environments that are accessible and usable by as many people as reasonably possible, regardless of age, sex/gender, sensory, cognitive and physical capabilities, and cultural background, without the need for adaptation or specialized design. Therefore, Inclusive Design considers diversity from the start of the design process, making technology adapt to the needs of people rather than requiring people to adapt to it [9, 62].

Despite the importance of accessibility, it is often overlooked during the early stages of design [62]. This oversight largely stems from a market perception that views accessibility as merely a set of compliance requirements, rather than as an opportunity to expand market reach and enhance the experience for all users. Research indicates that incorporating accessibility from the outset not only reduces the likelihood of costly and complex modifications later in development but also contributes to a more inclusive product that benefits a wider range of users [67]. This same research demonstrates that designs prioritizing accessibility yield higher user satisfaction and broader market potential, underscoring the strategic value of accessibility beyond compliance.

To address this, Human-Centred Design (HCD) provides a framework where users are actively involved throughout the design process. From needs analysis to co-creation and user evaluation sessions, HCD ensures that products are designed with a deep understanding of user needs [68]. However, while HCD is essential for meaningful accessibility, it can be resource-intensive demanding significant time, cost, empathy, and expertise [69].

In this context, incorporating pre-established accessibility guidelines can enhance the efficiency and effectiveness of HCD tools. By providing clear and structured principles, these guidelines allow design teams to focus more on user engagement and iterative improvements, rather than spending time debating basic accessibility principles. Although interactions with vulnerable populations are essential from an HCD perspective, employing predefined guidelines can improve the quality and impact of these interactions.

Accessibility guidelines provide support throughout the entire design process, starting from the earliest stages, by establishing a solid foundation for accessibility. They facilitate the ideation phase by helping to incorporate the accessibility features defined in the initial stages, aiding in the creation of concepts that are inclusive. Furthermore, these guidelines remain important in the later, more detailed phases of development and implementation, where they help define technology attributes and parameters that address the diverse range of user characteristics [70]. This approach not only reduces reliance on the experience or sensitivity of individual designers but also optimizes resource use by providing a standardized foundation for designers to build upon [71].

Although there are known accessibility recommendations for ICT and the web [72], to the authors knowledge, there has been limited analysis on how these guidelines are structured and defined to ensure that accessibility in future emerging technologies does not rely on the personal experience and sensitivity of the designer. Therefore, this paper presents a Systematic Literature Review (SLR) to identify the characteristics of recommendations for accessible digital technologies.

By doing so, it seeks to identify potential gaps and establish a foundational starting point for making emerging technologies accessible from the initial phases of design. This effort will help ensure that accessibility is prioritized early on, thereby reducing the need for costly modifications later.

2 Research methodology

The primary purpose of this literature review is to collect and analyse the characteristics of guidelines and recommendations that support the accessible design of digital technologies from the perspective of Inclusive Design. To this end, a SLR, which identifies and analyses all research works published until May 2024 was conducted. This approach aims to ensure comprehensive and rigorous coverage of the existing literature in the field of study.

The literature review was conducted by following the methodological procedure outlined by Kitchenham et al. [73] and the recommendations provided by Carrera-Rivera et al. [74]. These guidelines encompass several components including: (1) the formulation of research questions (RQ), (2) the process of searching and selecting data/information sources, (3) the establishment of inclusion/exclusion criteria for the selection of documents, (4) the development of the systematic review strategy, and finally, (5) the execution of data extraction and synthesis. Each of these phases is presented below.

2.1 Research questions

Within the framework of this SLR, two fundamental research questions were formulated. These questions guide the identification and extraction of the necessary data elements to address the objectives of this study. Table 1 presents the research questions.

Table 1 Research questions

ID	Research questions
RQ-1	What are the characteristics of accessibility guidelines for digital technologies?
RQ-2	How are new accessibility guidelines for different digital technologies defined?

In this context, it is essential that accessibility recommendations aim to include as many people as reasonably possible, thereby addressing discrimination and ensuring an equivalent user experience for all individuals. While some recommendations may enhance usability, resulting in a more effective, efficient, and satisfactory design, it is important to acknowledge that usability does not necessarily equate to accessibility [75]. A system can be usable but not accessible. Therefore, the objective of the recommendations identified in this article is to ensure that technologies are designed to be used by the widest possible range of people without requiring specific adaptations.

2.2 Data/Information sources

Scholars use varying terms to describe the concepts under study. Therefore, a combined search was conducted covering four groups of keywords, focusing on accessibility, digital technologies, guidelines, and Inclusive Design. The terms presented in Table 2 were used in the search for information.

Table 2 Search keywords

Search term	Keywords
Digital inclusion	"accessib*" OR "inclusiv*" OR "equit*" OR "enabl*" OR “diversi*”
Digital technologies	"artificial intelligence" OR "vr" OR "mr" OR "xr" OR "ar" OR "virtual reality" OR "augmented reality" OR "mixed reality" OR "extended reality" OR "immersive technologies" OR "emerging technologies" OR " robot*" OR "metaverse" OR "AI" OR "new technolog*" OR "cutting edge technolog*" OR "innovative technolog*" OR "digital technolog*" OR "information technolog*" OR "communication technolog*”
Guidelines	"protocol" OR "standard*" OR "practi*" OR "recommendation*" OR "guidelin*" OR "procedure*" OR "framework" OR "directive*" OR "criteri*" OR "rule*" OR "instruction" OR "methodolog*”

Search term	Keywords
Inclusive design	"inclusive design" or "universal design" or "design for all"

Thus, the following main search string was constructed:

("accessib*" OR "inclusiv*" OR "equit*" OR "enabl*" OR “diversi*”) AND ("artificial intelligence" OR "vr" OR "mr" OR "xr" OR "ar" OR "virtual reality" OR "augmented reality" OR "mixed reality" OR "extended reality" OR "immersive technologies" OR "emerging technologies" OR " robot*" OR "metaverse" OR "AI" OR "new technolog*" OR "cutting edge technolog*" OR "innovative technolog*" OR "digital technolog*" OR "information technolog*" OR "communication technolog*”) AND ("protocol" OR "standard*" OR "practi*" OR "recommendation*" OR "guidelin*" OR "procedure*" OR "framework" OR "directive*" OR "criteri*" OR "rule*" OR "instruction" OR "methodolog*”) AND ("inclusive design" or "universal design" or "design for all")

The electronic databases used for the search are shown in Table 3.

Table 3 Databases, search dates and number of results obtained

Data bases	Area	Date search was carried out	No. of results
Web of Science	Interdisciplinary	12/05/2024	149
Scopus	Interdisciplinary	14/05/2024	166
ACM Digital Library	Computing and information technology	18/05/2024	246
Compendex	Engineering	14/05/2024	120

2.3 Literature search

The search was conducted in each database up to the month of May 2024. The search string was adapted in accordance with the requirements of each database, as detailed in Table 3. Additionally, two further criteria were incorporated into the search through advanced search options (Table 4).

Table 4 Additional criteria incorporated in advanced search options

Criteria	Code	Description
Limited quality	LQ	Limit the search to publications that are articles, reviews, or book chapters
Limited language	LL	Limit the search to publications primarily written in English or Spanish

A total of 681 articles were identified, with approximately half of them found in the ACM Digital Library database, which focuses on the fields of Computing and Information Technology.

2.4 Literature selection

Following the guidelines proposed by Carrera-Rivera et al. [74], the next step involved literature selection. Inclusion and exclusion criteria were applied to ensure that all studies selected were directly related to Inclusive Design recommendations for digital technologies.

Criteria for inclusion/exclusion. Table 5 outlines the inclusion and exclusion criteria applied during the literature selection. Initially, duplicate articles (DP) were identified. Following this step, article selection was carried out through the review of titles and abstracts, considering the inclusion criteria of direct relevance (DR) and partial relevance (PR), and the exclusion criterion for loosely related articles (LR1). After reading the full text, publications that did not provide any Inclusive Design or accessibility recommendations (LR2) were also identified and excluded.

Table 5 Inclusion and exclusion criteria

I/E	Criteria	Code	Description
Exclusion	Loosely related	LR 1	An abstract indicates that the full text of the article does not respond to any research question
		LR2	After reading the full text, does not respond to any research question
	Duplicated publication	DP	A paper is duplicated on the different studied databases
Inclusion	Directly related	DR	An abstract indicates that the full text of the article responds to the three research questions
	Partially related	PR	An abstract indicates that the full text of the article responds at least one of the research questions

Systematic process review. Figure 2 illustrates the flow of the SLR process aimed at addressing the research topic and minimizing subjectivity and bias. In the first phase, a total of 681 articles were identified, of which 104 were found to be duplicates and therefore discarded. In the second phase, titles, abstracts, and keywords were read considering the inclusion and exclusion criteria defined earlier (Table 5). A total of 577 titles and abstracts were reviewed, of which 491 were discarded. Thus, a total of 90 articles were read in full text. During this process, 36 publications were identified that did not provide any recommendations. Additionally, among those that included recommendations, 22 publications did not include accessibility and were thus excluded. Consequently, 32 publications were selected for in-depth analysis, data extraction, and synthesis.

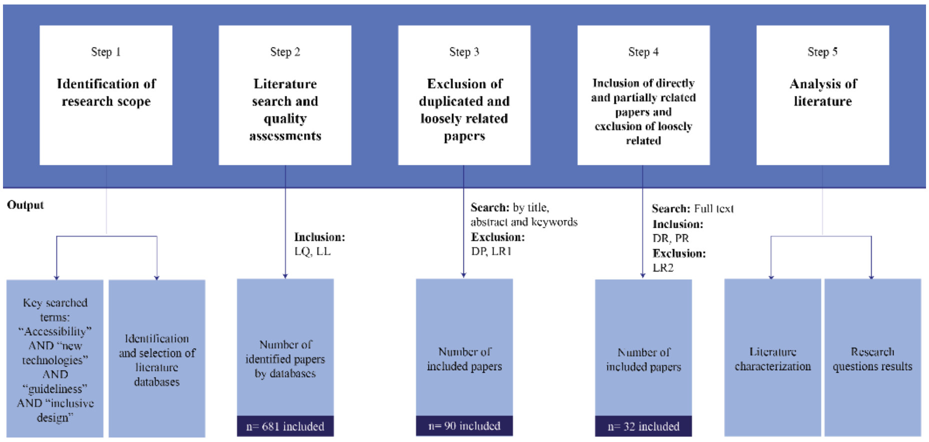


Fig. 2 Data collection process

3 Results

3.1 Literature characterisation

This section presents a quantitative overview of the selected works, addressing research trends, the most cited publications, as well as the journals and their impact.

Evolution in the Field. As shown in Figure 3, the earliest identified article dates back to 1988 [76], marking the beginning of work on interface systems for people with disabilities. Initially, the earliest articles focused on ICTs, websites, and their applications, including one related to robots [77] and a book on virtual reality [78]. However, from 2016 onwards, an upward trend becomes evident, with more than 56.2% of all analysed publications.

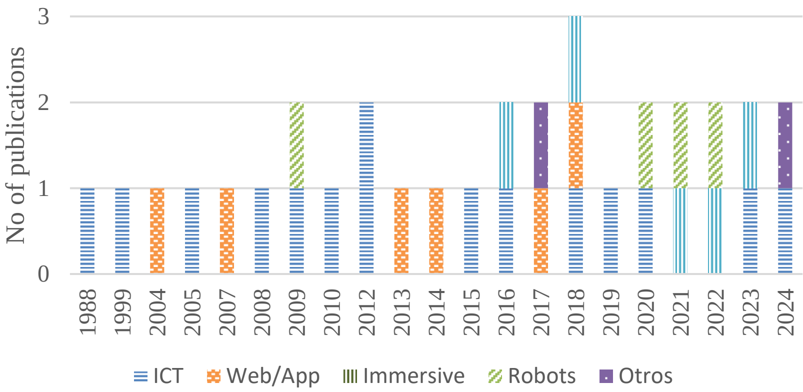


Fig. 3 Number of articles published during the years

In the past eight years, while the initial trend of working on ICT accessibility persists, representing 33.3% of the publications, there is also a noticeable increase in research on accessible immersive technologies, which account for 27.7% of all publications. Research addressing recommendations for accessible robots follows with 16.6% of the publications in this technology. The remaining publications focus on applications and websites and a variety of other technologies such as interactive television and AI.

Nature of Journals. The journal that recorded the highest number of identified articles, totalling three, is "Universal Access in the Information Society". This international interdisciplinary journal is dedicated to exploring the accessibility, usability, and acceptability of technologies in the information society, ensuring their universal accessibility in terms of time, place, medium, and device for any individual. According to Guanyu Li et al. [2], this journal is a leader in cited publications in the field of Design for Digital Inclusion (DfDI).

Additionally, two articles were identified in "ACM Transactions on Computer-Human Interaction," a world-renowned conference on human-computer interaction (HCI) that addresses how people interact with technology and how to design this interaction to be more effective, efficient, and satisfying. Another two publications were found in "Paladyn," which explores the analogy between robotic autonomy and human behaviour. Two articles were also identified in "PLoS ONE," a multidisciplinary science journal, and in "Translation Studies," within the field of translation. The journals in which two or more publications were identified are presented in Figure 4.

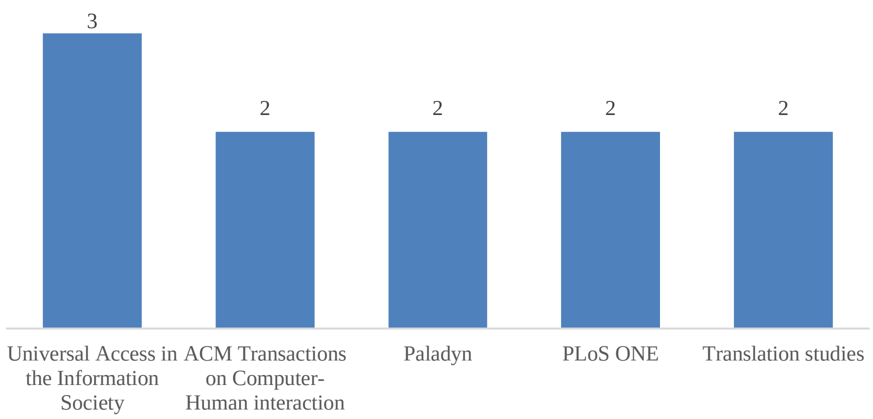


Fig. 4 Journals in which two or more articles have been identified

Regarding the impact of the publications, Table 6 shows the quartile distribution of all the collected journals. Of the total, 33.3% of the publications belong to Quartile 1, 40.7% to Quartile 2, nearly 19% to Quartile 3, and 7.4% to Quartile 4.

Table 6 Impact of journals identified (SJR: Schimago Journal Rank)

Journal	Quartile	SJR 2024
ACM Sigchi	Q3	0.35
ACM Transactions on accessible computing	Q2	0.57
ACM Transactions on computer human interaction	Q2	0.84
Assistive Technology	Q2	0.35
British Journal of Educational Technology	Q1	2.11
Computers in human behaviour	Q1	2.46
Disability and rehabilitation: assistive technology	Q2	0.5
EAI Endorsed transactions on energy web	Q4	0.21
Electronics	Q2	0.62
Frontiers in Education	Q2	0.62
Interacting with computers	Q2	0.36
International journal of education and information technologies	Q1	1.24
International journal of Emergency management	Q3	0.18
International journal of information and learning technology	Q2	0.66
International Journal of modern education and computer science	Q3	0.29
Journal of educational technology and society	Q1	1.04
Paladyn	Q3	0.47
PLoS ONE	Q1	0.88
PS Political Science and Politics	Q1	0.83
Robotics	Q1	0.81
SN Computer Science	Q2	0.6
Technology and disability	Q3	0.19
Telecommunication Journal of Australia	Q4	0.10
Telematics and informatics	Q1	1.87
Translation studies	Q1	0.73
Transportation research record	Q2	0.62
Universal access in the information society	Q2	0.75

Number of Citations per Article. The most cited article is by Abascal et al. [40] with 286 citations. The second most cited article, with a total of 142 citations, is by Zallio & Clarkson [55]. In third place is the publication by Sevilla et al. [79], with a total of 103 citations. Table 7 provides details of the 10 most cited articles identified in this review, together with their year of publication and author.

Table 7 10 most citated papers, retributive from May 2024

Ref.	Paper title	Authors	Year	No. of citations
[40]	Moving towards inclusive design guidelines for socially and ethically aware HCI	Abascal J, Nicolle C	2005	286
[55]	Designing the metaverse: A study on inclusion, diversity, equity, accessibility and safety for digital immersive environments	Zallio M, Clarkson PJ	2022	142
[79]	Web accessibility for individuals with cognitive deficits: A comparative study between an existing commercial Web and its cognitively accessible equivalent	Sevilla J, Herrera G, Alcantud F	2007	103

Ref.	Paper title	Authors	Year	No. of citations
[80]	Web site accessibility: what logo will we use today?	Witt N, Mcdermott A	2004	55
[81]	Whiteboard: Synchronism, accessibility, protagonism and collective authorship for human diversity on Web 2.0	Santarosa L, Conforto D, Machado R	2014	42
[75]	Accessible and usable websites and mobile applications for people with autism spectrum disorders: A comparative study	Dattolo A, Luccio F	2017	34
[82]	Attuning speech-enabled interfaces to user and context for inclusive design: Technology, methodology and practice	Neerincx M, Cremers A, Truong K	2009	32
[53]	Accessible play in everyday spaces: Mixed reality gaming for adult powered chair users	Seaborn K, Edey J, Fels D	2016	28
[83]	Audio description in 360º videos	Fidyka A, Matamala A	2018	28
[61]	A proposal of accessibility guidelines for human-robot interaction	Qbilat M, Iglesias A, Belpaeme T	2021	27

3.2 Characteristics of accessibility recommendations for digital technologies

In response to RQ-1, which seeks to identify the characteristics of accessibility recommendations applicable to digital technologies, the articles are presented in Table 8 for this analysis. This table sets out articles containing guidelines designed to address discriminatory aspects and promote accessibility.

For the analysis, recommendations were extracted from the 32 identified articles and classified according to the technologies they address. The category of ICT is the most represented, with 14 articles covering applications ranging from health and education to cyber infrastructure and emergency communications. Web/apps also have significant representation with 6 articles. Immersive technologies and robots follow with 5 and 4 articles, respectively, highlighting the growing importance of these emerging technologies in digital inclusion. Additionally, a category labelled "Others" was classified, encompassing 2 articles that include various technologies such as interactive TV and AI.

Regarding the scope of the guidelines, it is noteworthy that the majority of the references are primarily identified in the education sector, with 11 references coming from this field. This indicates a concentration of efforts in the literature to make educational technological environments accessible. The next most common field is health, with 5 references, mainly focusing on the personalization of technologies for older adults. The field of games is represented with 2 references, emphasizing the importance of accessibility in this area as well.

As recommended in Inclusive Design, 87.5% of the references consider the diversity of the population when proposing accessibility recommendations. Among these, people with disabilities are the most frequently addressed group, followed by older adults. Specifically, within the category of people with disabilities, 11 references focus on disabilities in general, while others address specific capacities: 7 references focus on visual impairments, 6 on cognitive disabilities, 1 on hearing impairments, and 2 on motor disabilities. Additionally, 4 references target specific cases within cognitive disabilities, such as dementia, autism spectrum disorders, developmental disabilities, and difficulties with reading and writing.

When analysing the recommendations by considering the type of technology and the target audience, specific patterns emerged. Immersive technologies, such as virtual reality, focused on individuals with visual, auditory, and motor disabilities. For instance, references [84] and [83] addressed virtual reality for people with visual impairments, while reference [85] centred on extended reality for individuals with auditory impairments. Similarly, reference [53] discussed mixed reality for people with motor disabilities.

Table 8 References for the SLR: technology classification, number of guidelines, field, target and total guidelines with percentage per technology

Ref	No. of guidelines	Field	Target
ICT			
[16]	18	Education	People with cognitive disabilities
[33]	13	Cyber infrastructures	People with disabilities
[40]	16	-	People with disabilities
[76]	7	Education	Children with disabilities
[82]	12	Voice technologies	People with sensory, physical, cognitive disabilities, and allergies
[86]	6	Health	Older adults
[87]	42	Distance communication	People with cognitive disabilities affecting reading and writing
[88]	31	Education, games	People with visual impairments
[89]	13	Education	People with visual impairments
[90]	28	Education	Students
[91]	4	Emergency communications	-
[92]	12	Traveller information systems	People with sensory and/or cognitive disabilities
[93]	47	Video calls	People with dementia
[94]	9	Education	People with visual impairments
[95]	22	Education	Students with disabilities
Total	**280 (47%)**		
Web/apps			
[39]	40	Education, gesture interaction	People with developmental disabilities
[75]	27	-	People with autism spectrum disorders
[79]	20	E-commerce	People with cognitive disabilities
[80]	5	Education	-
[81]	15	-	People with disabilities
[96]	58	-	People with disabilities
Total	**165 (28%)**		
Robotics			
[61]	18	Home	People with disabilities: vision, hearing, cognition, mobility
[97]	9	Health, rehabilitation	Older adults, people with disabilities
[98]	7	Health, exoskeletons	People with motor disabilities
[99]	56	Voice interfaces	People with visual impairments
	90 (15%)		

Ref	No. of guidelines	Field	Target
Immersive technologies			
[53]	10	Games, mixed reality	People with motor disabilities
[55]	10	Metaverse	Experts
[84]	8	Virtual Reality, 360º videos	People with visual impairments
[83]	3	Virtual Reality, 360º videos	People with visual impairments
[85]	12	Education, extended reality	People with hearing impairments
Total	**43 (7%)**		
Others			
[100]	10	Home, interactive TV	People with visual impairments
[101]	8	Education, augmented intelligence	People with disabilities
Total	**18 (3%)**		

On the other hand, ICT generally addresses people with disabilities without specifying a particular type of disability, as 8 out of the 15 references target this group broadly. In the field of education, the guidelines apply to a variety of disabilities, both general and specific, such as visual and cognitive impairments. However, in the health sector, the guidelines are more focused on older adults. This reflects the diversity of accessibility needs across different technological contexts and target groups.

When focusing on the source of the identified guidelines, Table 9 reveals that 25 references recommend design approaches such as HCD, Universal Design principles, Inclusive Design, and Design for All. These approaches often employ tools like focus groups, interviews, user journeys, user analysis, observations, and workshops. This trend is particularly evident in more recent technologies like immersive and robots. Notably, all five references related to immersive technologies utilize design approaches for generating guidelines, similar to the references concerning robots.

Mature technologies, such as ICT and web/apps, tend to rely on more established sources of accessibility guidelines. For example, the Web Content Accessibility Guidelines (WCAG) is the most cited source, with 7 references in ICT and 6 in web/apps. Additionally, even though WCAG is not primarily oriented towards robots, there is also a reference that proposes accessibility guidelines for robots based on WCAG.

Furthermore, although most sources originate from the field of accessibility, it is important to highlight those other domains, such as usability, have also been referenced for defining accessibility guidelines.

Thanks to the analysis of the 32 publications, a total of 596 accessibility guidelines applicable to digital technologies were compiled. As shown in Table 8, the ICT category comprises the largest number of guidelines, totalling 280 and representing 47% of the set. The "Web/app" category follows with 27.5% of the total, amounting to 165 guidelines. Robots constitute 15% with 90 guidelines. The category of immersive technologies accounts for 7% with a total of 43 guidelines. The smallest number of guidelines were found in the "Other" category, with 18 guidelines, representing 3% of the total.

Table 9 Guideline sources

Domains	Guideline sources	Ref.	ICT	Web/app	Robots	Immersive	Others
Accessibility	WCAG	[72]	7	6	1	-	-
	Americans with Disability Act (ADA) of 1990	[102]	3	-	-	-	-
	Section 503 of the Rehabilitation Act of 1973	[103]	1	-	-	-	-
	Section 504 of the Rehabilitation Act of 1973	[104]	1	-	-	-	-
	Section 508 of the Rehabilitation Act of 1973	[105]	2	-	-	-	-
	EN 301 549	[106]	1	-	-	-	-
	Game Accessibility Guidelines (GAG)	[107]	1	-	-	-	-
	ATAG	[108]	-	1	-	-	-
	BBC	[109]	-	-	1	-	-
	Funka Nu	[110]	-	-	1	-	-
	IBM	[111]	-	-	1	-	-
	WAI-ARIA[112]	-	-	1	-	-	
	PUX	[113]	-	-	1	-	-
	ADLAB Guidelines	[114]	-	-	-	1	-
	Guidelines for the design of accessible information and communication technology systems	[115]	-	-	-	-	1
Usability	Usability guidelines for PDAs	-	1	-	-	-	-
	Play – the Desurvire's Heuristics for good usability in games	[116]		1	-	-	-
	Usability guidelines. U.S. Department of Health & Human Services	[117]		1	-	-	-
	Nielsen Norman Group Usability Heuristics	[118]	-	1	-	-	-
	Guidelines for Easy Navigation Design	-	-	1	-	-	-
	Digital TV usability checklist	[119]	-	-	-	-	1
Design approaches	Human-centred design (HCD)	[120]	1	1	2	4	1
	Universal Design Principles	[121]	3	1	1	-	-
	Universal Design for Learning Guidelines	[122]	4	-	-	-	-
	Universal Design in Instruction Principles	[123]	1	-	-	-	-
	Inclusive Design	[124]	2	-	1	1	1
	Design for All guidelines	[125]	1	-	-	-	-
Others	Gee's learning principles from good games	[126]	1	-	-	-	-
	Google general principles of mobile app design	[127]	-	1	-	-	-

In addition to categorizing the recommendations by type of technology, some identified guidelines have been organized into various subgroups in their original articles. 11 references have been identified that classify the guidelines in this manner. For example, in the field of ICT technologies, Datollo A. et al. [16] classified the recommendations into three groups: (1) Content and navigation, (2) Online navigation, and (3) Game features. Other authors used more recognized categorizations such as the principles of Universal Design [93], which include (1) Equitable use, (2) Flexible use, (3) Simple and intuitive use, (4) Perceptible information, (5) Tolerance for error, (6) Low physical effort, and (7) Appropriate size and space for approach and use. In the same technology, Taylor M. et al. [94] proposed following the same classification of the seven principles of Universal Design, adding three additional categories: (8) Perceptible, (9) Community, and (10) Context. Continuing with Universal Design, Varoneis E. et al. [90] suggested creating subgroups based on the type of disability they support [90], namely, Universal Design for (1) Visual, (2) Auditory, (3) Motor, and (4) Cognitive disabilities. Similarly, Qbilat M. et al. [61] proposed classifying accessibility guidelines generated for robots according to the WCAG principles, grouping the guidelines into (1) Perceivable, (2) Operable, (3) Understandable, and (4) General.

Table 10 Specific classification in origin articles

Type of technology	Ref.	Classification subgroups
ICT	[16]	(1) Content and navigation, (2) Online navigation, (3) Game features
	[87]	(1) General aspects, (2) Access to standard technology devices, (3) Access to websites, services, and applications, (4) Alternative access, (5) General aspects of assistive technologies, (6) Augmentative and alternative communication (ACC) and remote communication
	[90]	Universal Design for (1) Visual disabilities, (2) Auditory disabilities, (3) Motor disabilities, (4) Cognitive disabilities
	[93]	7 Principles of Universal Design: (1) Equitable use, (2) Flexible use, (3) Simple and intuitive use, (4) Perceptible information, (5) Tolerance for error, (6) Low physical effort, (7) Appropriate size and space for approach and use
	[94]	7 Principles of Universal Design: (1) Equitable use, (2) Flexible use, (3) Simple and intuitive use, (4) Perceptible information, (5) Tolerance for error, (6) Low physical effort, (7) Appropriate size and space for approach and use, (8) Perceptible, (9) Community, (10) Context
	[95]	(1) Physical action, (2) Perception, (3) Engage interest, (4) Language and symbols, (5) Comprehension, (6) Sustaining effort and persistence, (7) Self-regulation, (8) Communication
Web/app	[39]	(1) Application design, (2) Research study design, (3) Context guidance
	[75]	(1) Graphic design, (2) Structure and navigation, (3) User, (4) Language
Robots	[61]	WCAG: (1) Perceivable, (2) Operable, (3) Understandable, (4) General
	[99]	(1) Dialogue content, (2) Social manners, (3) Aesthetics and anthropomorphism, (4) Support for passive users, (5) Short commands, (6) Individualization, (7) Speech recognition and output
Immersive technologies	[53]	(1) Controls, (2) Display, (3) Context, (4) Mechanics, (5) Multimodality

Following the approach outlined by Varoneis E. et al. [90], this article categorizes the recommendations based on the abilities they impact. According to Goodman-Deane J. et al. [128], grouping guidelines based on individual abilities facilitates their application in the field of accessibility. The established groups focus on the primary capacities required to interact with a product, service or environment: vision, hearing, cognition, dexterity, mobility, and touch [129, 130]. A guideline is considered to affect a capacity when it reduces the demand on that capacity, thereby improving the accessibility of the technology and expanding the group of people who can benefit from it. In addition to these groups, three additional categories have been created: "general", "other", and "discarded":

- General: Recommendations with broader application, where their implementation reduces the demand on four or more capacities;
- Other: Recommendations that impact capacities indirectly or consider other aspects;

- Discarded: Recommendations whose implementation does not generate any impact.

The recommendations collected in Table 8 have been categorized according to the capacities into the nine mentioned categories. It is important to note that 76 recommendations have been identified that impact more than one capacity, but not enough to classify them in the "General" category. For example, "Responses to questions should be reinforced with visual and/or auditory feedback" [16] is a recommendation that has been included in both the vision and hearing categories, as it affects both capacities.

After the classification, a total of 672 recommendations have been collected. Figure 5 shows the distribution of these recommendations: 34% focus on cognition, 19% are classified as general, 18% on vision, 10% on other aspects, 7% are discarded, 5% on hearing, 4% on dexterity, 2% on mobility, and 1% on touch.

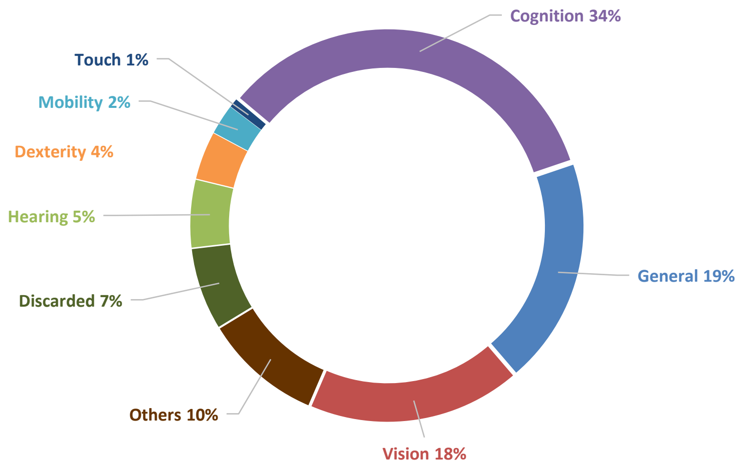
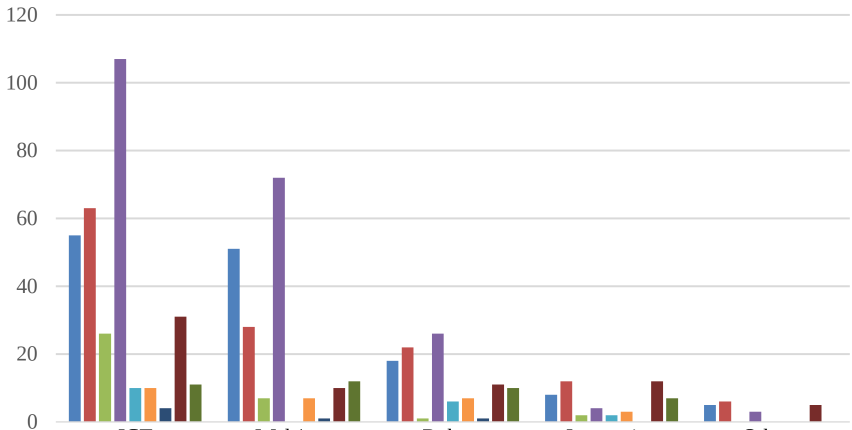


Fig. 5 Distribution of guidelines

Table 11 provides a detailed comparison of the number of accessibility recommendations categorized by the types of technology and their respective capabilities (for a detailed list of guidelines, see the full document [here]). It is evident that the "Cognition" category is the most prevalent across all technological areas, except for immersive technologies, where "Vision" is the most prominent category.

Table 11 Distribution of guidelines according to capabilities and technologies



	ICT	Web/app	Robots	Immersive	Others
General	55	51	18	8	5
Vision	63	28	22	12	6
Hearing	26	7	1	2	0
Cognition	107	72	26	4	3
Mobility	10	0	6	2	0
Dexterity	10	7	7	3	0
Touch	4	1	1	0	0
Others	31	10	11	12	5
Discarded	11	12	10	7	0

The "General" category includes 55 references for ICT, 51 for Web/apps, 18 for robots, 8 for immersive, and 5 for other technologies. This category encompasses a variety of recommendations applicable to all technologies, such as providing assistance, offering user feedback, minimizing errors and ensuring tolerance, flexibility of use, and compatibility with assistive technologies. Additionally, this category includes recommendations for user-centred design, such as involving users in the design process and considering accessibility from the outset of technological development.

The "Vision" category represents 18% of the recommendations, with a notable focus on immersive technologies, where there are 12 specific recommendations for immersion that are not considered in other technologies. For example, recommendations include "Head movements trigger different audio description cues related to various sections of the visual scene" [83] and "Use different levels of surround sound to help individuals feel more immersed in the content and distinguish the main action from surrounding actions in the scene" [83]. Additionally, other vision-related recommendations are identified across all technologies, such as 63 for ICT, 28 for Web/apps, 22 for robots, and 5 for other technologies. These recommendations include common accessibility features such as text size, contrast, brightness, and the option to zoom, among others.

The "Hearing" category has relatively few recommendations, except in the case of ICT, where 26 recommendations are identified. For Web/apps, there are 7 recommendations, 1 for robots, 2 for immersive technologies, and none for the "Other" category. Out of the 38 total recommendations in this category, 30 include guidelines related to multimodality, such as "Use different modes: pictorial, verbal, tactile for the redundant presentation of essential information" [79].The remaining 8 recommendations focus on aspects like volume adjustment and background noise reduction across all technologies, among other considerations.

The next category, related to "Cognition", includes a total of 107 guidelines for ICT, 72 for Web/apps, 26 for robots, 4 for immersive technologies, and 3 in the "Other" category. The recommendations in this category focus on reducing the cognitive load of using technologies. For instance, they suggest the use of simple and clear language, consistent structures and navigation throughout the experience, and the management of levels that enable users to achieve goals and adapt to new knowledge progressively.

The categories of "Mobility" and "Dexterity" are present across all technologies, with a maximum of 7% of the guidelines for the most represented technology, ICTs. In this category, 10 recommendations have been identified for "Mobility" and another 10 for "Dexterity." For Web/apps, no recommendations were found for "Mobility," but there are 7 for "Dexterity." For robots, 6 recommendations for "Mobility" and 7 for "Dexterity" have been identified. Immersive technologies have 2 guidelines for "Mobility" and 3 for "Dexterity". Notably, no recommendations were found in these categories for other technologies. These recommendations include guidelines addressing the complexity and dexterity of the required movements, such as "Simplify the movement necessary for navigation" [90] and "Consider speed to minimize fatigue" [97]. Additionally, the importance of personalization is highlighted with recommendations such as "Allow alternative configurations and/or reassignment of keys/buttons/gestures" [53] and "Enable voice interfaces for input and/or output" [83].

The "Tactile" category has the fewest accessibility recommendations, with a total of 5 guidelines identified in ICTs, Web/apps and robots. These recommendations primarily focus on multimodality, such as the guideline suggesting, "Communicate necessary information effectively, regardless of environmental conditions or individuals' sensory abilities" [33].

The "Others" category is notably prominent in immersive technologies and robots, with 24% (12 recommendations) and 14% (11 recommendations) of the recommendations, respectively. In comparison, this category does not exceed 9.5% (28 recommendations) in ICTs. These guidelines cover various aspects that do not specifically reduce the demand on any particular capacity, thus they are grouped into this category. Some of the recommendations include "Consider the potential psychological, mental, and emotional impact of virtual reality" [55] ,"Integrate socially acceptable gestures, avoiding dangerous behaviours" [39] , and "Design the robot's voice output with social manners and etiquette, offering polite and task-oriented communication" [99].

4 Discussion

This article has focused on analysing the characteristics and the definition process of accessibility recommendations identified for various technologies. After reviewing the 32 selected references, a total of 596 guidelines were identified. These recommendations aim to support the development of accessible technologies, ranging from established fields like ICT and web/apps to emerging technologies such as immersive technologies, robots and AI.

4.1 Impact of technological maturity on accessibility guidelines

The analysis revealed a significant disparity between accessibility recommendations for established technologies (e.g., ICT and web/apps) and emerging ones (e.g., immersive environments, robotics, AI). Well-established technologies benefit from long-standing, globally recognised standards, references such as the Web Content Accessibility Guidelines (WCAG) [72], ADA Accessibility Standards [102], Section 508 of the Rehabilitation Act of 1973 [105] and EN 301 549: European Standard for Accessibility for Information and Communication Technology Products and Services [101]. These well-defined frameworks have guided accessibility practices across various domains for years, providing clear, mature reference points for designers and developers.

In contrast to the lack of specific regulatory frameworks or mature accessibility standards for emerging technologies, some existing standards, such as WCAG, have been adapted as foundational guidelines. Originally designed for web applications, WCAG has been used as a starting point for newer fields. For example, Qbilat M. et al. [61] used WCAG as a basis for developing accessibility guidelines for robots, integrating these guidelines with HCD tools like user testing. However, emerging technologies still rely on qualitative methodologies and HCD practices to develop accessibility recommendations. Tools such as customer journey maps, workshops, and user testing play a crucial role in generating recommendations, especially when considering the needs of people with disabilities or older adults, as suggested by Inclusive Design principles [124]. Generally, the method for reviewing guidelines involves testing solutions with users to identify barriers and opportunities for improvement.

This disparity highlights the pressing need for more comprehensive and standardized accessibility guidelines tailored specifically to emerging technologies. As A. Rothberg notes [131], the integration of accessibility guidelines early in the design process can accelerate development by embedding accessibility into the framework from the outset. Moreover, ensuring that accessibility is addressed through a structured and repeatable process guarantees more consistent and scalable outcomes [132]. This allows HCD professionals to focus on iterative improvements without needing to rediscover accessibility needs at every step, thereby reducing the resources required and enhancing overall efficiency.

4.2 Types of accessibility guidelines

The analysis of accessibility guidelines across various technologies revealed the lack of a universally accepted classification system in the existing literature. However, delving into the guidelines themselves, three distinct types of accessibility recommendations emerged based on their applicability to different technological domains: (1) generic, (2) adapted, and (3) specific.

1. **Generic recommendations** refer to those that were identified in all technologies. For example, in the case of "Vision", recommendations related to contrast, brightness, or zoom are identified in all technologies;
2. **Adapted recommendations**, appear across all technologies but which require specific adaptation depending on the technology. This is the case, for example, of multimodality. Although this is identified as an accessibility recommendation in all technologies, its implementation in immersive environments may require adaptation due to the additional complexities it may present. For example, Fidyka et al. [83] highlight the need to work on the challenges that applying multimodality in immersive environments can pose, such as 3D subtitles;
3. **Specific recommendations** are tailored to promote accessibility for each technology. Following the example of "Vision" in the case of immersive technologies, this category would include recommendations such as: "Head movements trigger different audio description cues related to different sections of the visual scene" [83] and "Use different levels of surround sound to help people feel more immersed in the content and differentiate the main action from surrounding actions in the scene" [83]. These recommendations are related to responding to the nature of each technology. Thus, Fidyka et al. [84] reinforced this idea, pointing out the need to analyse and develop specific recommendations.

By differentiating between generic, adapted, and specific recommendations, it becomes evident that accessibility needs vary greatly depending on the technology. This highlights the importance of developing guidelines that not only account for universal needs but also adapt to the distinct features of each technological domain.

4.3 New considerations for emerging technologies

Another finding is the growing recognition of the "Other" category of recommendations. It reflects the diversity of accessibility considerations necessary in the development of new technologies, beyond those related to specific capacities that had not been previously addressed. Ethical considerations are one such aspect, particularly for emerging technologies. Ethical issues, such as privacy, decision-making, and the integrity of users, are increasingly being addressed in accessibility recommendations, as demonstrated by Fox D. et al. [51, 133] and Zallio M. et al. [55]. An example of this includes recommendations such as "The ethical considerations associated with the use of intelligent and responsive systems, particularly in contexts where decision-making impacts individuals or communities, are very important" [96] and "Valuing privacy, ethics, and the integrity of individuals in designs" [53]. This category underscores the importance of a holistic approach to accessibility that includes ethical considerations and social impact, to ensure that emerging technologies are developed in a way that is inclusive and beneficial to all users —going beyond mere usability for the greatest number of people.

Finally, it is important to address the role of AI within the context of accessibility. This SLR identified an initial study on AI [101], which outlined eight general accessibility recommendations, including "adaptability", "ethical considerations", and "user-centred design". As Schaffers H. [134] emphasized, AI is a rapidly evolving technology that must not be overlooked in discussions of accessibility. Looking ahead, AI is expected to play a more prominent role in addressing accessibility challenges, ensuring that its development and implementation are inclusive and accessible to all users. This shift will be critical in fostering more equitable technological landscapes as AI becomes increasingly integrated into everyday systems.

5 Research Gaps and Future Research Directions

This analysis of accessibility recommendations across various technologies has uncovered several opportunities for future research. To date, the literature has primarily focused on accessibility in ICT and Web/apps by applying Inclusive Design principles and accessibility [115]. However, emerging technologies such as immersive, robotics, and AI have not received the same level of attention. According to Zallio M. et al. [55], there has been limited progress in advancing knowledge on how to design immersive technologies in a safe, accessible, and inclusive manner. Similarly, the increasing use of social robots, particularly for elderly populations, presents a growing need for focused accessibility research [61].

In the realm of web development, it is common to see accessibility guidelines implemented post-development, which necessitates the use of assistive technologies that often come with high costs [62]. The critical question is how to integrate these guidelines from the early stages of design [82]. Therefore, accessibility considerations must be included at the beginning of the development process, not as an afterthought or a patch applied to the finished product. The literature agrees that all types of new technologies should offer accessible content and platforms without requiring specific adaptations, thereby meeting the needs of all members of society [28].

Owing to the lack of specific regulations, emerging technologies are often developed without comprehensive accessibility standards, relying instead on iterative user testing and qualitative analyses. This raises an important question: how long does it take for sufficient accessibility guidelines to emerge for new technologies? Building accessibility from the ground up in newer domains presents significant challenges. Currently, the accessibility of these technologies largely depends on the experiences, empathy, and judgment of designers and developers. White et al. [97] highlighted that involving users is essential to achieve accessibility in new technologies, although it presents many challenges according to Creed [135]. Relying on a group of people that does not represent the diversity of capabilities can be risky, despite the fact that this is common practice

[135]. Therefore, it is crucial to analyse how to adopt a HCD methodology when developing new technologies [84].

Despite the technology maturity, even well-established technologies such as ICT and web applications continue to receive updates to their accessibility standards. This invites further exploration. Is the continued release of new guidance for mature technologies indicative of shortcomings in the original guidelines? Or is it due to evolving use cases and advancements in technology that were not originally foreseen? Understanding whether these updates are filling gaps or addressing novel challenges will help shape how accessibility guidelines for newer technologies are developed from the outset.

Although this SLR has identified several recommendations, a significant challenge lies in the distribution of guidelines from various sources, resulting in repetition, but with differing formulations and levels of detail [136]. Additionally, interpreting these guidelines is problematic because they do not adequately address the needs of those who must implement them [76]. They are often described as difficult to read and comprehend and a lack of concrete examples and application criteria can lead to multiple interpretations. Furthermore, it is crucial that these guidelines continually evolve to keep pace with the rapid advancements in technology [137].

Another area for further study involves determining whether certain accessibility recommendations can be applied universally across all technologies or whether some technologies require technology-specific guidelines. For example, immersive technologies may necessitate recommendations tailored specifically to the unique challenges of virtual reality. According to Campoverde-Molina M. et [138], accessibility guidelines designed for web applications may not fully accommodate the needs of these immersive experiences, where user interactions are more intricate and dynamic. Understanding the limitations of universal guidelines and identifying when customization is necessary will be key to improving the accessibility of emerging technologies.

Finally, considerations beyond just capabilities, such as ethical issues, should also be examined. Organizations like the European Commission [136] and UNESCO [137, 139] are addressing ethics, diversity, inclusion, and accessibility in emerging technologies, but current regulations do not yet adequately cover their application, leaving users exposed to unaddressed risks [140].

6 Limitations

This review is not without its limitations:

- The SLR method does not ensure the complete identification of all pertinent publications within a specific field of study;
- By exclusively focusing on peer-reviewed articles, potentially relevant case studies presented at conferences, might have been overlooked. In addition, grey literature, such as legal frameworks and documentation produced by benchmark product developers are other potentially useful sources of information;
- Reviewer bias should be considered; despite efforts to maintain objectivity in the review process, some bias may have inadvertently been introduced;

- The selection of databases plays a crucial role. Although the databases were chosen carefully to comprehensively cover the research area and an exhaustive search strategy was employed to maximize the capture of relevant publications, expanding the database selection could potentially have uncovered additional critical articles;
- Limiting the search to publications only in English and Spanish constitutes another restriction of the study.

7 Conclusions

Digital inclusion presents a significant challenge today, as technologies play an increasing role in the daily lives of all people. While technology has the potential to be a facilitator of accessibility, it often acts as a barrier due to its design. According to McGinley C. [66, 141], many older adults and people with disabilities are excluded from the digital society not due to their inherent capabilities, but because of the inadequacies in how technologies are designed. This paper addresses the pressing issue of the digital divide in digital technologies, highlighting the role of accessibility in bridging this gap.

In this SLR, 596 accessibility recommendations for digital technologies have been identified. These recommendations were analysed based on the type of technology, the domain, the target audience, their sources, and were grouped according to the capacities they address, to facilitate comparison.

The analysis has revealed that technological maturity influences the sources used to generate accessibility recommendations. While newer technologies, such as immersive and robots, adopt HCD approaches, established technologies like ICT and Web/apps rely on well-recognized and accepted accessibility guidelines, such as WCAG, ADA, and Section 508. These findings suggest that newer technologies still require more robust development of specific accessibility guidelines that can adapt to their particular characteristics. Integrating these guidelines from the earliest stages of the design process would not only streamline development and facilitate the implementation of accessibility, but also reduce reliance on the personal experience and empathy of individual designers. This proactive approach optimizes resource use, embedding accessibility as a structured and repeatable component of the design process, rather than treating it as an afterthought.

Although certain accessibility recommendations, such as multimodality, zoom options, and contrast adjustments, apply across most technologies, these generalized solutions may not be sufficient to address the unique challenges of every field. For instance, immersive technologies require tailored guidelines to handle complexities like 3D environments. The necessity for more specific, technology-driven recommendations underscores the need for a more granular approach to accessibility.

The general conclusion from the analysis is that there is significant room for improvement in developing accessibility guidelines for emerging technologies to ensure they are applicable by designer and developers. Guidelines must be clear, specific to each type of technology, and evolving to stay updated with technological advances, as accessibility needs can vary greatly.

Additionally, in the field of AI, the number of recommendations identified in this SLR was limited, however this is expected to change soon due to the rapid evolution of these technologies. For these reasons, it is essential to promote research in Inclusive Design to develop accessibility guidelines applicable to newer technologies. In this vein, the Institute of Electrical and Electronics Engineers [51] emphasizes the importance of integrating accessibility principles in the early stages of new technology design.

Merritt et al. [142] argued that accessibility can be achieved without negatively impacting user experience, emphasizing the importance of balancing accessibility with overall user satisfaction. While significant progress has been made in identifying accessibility recommendations, there is still work to be done to ensure all technologies, especially the most recent ones, are accessible to everyone. Continuous collaboration among researchers, developers, and end users will be key to advancing the goal of supporting digital inclusion. Implementing accessibility guidelines from the early stages of design will be critical to ensure future technologies are accessible to all, without the need for costly and complicated post-development adaptations.

Statements and Declarations

Competing interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Funding

No funding was received to assist with the preparation of this manuscript.

Authors contributions

All authors contributed to this study. The methodology was proposed by Amaia Beitia Amondarain, Arantxa González de Heredia López de Sabando and Daniel Justel. Material preparation and data collection were performed by Amaia Etxabe Antia. The subsequent analysis was carried out by Amaia Etxabe Antia, Amaia Beitia Amondarain and Arantxa González de Heredia López de Sabando. A first draft of the manuscript was written by Amaia Etxabe Antia and all authors improved previous versions of the manuscript. All authors read and approved the final manuscript.

References

1. European Commission (2022) Digital inclusion | Shaping Europe's digital future. https://digital-strategy.ec.europa.eu/en/policies/digital-inclusion. Accessed 31 Jan 2024
2. Li G, Li D, Tang T (2023) Bibliometric Review of Design for Digital Inclusion. Sustainability (Switzerland) 15
3. Annable G, Goggin G, Stienstra D (2007) Accessibility, disability, and inclusion in information technologies: Introduction. Information Society 23:145–147. https://doi.org/10.1080/01972240701323523/ASSET//CMS/ASSET/0BFD41E1-6938-422B-A7FC-363E6BEC85C1/01972240701323523.FP.PNG
4. DiMaggio P, Hargittai E, DiMaggio P, Hargittai E (2001) From the "Digital Divide" to "Digital Inequality": Studying Internet Use as Penetration Increases. https://doi.org/https://doi.org/10.31235/osf.io/rhqmu
5. Livingstone S, Helsper E (2007) Gradations in digital inclusion: Children, young people and the digital divide. New Media Soc 9:671–696. https://doi.org/10.1177/1461444807080335
6. van Dijk JAGM (2006) Digital divide research, achievements and shortcomings. Poetics 34:221–235. https://doi.org/10.1016/J.POETIC.2006.05.004
7. Warschauer M (2004) Technology and Social Inclusion: Rethinking the Digital Divide. Technology and Social Inclusion. https://doi.org/10.7551/MITPRESS/6699.001.0001
8. Ali MA, Alam K, Taylor B (2020) Determinants of ICT usage for healthcare among people with disabilities: The moderating role of technological and behavioural constraints. J Biomed Inform 108:. https://doi.org/10.1016/j.jbi.2020.103480
9. Mavrou K, Hoogerwerf E-J (2016) Towards full digital inclusion: the ENTELIS manifesto against the digital divide. J Assist Technol 10:171–174. https://doi.org/10.1108/JAT-03-2016-0010
10. Vicente MR, Lopez AJ (2010) A Multidimensional Analysis of the Disability Digital Divide: Some Evidence for Internet Use. INFORMATION SOCIETY 26:48–64. https://doi.org/10.1080/01615440903423245
11. Gruzdeva MA (2022) The Age Factor in the Digital Divide: The Edges of Inequality. ECONOMIC AND SOCIAL CHANGES-FACTS TRENDS FORECAST 15:228–241. https://doi.org/10.15838/esc.2022.4.82.14
12. Tan KSY, Chan CML (2018) Unequal access: Applying Bourdieu's practice theory to illuminate the challenges of ICT use among senior citizens in Singapore. J Aging Stud 47:123–131. https://doi.org/10.1016/j.jaging.2018.04.002
13. Engwall K (2022) Online activities for individuals with intellectual disabilities at a day centre in the wake of COVID-19. Br J Learn Disabil. https://doi.org/10.1111/bld.12512
14. Mascheroni G, Cino D, Mikuska J, Smahel D (2022) Explaining inequalities in vulnerable children's digital skills: The effect of individual and social

discrimination. New Media Soc 24:437–457. https://doi.org/10.1177/14614448211063184
15. Rikard R V, Berkowsky RW, Cotten SR (2018) Discontinued Information and Communication Technology Usage among Older Adults in Continuing Care Retirement Communities in the United States. Gerontology 64:188–200. https://doi.org/10.1159/000482017
16. Sauvé L, Plante P, Mendoza GAA, et al (2023) Developing the Digital Literacy of People with Cognitive Limitations in the Workplace. SN Comput Sci 4:. https://doi.org/10.1007/s42979-022-01585-0
17. National Council on Disability, Baker (co-Pi PM, Todd R, et al (2011) The Power of Digital Inclusion, Technology's Impact on Employment and Opportunities for People with Disabilities
18. Stavroussi P, Karagiannidis C (2020) Assisting Students with Intellectual Disability Through Technology. Encyclopedia of Education and Information Technologies 157–164. https://doi.org/10.1007/978-3-030-10576-1_147
19. Lowenthal PR, Persichini G, Conley Q, et al (2021) Digital literacy in special education: Preparing students for college and the workplace
20. Neter E, Chachashvili-Bolotin S, Erlich B, Ifrah K (2021) Benefiting From Digital Use: Prospective Association of Internet Use With Knowledge and Preventive Behaviors Related to Alzheimer Disease in the Israeli Survey of Aging. JMIR Aging 4:. https://doi.org/10.2196/25706
21. Reisdorf BC, DeCook JR (2022) Locked up and left out: Formerly incarcerated people in the context of digital inclusion. New Media Soc 24:478–495. https://doi.org/10.1177/14614448211063178
22. Manzoor M, Vimarlund V (2018) Digital technologies for social inclusion of individuals with disabilities. Health Technol (Berl) 8:377–390. https://doi.org/10.1007/s12553-018-0239-1
23. Lythreatis S, Singh SK, El-Kassar AN (2022) The digital divide: A review and future research agenda. Technol Forecast Soc Change 175:. https://doi.org/10.1016/j.techfore.2021.121359
24. Olphert W, Damodaran L (2013) Older people and digital disengagement: A fourth digital divide? Gerontology 59:564–570. https://doi.org/10.1159/000353630
25. Ragnedda M (2018) The evolution of the digital divide. The Third Digital Divide 9–28. https://doi.org/10.4324/9781315606002-2/EVOLUTION-DIGITAL-DIVIDE-MASSIMO-RAGNEDDA
26. van Dijk J, Hacker K (2003) The digital divide as a complex and dynamic phenomenon. INFORMATION SOCIETY 19:315–326. https://doi.org/10.1080/01972240309487
27. Angeline M, Luthfia A, Safitri Y, et al (2021) Towards Digital Equality: Assessing Youths' Digital Literacy Capabilities. In: 2021 International Conference on Information Management and Technology (ICIMTech). pp 282–286
28. Jan van Dijk (2020) The Digital Divide. Polity Press
29. Shakina E, Parshakov P, Alsufiev A (2021) Rethinking the corporate digital divide: The complementarity of technologies and the demand for digital skills.

Technol Forecast Soc Change 162:. https://doi.org/10.1016/j.techfore.2020.120405

30. Helsper EJ (2012) A Corresponding Fields Model for the Links Between Social and Digital Exclusion. Communication Theory 22:403–426. https://doi.org/10.1111/J.1468-2885.2012.01416.X
31. Hargittai E (2002) Second-level digital divide: Differences in people’s online skills. First Monday 7:. https://doi.org/10.5210/FM.V7I4.942
32. van Deursen A, van Dijk J (2010) Internet skills and the digital divide. http://dx.doi.org/101177/1461444810386774 13:893–911. https://doi.org/10.1177/1461444810386774
33. Myhill WN, Samant D, Blanck P, et al (2008) Developing Accessible Cyberinfrastructure-Enabled Knowledge Communities in the National Disability Community: Theory, Practice, and Policy. Assistive Technology 20:157–174. https://doi.org/10.1080/10400435.2008.10131943
34. Ragnedda M (2017) The third digital divide: A weberian approach to digital inequalities. The Third Digital Divide: A Weberian Approach to Digital Inequalities 1–128. https://doi.org/10.4324/9781315606002/THIRD-DIGITAL-DIVIDE-MASSIMO-RAGNEDDA
35. Tokés GE (2021) The Third-level Digital Divide among Elderly Hungarians in Romania. Acta Ethnographica Hungarica 66:241–259. https://doi.org/10.1556/022.2021.00005
36. van Deursen AJAM, Helsper EJ, Eynon R (2015) Development and validation of the Internet Skills Scale (ISS). https://doi.org/101080/1369118X20151078834 19:804–823. https://doi.org/10.1080/1369118X.2015.1078834
37. Mavrou K, Meletiou-Mavrotheris M (2015) Views and considerations on ICT-AT competences development within the ENTELIS project: The Case of Cyprus. In: SikLanyi C, Hoogerwerf EJ, Miesenberger K, Cudd P (eds) ASSISTIVE TECHNOLOGY: BUILDING BRIDGES. pp 671–678
38. Mcmahon D;, Walker Z (2019) Leveraging emerging technology to design an inclusive future with universal design for learning. CEPS Journal 9:75–93. https://doi.org/10.25656/01:18139
39. Sharma S, Varkey B, Achary K, et al (2018) Designing gesture-based applications for individuals with developmental disabilities: Guidelines from user studies in India. ACM Trans Access Comput 11:. https://doi.org/10.1145/3161710
40. Abascal J, Nicolle C (2005) Moving towards inclusive design guidelines for socially and ethically aware HCI. Interact Comput 17:484–505. https://doi.org/10.1016/j.intcom.2005.03.002
41. Damodaran L (2001) Human factors in the digital world enhancing life style - The challenge for emerging technologies. In: International Journal of Human Computer Studies. Academic Press, pp 377–403
42. Paimre M (2020) Online Health Information Seeking Behaviour of Working and Non-working Estonian Older Adults as Compared to Students. In: Guldemond N, Ziefle M, Maciaszek L (eds) PROCEEDINGS OF THE 6TH

INTERNATIONAL CONFERENCE ON INFORMATION AND COMMUNICATION TECHNOLOGIES FOR AGEING WELL AND E-HEALTH (ICT4AWE). SCITEPRESS, pp 77–84
43. Tirado-Morueta R, Rodriguez-Martin A, Alvarez-Arregui E, et al (2021) Determination of Internet appropriation by older people through technological support services. New Media Soc. https://doi.org/10.1177/14614448211019155
44. Tirado-Morueta R, Rodríguez-Martín A, Álvarez-Arregui E, et al (2021) The digital inclusion of older people in Spain: Technological support services for seniors as predictor. Ageing Soc. https://doi.org/10.1017/S0144686X21001173
45. Aung MN, Koyanagi Y, Nagamine Y, et al (2022) Digitally Inclusive, Healthy Aging Communities (DIHAC): A Cross-Cultural Study in Japan, Republic of Korea, Singapore, and Thailand. Int J Environ Res Public Health 19:. https://doi.org/10.3390/ijerph19126976
46. Kim S, Yao W, Du X (2022) Exploring Older Adults' Adoption and Use of a Tablet Computer During COVID-19: Longitudinal Qualitative Study. JMIR Aging 5:. https://doi.org/10.2196/32957
47. Mubarak F, Suomi R (2022) Elderly Forgotten? Digital Exclusion in the Information Age and the Rising Grey Digital Divide. Inquiry (United States) 59:. https://doi.org/10.1177/00469580221096272
48. Tirado-Morueta R, Aguaded-Gomez JI, Ortiz-Sobrino MA, et al (2020) Determinants of social gratifications obtained by older adults moderated by public supports for Internet access in Spain. TELEMATICS AND INFORMATICS 49:. https://doi.org/10.1016/j.tele.2020.101363
49. United Nations Educational S and CO (2018) Designing Inclusive Digital Solutions and Developing Digital Skills
50. Gandy M, Baker PMA, Zeagler C (2017) Imagining futures: A collaborative policy/device design for wearable computing. Futures 87:106–121. https://doi.org/10.1016/j.futures.2016.11.004
51. Dylan Fox, Isabel Guenette Thornton (2022) Extended reality (xr) ethics and diversity, inclusion, and accessibility. IEEE
52. Geerts D, Vatavu RD, Burova A, et al (2021) Challenges in designing inclusive immersive technologies. ACM International Conference Proceeding Series 182–185. https://doi.org/10.1145/3490632.3497751
53. Seaborn K, Edey J, Dolinar G, et al (2016) Accessible play in everyday spaces: Mixed reality gaming for adult powered chair users. ACM Transactions on Computer-Human Interaction 23:. https://doi.org/10.1145/2893182
54. Creed C, Al-Kalbani M, Theil A, et al (2023) Inclusive AR/VR: accessibility barriers for immersive technologies. Univers Access Inf Soc. https://doi.org/10.1007/s10209-023-00969-0
55. Zallio M, Clarkson PJ (2022) Designing the metaverse: A study on inclusion, diversity, equity, accessibility and safety for digital immersive environments. Telematics and Informatics 75:. https://doi.org/10.1016/j.tele.2022.101909

56. Zwoliński G, Kamińska D, Haamer RE, et al (2023) Enhancing empathy through virtual reality: Developing a universal design training application for students. Med Pr 74:199–210. https://doi.org/10.13075/mp.5893.01407
57. Smith K (2012) Universal life: the use of virtual worlds among people with disabilities. Univers Access Inf Soc 11:387–398. https://doi.org/10.1007/s10209-011-0254-8
58. (2024) Innovation and AI for Accessibility | Microsoft Accessibility. https://www.microsoft.com/en-us/accessibility/innovation. Accessed 31 Jan 2024
59. Washington Group on Disability Statistics (2020) Introducción a las listas de preguntas del Grupo de Washington sobre Estadísticas de la Discapacidad
60. Ding B, Qin C, Zhao R, et al (2024) Data Augmentation using LLMs: Data Perspectives, Learning Paradigms and Challenges. Findings of the Association for Computational Linguistics ACL 2024 1679–1705. https://doi.org/10.18653/V1/2024.FINDINGS-ACL.97
61. Qbilat M, Iglesias A, Belpaeme T (2021) A proposal of accessibility guidelines for human-robot interaction. Electronics (Switzerland) 10:1–14. https://doi.org/10.3390/electronics10050561
62. Regine M. Gilberts, Ron Rateau (2019) Inclusive Design for a Digital World. Apress, New York
63. Taherian S, Davies C (2018) Multiple stakeholder perceptions of assistive technology for individuals with cerebral palsy in New Zealand. Disabil Rehabil Assist Technol 13:648–657. https://doi.org/10.1080/17483107.2017.1369585
64. Turchioe M, Grossman L V, Baik D, et al (2020) Older Adults Can Successfully Monitor Symptoms Using an Inclusively Designed Mobile Application. J Am Geriatr Soc 68:1313–1318. https://doi.org/10.1111/jgs.16403
65. Menger F, Morris J, Salis C (2016) Aphasia in an Internet age: wider perspectives on digital inclusion. Aphasiology 30:112–132. https://doi.org/10.1080/02687038.2015.1109050
66. British Standards (2005) BS 7000-6:2005 Design management systems. Managing inclusive design. Guide
67. Lazar Jonathan, Goldstein Daniel, Taylor Anne (2015) Ensuring Digital Accessibility through Process and Policy. Morgan Kaufmann, an imprint of Elsevier Ltd.
68. Miesenberger K, Edler C, Dirks S, et al (2020) User Centered Design and User Participation in Inclusive R&D. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 12376 LNCS:3–9. https://doi.org/10.1007/978-3-030-58796-3_1
69. Chang-Arana ÁM, Piispanen M, Himberg T, et al (2020) Empathic accuracy in design: Exploring design outcomes through empathic performance and physiology. Design Science 6:. https://doi.org/10.1017/dsj.2020.14
70. Beitia Amondarain A (2022) TESIS DOCTORAL Desarrollo de herramientas para el diseño accesible. Caso de interfaces de electrodomésticos
71. Horton S (2021) Empathy cannot sustain action in technology accessibility. Front Comput Sci 3:. https://doi.org/10.3389/fcomp.2021.617044

72. WCAG 2 Overview | Web Accessibility Initiative (WAI) | W3C. https://www.w3.org/WAI/standards-guidelines/wcag/. Accessed 20 May 2024
73. Kitchenham B, Charter (2007) Guidelines for performing Systematic Literature Reviews in Software Engineering - EBSE Technical Report EBSE-2007-01
74. Carrera-Rivera A, Larrinaga F, Lasa G (2022) How-to conduct a systematic literature review: A quick guide for computer science research. Comput Ind 142:. https://doi.org/10.1016/j.compind.2022.103730
75. Dattolo A, Luccio FL (2017) Accessible and usable websites and mobile applications for people with autism spectrum disorders: A comparative study. EAI Endorsed Transactions on Energy Web 17:. https://doi.org/10.4108/eai.17-5-2017.152549
76. Ferrier L, Fel H (1988) AN AUTHORING SYSTEM FOR THE CREATION OF INTERFACES FOR DISABLED USERS
77. Dario P, Guglielmelli E, Laschi C, Teti G (1999) MOVAID: a personal robot in everyday life of disabled and elderly people. https://doi.org/10.3233/tad-1999-10202
78. Jerald J (2015) The VR Book. The VR Book. https://doi.org/10.1145/2792790
79. Sevilla J, Herrera G, Martínez B, Alcantud F (2007) Web accessibility for individuals with cognitive deficits: A comparative study between an existing commercial Web and its cognitively accessible equivalent. ACM Transactions on Computer-Human Interaction 14:. https://doi.org/10.1145/1279700.1279702
80. Witt N, Mcdermott A (2004) Web site accessibility: what logo will we use today? British Journal of Educational Technology 35:45–56. https://doi.org/10.1111/j.1467-8535.2004.00367.x
81. Santarosa L, Conforto D, Machado RP (2014) Whiteboard: Synchronism, accessibility, protagonism and collective authorship for human diversity on Web 2.0. Comput Human Behav 31:591–601. https://doi.org/10.1016/j.chb.2013.06.028
82. Neerincx MA, Cremers AHM, Kessens JM, et al (2009) Attuning speech-enabled interfaces to user and context for inclusive design: Technology, methodology and practice. Univers Access Inf Soc 8:109–122. https://doi.org/10.1007/s10209-008-0136-x
83. Fidyka A, Matamala A (2018) Audio description in 360º videos. Translation Spaces 7:285–303. https://doi.org/10.1075/ts.18018.fid
84. Fidyka A, Matamala A (2021) Retelling narrative in 360° videos: Implications for audio description. Translation Studies 14:298–312. https://doi.org/10.1080/14781700.2021.1888783
85. Segura M, Osorio R, Zavala A (2023) Extended Reality Model for Accessibility in Learning for Deaf and Hearing Students (Programming Logic Case). International Journal of Modern Education and Computer Science 15:1–17. https://doi.org/10.5815/ijmecs.2023.04.01
86. Ianculescu M, Lupeanu E, Alexandru, et al (2012) A demand for more personalized accessible medical informatics in an aging world. In:

INTERNATIONAL JOURNAL OF EDUCATION AND INFORMATION TECHNOLOGIES
87. Buchholz M, Holmgren K, Ferm U (2020) Remote communication for people with disabilities: Support persons' views on benefits, challenges, and suggestions for technology development. Technol Disabil 32:69–80. https://doi.org/10.3233/TAD-190254
88. Valério Neto L, F Fontoura Junior PH, Bordini RA, et al (2019) Details on the Design and Evaluation Process of an Educational Game Considering Issues for Visually Impaired People Inclusion. Source: Journal of Educational Technology & Society 22:4–18. https://doi.org/10.1109/ICALT.2019.00097
89. Rodriguez-Ascaso A, Letón E, Muñoz-Carenas J, Finat C (2018) Accessible mathematics videos for non-disabled students in primary education. PLoS One 13:. https://doi.org/10.1371/journal.pone.0208117
90. Varonis EM (2015) From barriers to bridges: Approaching accessibility in course design. International Journal of Information and Learning Technology 32:138–149. https://doi.org/10.1108/IJILT-12-2014-0033
91. Langdon P, Hosking I (2010) Inclusive wireless technology for emergency communications in the UK'. Int J Emergency Management 7:47–58. https://doi.org/https://doi.org/10.1504/IJEM.2010.032044
92. Hunter-Zaworski K, Stewart R, Hunter-Zaworski K (1999) DISCUSSION OF PROJECT ACTIVITIES Description of Ergonomic Guidelines Next Frontier in Accessible Traveler Information Systems World Wide Web-Based Information Systems. Transp Res Rec 1671:
93. Boman IL, Rosenberg L, Lundberg S, Nygård L (2012) First steps in designing a videophone for people with dementia: Identification of users' potentials and the requirements of communication technology. Disabil Rehabil Assist Technol 7:356–363. https://doi.org/10.3109/17483107.2011.635750
94. Taylor MA (2016) Improving Accessibility for Students with Visual Disabilities in the Technology-Rich Classroom. PS Polit Sci Polit 49:122–127. https://doi.org/10.1017/S1049096515001134
95. Rodriguez-Ascaso A, Molanes-López EM, Pérez-Martín J, Letón E (2024) Performance of students with different accessibility needs and preferences in "Design for All" MOOCs. PLoS One 19:. https://doi.org/10.1371/journal.pone.0299090
96. Wood D, Morris C, Candler D (2013) DIGNITY, DIVERSITY AND DEMOCRACY THROUGH INCLUSIVE DESIGN: DESIGNING AN ACCESSIBLE WEBSITE FOR "DIGNITY FOR DISABILITY" THE TELSTRA-TJA CHRISTOPHER NEWELL PRIZE PAPERS. Telecommunications Journal of Australia
97. White AS, Adams R, Prior S (2009) Evaluating choice in universal access: An example from rehabilitation robotics. Univers Access Inf Soc 8:155–163. https://doi.org/10.1007/s10209-008-0140-1
98. Søraa RA, Fosch-Villaronga E (2020) Exoskeletons for all: The interplay between exoskeletons, inclusion, gender, and intersectionality. Paladyn 11:217–227. https://doi.org/10.1515/pjbr-2020-0036

99. Langer D, Legler F, Kotsch P, et al (2022) I Let Go Now! Towards a Voice-User Interface for Handovers between Robots and Users with Full and Impaired Sight. Robotics 11:. https://doi.org/10.3390/robotics11050112
100. Oliveira R, de Abreu JF, Almeida AM (2017) Promoting interactive television (iTV) accessibility: an adapted service for users with visual impairments. Univers Access Inf Soc 16:533–544. https://doi.org/10.1007/s10209-016-0482-z
101. Alvarez-Icaza I, Huerta O (2024) Augmented intelligence for open education: bridging the digital gap with inclusive design methods. Front Educ (Lausanne) 9:. https://doi.org/10.3389/feduc.2024.1337932
102. Americans with Disabilities Act of 1990, As Amended | ADA.gov. https://www.ada.gov/law-and-regs/ada/. Accessed 20 May 2024
103. Section 503 | U.S. Department of Labor. https://www.dol.gov/agencies/ofccp/section-503. Accessed 20 May 2024
104. Section 504, Rehabilitation Act of 1973 | U.S. Department of Labor. https://www.dol.gov/agencies/oasam/centers-offices/civil-rights-center/statutes/section-504-rehabilitation-act-of-1973. Accessed 20 May 2024
105. Section 508 of the Rehabilitation Act | Federal Communications Commission. https://www.fcc.gov/general/section-508-rehabilitation-act. Accessed 20 May 2024
106. European Comission (2019) EN 301 549 -2019 Accessibility requirements for ICT products and services
107. Ellis B, Ford-Williams G, Graham L, et al Game accessibility guidelines. https://gameaccessibilityguidelines.com/. Accessed 12 Jun 2024
108. Authoring Tool Accessibility Guidelines (ATAG) Overview | Web Accessibility Initiative (WAI) | W3C. https://www.w3.org/WAI/standards-guidelines/atag/. Accessed 20 May 2024
109. Mobile Accessibility Guidelines - Accessibility for Products - BBC. https://www.bbc.co.uk/accessibility/forproducts/guides/mobile/. Accessed 20 May 2024
110. Welcome to the Funka Foundation The Funka Foundation. https://stiftelsen-funka.org/. Accessed 20 May 2024
111. Home – IBM Accessibility. https://www.ibm.com/able/. Accessed 20 May 2024
112. ARIA Authoring Practices Guide | APG | WAI | W3C. https://www.w3.org/WAI/ARIA/apg/. Accessed 20 May 2024
113. Personal User Experience (PUX) Recommendations and Lessons Learned
114. ADLAB Audio Description guideline. http://www.adlabproject.eu/Docs/adlab%20book/. Accessed 20 May 2024
115. Agency for Special Needs E, Education I (2015) GUIDELINES FOR ACCESSIBLE INFORMATION ICT FOR INFORMATION ACCESSIBILITY IN LEARNING (ICT4IAL) Guidelines for Accessible Information
116. Desurvire H, Wiberg C (2009) Game usability heuristics (PLAY) for evaluating and designing better games: The next iteration. In: Lecture Notes in

Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). pp 557–566

117. Leavitt MO, Shneiderman B Research-Based Web Design & Usability Guidelines
118. Nielsen Norman 10 Usability Heuristics for User Interface Design. https://www.nngroup.com/articles/ten-usability-heuristics/. Accessed 20 May 2024
119. Solano A, Rusu C, Roncagliolo S, et al (2011) Usability Heuristics for Interactive Digital Television
120. What is User Centered Design (UCD)? — updated 2024 | IxDF. https://www.interaction-design.org/literature/topics/user-centered-design. Accessed 14 Jun 2024
121. About Universal Design - Centre for Excellence in Universal Design. https://universaldesign.ie/about-universal-design. Accessed 20 May 2024
122. UDL: The UDL Guidelines. https://udlguidelines.cast.org/. Accessed 20 May 2024
123. Universal Design of Instruction (UDI): Definition, Principles, Guidelines, and Examples | DO-IT. https://www.washington.edu/doit/universal-design-instruction-udi-definition-principles-guidelines-and-examples. Accessed 20 May 2024
124. University of Cambridge (2024) What is inclusive design? https://www.inclusivedesigntoolkit.com/whatis/whatis.html. Accessed 20 May 2024
125. European Commission (2019) EN 17161:2019. Design for All - Accessibility following a Design for All approach in products, goods and services - Extending the range of users - European Commission. https://accessible-eu-centre.ec.europa.eu/content-corner/digital-library/en-171612019-design-all-accessibility-following-design-all-approach-products-goods-and-services_en. Accessed 20 May 2024
126. James Paul Gee: Learning Principles. https://mason.gmu.edu/~lsmithg/jamespaulgee2print.html. Accessed 20 May 2024
127. Google Introduction to the principles of mobile app design - Think with Google. https://www.thinkwithgoogle.com/marketing-strategies/app-and-mobile/principles-of-mobile-app-design-introduction/. Accessed 20 May 2024
128. Goodman-Deane J, Bradley M, Clarkson PJ (2021) Relating age, digital interface competence, and exclusion. Gerontechnology 20:1–14. https://doi.org/10.4017/gt.2021.20.2.24-468.11
129. Goodman-Deane J, Bradley M, Waller S, Clarkson PJ (2020) Quantifying Exclusion for Digital Products and Interfaces. https://doi.org/10.1007/978-3-030-43865-4_15
130. Waller SD, Langdon P, Clarkson P (2013) Visualising the number of people who cannot perform tasks related to product interactions. Univers Access Inf Soc. https://doi.org/https://doi.org/10.1007/s10209-013-0297-0
131. Rothberg MA (2019) Designing for Inclusion: Ensuring Accessibility for People with Disabilities. Consumer Informatics and Digital Health: Solutions for

Health and Health Care 125–143. https://doi.org/10.1007/978-3-319-96906-0_7
132. Melles M, Albayrak A, Goossens R (2021) Innovating health care: key characteristics of human-centered design. International Journal for Quality in Health Care 33:37–44. https://doi.org/10.1093/INTQHC/MZAA127
133. Dylan Fox (2022) A Hacker's Guide to XR Accessibility. In: Medium. https://medium.com/@dylan.r.fox/a-hackers-guide-to-xr-accessibility-13a5ba0219c8. Accessed 30 Jan 2024
134. Schaffers H, Vartiainen M, Bus J (2020) Digital innovation and the future of work. Computing and Information Science and Technology 353
135. Frauenberger C, Good J, Keay-Bright W (2011) Designing technology for children with special needs: Bridging perspectives through participatory design. CoDesign 7:1–28. https://doi.org/10.1080/15710882.2011.587013
136. European Union's Horizon Europe research and innovation programme E (2023) Tailored guidelines for inclusive design and Ethics in industry
137. UNESCO (2017) Report of COMEST on robotics ethics
138. Campoverde-Molina M, Luján-Mora S, Valverde L (2023) Accessibility of university websites worldwide: a systematic literature review. Univers Access Inf Soc 22:133–168. https://doi.org/10.1007/S10209-021-00825-Z
139. (2024) Global Forum on the Ethics of Artificial Intelligence 2024 | UNESCO. https://www.unesco.org/en/articles/global-forum-ethics-artificial-intelligence-2024. Accessed 31 Jan 2024
140. Fosch-Villaronga E, Drukarch H (2023) Accounting for Diversity in Robot Design, Testbeds, and Safety Standardization. Int J Soc Robot 15:1871–1889. https://doi.org/10.1007/s12369-023-00974-6
141. McGinley C, Myerson J, Briscoe G, Carroll S (2022) Towards An Age-Friendly Design Lens. J Popul Ageing 15:541–556. https://doi.org/10.1007/s12062-022-09367-5
142. Merritt D (2017) User-generated accessibility in virtual world games. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). https://doi.org/10.1007/978-3-319-57987-0_28