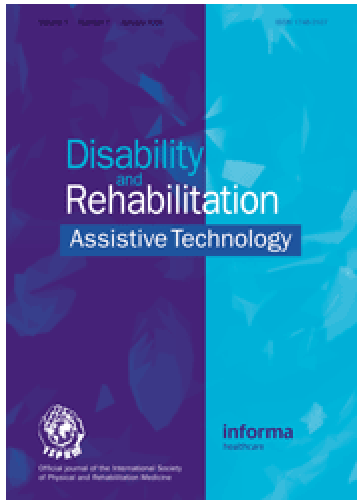

Two Decades of Assistive Technologies to Empower People with Disability: a Systematic Mapping Study

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Two Decades of Assistive Technologies to Empower People with Disability: a Systematic Mapping Study

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ABSTRACT
Purpose: Information and Communication Technologies have transformed our lives in different social areas, facilitating interpersonal relationships thanks to technological tools. In the specific case of people with disabilities, Assistive Technologies (ATs) break down barriers and increase opportunities to become active members of the society with equal opportunities. **Materials and methods:** This paper presents a systematic mapping study that analyzes the current state-of-the-art of ATs proposed in the literature to support the empowering of people with disability. Specifically, this paper focuses on (1) describing a global vision of the scientific literature published in the last 20 years about ATs in the computer science field and (2) identifying research needs, gaps, and trends. **Results:** For this purpose, an in-depth analysis of 389 primary studies is presented. The information obtained from the mapping process is also constrained. Concretely, 35 ATs versus 22 disabilities are compared, obtaining striking peaks for some disabilities described in the discussion. **Conclusions:** Finally, the findings show that several areas have been covered only lightly, revealing interesting future directions and challenges for junior researchers.

KEYWORDS
Systematic Mapping Study; Assistive Technologies; People with disabilities

1. Introduction

The enormous technological development in recent decades has led to a social revolution, coining the term known as Information Society [1]. This term refers to the prominent role that current technological innovations (i.e., software tools, techniques, or devices) have had and have in improving people's interpersonal relationships and producing and sharing large amounts of information in a quasi-instantaneous way [2]. In this context, Information and Communication Technologies (ICTs) have transformed our lives in different areas of society (i.e., education, labor relations, or personal relationships, among others) [3], allowing and facilitating these interpersonal relationships. From a social perspective, the development of ICTs has allowed personal growth as an individual and citizen of society with equal opportunities [4]. ICTs play an essential role for people with disabilities by enhancing their personal development and independence and by assisting their daily lives [5]. For instance, ICTs enable them

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to improve their quality of life by communicating independently for people who lack intelligible speech, facilitating independent mobility for people with severe motor impairments, or describing scenes for blind people.

These benefits allow breaking down barriers [6] and expanding social integration [7] for people with disabilities. Nevertheless, some authors affirm that traditionally, technologies are conceived, designed and developed for use by neurotypical people, without adequately considering using them by people with disabilities [8,9]. Therefore, it is necessary to promote universal design patterns to place the user at the center of technology, not vice versa, using product design paradigms oriented to end-users.

Over the last decades, a specialization of ICTs has emerged to improve the independence and autonomy of people with disabilities. These technologies, commonly known as Assistive Technologies (ATs), have become an increasingly important tool for improving the quality of their lives [10]. According to the United States legislation [11], AT is defined as *"any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase functional capabilities of individuals with disabilities"*. The World Health Organization (WHO) states that, *"more than one billion people in the world live with some form of disability, of whom nearly 200 million experience considerable difficulties in functioning"* [12]. These numbers show how ATs can benefit millions of persons with disability in multiple ways: moving, seeing, communicating, eating or dressing, among others.

It is relevant to highlight the importance of choosing the appropriate terminology and language to understand its real-world implications —SIGACCESS Accessible Writing Guide [13] [14]. We refer to the use of "disability" terminology. Traditionally, there are two ways to mention an individual's disability [15,16]. The former refers to the use of a person-first language (i.e., "people with disability"), whereas the latter refers to the use of an identity-first language (i.e., "disabled person"). The semantics associated with these expressions have been discussed in recent years because of social connotations and stigmas [17,18]. Most scientific and professional authors defend the use of person-first languages, arguing the individual's humanization, that is, the individual's identities and experiences are emphasized instead of highlighting his/her disease or disability [19–22]. Conversely, some authors defend using the second terminology (that is, identity-first language) against the first language. In this context, some authors argue that person-first language fails to recognize diverse views on disability [15] or reduce stigma [23]. After considering these previous references, it is possible to conclude that there is no consensus in the scientific literature about the most appropriate and accepted way to use these expressions. In this context, we have decided to use the person-first language to promote human dignity and maintain this work's scientific rigor.

This study aims to discuss the state-of-the-art about ATs which are used by people with disabilities during activities of daily living. Although the accepted definitions of AT have been followed, we have analyzed them from an ICTs perspective, and given that all the authors are computer scientists, this may imply a prism that does not reflect the point of view of clinicians, although we have tried to be as exhaustive as possible. For instance, the term "mobility devices" used by a clinician would be included in the category "Robotics - Assistive Robots (humanoids, wheelchairs)" and "communication devices" would be included in the category "Human Computer Interface". This paper analyzes the scientific literature published in the last 20 years about this topic, considering the type of work, disability, or disease on which it is focused, the technology, and the type of validation used. The results of this analysis contribute to highlight emerging trends and practices in this field. Therefore, this study aims to clarify the reader on the following topics: (1) what are the main applications of the AT which empower people with disabilities; (2) the scientific and technical solutions that have been proposed; and (3) evaluating the above solutions based on a classification scheme.

To achieve the objectives described above, this paper presents a Systematic Mapping Study (SMS) [24,25]. An SMS is a specific form of Systematic Literature Review (SLR) [26] with a broader aim, whose results provide researchers with a global view of a specific topic. Furthermore, it allows to show up a set of research necessities and trends in the field. SMSs are typically used as a starting point for doing more work with a higher level of rigor. SMS is a formal method widely known by the computer science community for conducting systematic reviews. The main differences concerning a literature review are that a replicable, rigorous, and reliable result is obtained by applying it. This SMS will be guided by the following Research Question (RQ): *"What is the state-of-the-art of ATs that have been proposed in the literature to support the empowering of people with disability?"*.

Finally, the rest of the paper is organized as follows. The closest related works to this proposal are described in Section 2. The research method is presented in Section 3. The threats to the validity of this study are presented in Section 5. The SMS execution is detailed in Section 4, and results are stated in Section 6. Section 7 summarizes the conclusions and proposes a set of future research lines based on the gap detected.

2. Related work

Researchers have published systematic reviews related to ATs on different aspects of theoretical proposals or technological solutions. However, to the best of our knowledge, no systematic reviews have examined ATs comprehensively. Instead, the majority of these reviews concentrate on particular types of disabilities or specific ATs. Nevertheless, the scope and weaknesses of related work since 2015 are briefly presented below.

Cunha et al. [27] presented a systematic review to catalog the state-of-the-art related to the application of Virtual Reality Technologies (VRT) as a mechanism to improve treatments of people with disabilities. Authors tried determining which disabilities are treated using VRT and the effectiveness of treatments based on this technology. This review was focused on intellectual disabilities (such as Autism Spectrum Disorders and Down Syndrome). Moreover, Climent et al. [28] reviewed the literature based on techniques involved in each step of wearable sensor modality for automated lifelogging.

Caspo et al. [29] performed a survey to analyze ATs based on wearable solutions applied in rehabilitation tasks for people with disabilities. Authors identified recent trends in software and hardware-based signal processing relevant to the development of these kinds of solutions. This study was focused on very specific technologies and disabilities (i.e., hearing loss and visual illnesses). Wang et al. [30] presented a survey on sensor modality-centered human activity recognition in the health care context. The major concern that these studies present was that no methodological formalism had been used to conduct this survey.

Leaman et al. [31] conducted a systematic review of studies published from 2005 to 2015 to identify which are the most relevant smart wheelchair solutions that have been used. Moreover, authors proposed new research lines and open issues on this topic, considering some of the most interesting the use of biometric techniques and Brain-Machine Interfaces (BMIs). Actually, BMIs are currently one of the most popular techniques for designing and developing AT devices. In this context, Lahr et al. [32]

conducted a survey to know the acceptance degree of BMI solutions applied to patients affected by Amyotrophic Lateral Sclerosis (ALS). However, authors did not mention what specific BMI technologies were evaluated and how these technologies have been selected for this survey.

Moreover, Baldassin et al. [33] presented a systematic study on ATs related to the use of computers. Authors identified 10 proposals and analyzed how these solutions can improve the quality of life of patients with traumatic and non-traumatic spinal cord injury. Although it is an interesting topic, the authors did not follow methodological review guidelines or selection criteria, which put the validity of the study at risk. In addition, the number of primary studies analyzed was too low. This fact may be caused because the authors only focused on digital libraries related to the healthcare context (e.g., PubMed or PsycINFO) without considering digital libraries related to computer science areas.

The research community had also dedicated significant efforts to (1) meet the needs of older people and people affected with dementia, and (2) propose techniques or tools based on ATs to improve the day-to-day life of these people. On the one hand, regarding people affected with some type of dementia, some systematic reviews were conducted. Ienca et al. [34] reviewed the proposals from 2000 to 2016 that use intelligent ATs with application in dementia care, focusing on Alzheimer's disease. A systematic review related to the use of electronic AT within healthcare centers aiming to improve care for people with dementia was presented by Daly et al. [35]. These studies had been conducted following formal methods. However, they did not apply quality criteria to evaluate primary studies, which hinder to discern the impact or relevance of these papers. As mentioned above, the queries of these studies had only been executed in digital libraries related to the healthcare context. On the other hand, regarding AT to improve the autonomy of older people, Kotteritzsch et al. [36] developed a systematic review on research papers (published from 2004 to 2014) that proposed AT to improve the autonomy and day-to-day life of older people in urban areas. Authors established a classification scheme to categorize primary studies according to attributes such as technology, application context, or target user, among others. Although the target people of the study was too relevant, the number of technologies considered in the study were very limited.

Moreover, some studies that put focus on ATs for improving the independence of people with cognitive disabilities or learning disabilities had been developed. Perelmutter et al. [37] presented a systematic review to analyze ATs and determine their effectiveness in improving the learning deficits of people with learning disabilities. These studies did not analyze the usefulness or application of these technologies for people with other disabilities or healthcare needs.

To sum up, although some proposals similar to this study have been conducted, various relevant gaps make this research necessary:

- Methodology: Unlike some related studies that lack adherence to formal methods, the current research rigorously follows formal methodologies. This ensures that our study can be easily replicated or updated, enhancing its credibility and reliability.
- Digital libraries: While many previous works predominantly focus on healthcare digital libraries, the current work also includes technology and computer science-related ones. By exploring a different domain, we broaden the scope of potential applications and uncover novel insights.
- Scope: Existing related works often address specific questions about particular

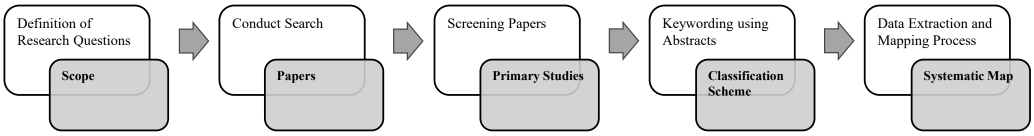


Figure 1. SMS methodology steps

disabilities and ATs. In contrast, this work takes a more comprehensive approach, examining the technology's application and support for any disability or group of disabilities. This broader perspective offers a holistic understanding of the field.

- Primary studies: Within the literature surveyed in this section, there is a shortage of primary studies in some related works. Conversely, our research encompasses a substantial number of primary studies covering the developments and findings from the last two decades. This comprehensive review enriches the knowledge base and strengthens the foundation of our study.

In conclusion, the current research bridges these gaps in the existing literature, contributing to a more thorough and well-rounded exploration of the intersection between technology and disability support. By employing rigorous methodologies and examining a broader range of digital libraries and primary studies, this work advances the understanding and potential applications of ATs for people with disabilities.

3. Research method

The development of this study follows the method and recommendations presented by Petersen et al. [24] for conducting an SMS. An SMS is a form of SLR but with a broader scope. The main objective of this type of study is to provide a classification of the most relevant research papers focused on a specific topic. In addition, it also seeks to identify which aspects have been better or worse researched by the scientific community to continue or propose new research lines. SMSs are defined by 5 steps (cf. Figure 1):

- (i) The *definition of the research questions* that will guide both the execution of the process and the results,
- (ii) the *execution of the search* that will result in the set of interesting papers related to the treated topic,
- (iii) the *screening of the papers*, where the filtering of papers is done based on the inclusion and exclusion criteria and will result in the primary studies,
- (iv) the *keywording using abstracts*, whose main objective is the creation of the classification scheme by reading the title and abstract of the primary studies and, finally,
- (v) the *data extraction and mapping process* to obtain the final mapping between the classification scheme and the primary studies will lead to the discussion.

Before executing each of the steps described above, it was necessary to define the following elements: the digital libraries where the queries would be executed, the keywords and queries, and finally, the inclusion and exclusion criteria to be able to screen the papers.

The choice of the digital libraries in which the queries will be executed has been made based on the authors' experience in the execution of other systematic reviews. Accordingly, those digital libraries that publish conferences or journals of their own, such as ACM Digital Library [38] or IEEE Explore [39], were selected. Moreover, Science Direct [40] and Scopus [41] were included. In addition, PubMed [42] has also been considered as a bibliographic source to better cover the health context; it is also considered one of the largest sources of scientific information to date. Google Scholar was discarded due to its relatively limited advanced search options and its indexing of a substantial number of sources that may lead to a higher number of less relevant results in the initial findings.

First, a preliminary search was carried out to define the keywords. Three main groups were defined to search the keywords: disability, target audience, and ATs. The most relevant titles were selected, and the documents were read to obtain the most used terms. The keywords repeated with more frequency by each of the groups are shown in Table 1.

Table 1. Keywords

Group	Keyword
Disability	"disabled", "disabilities"
Target Audience	"person", "people", "user"
Assistive Technologies	"assistive technology"

Once the keywords were defined, the queries were created so that any term from each group should appear in the title, abstract, or keywords of the paper. Besides, if the search engine allowed it, it was filtered by computer science or software engineering category, the the authors' main research field of this contribution.

Having selected the digital libraries and keywords, the queries for each library were built (cf. Table 2) to be executed as a second step of the methodology. It is important to note that queries were limited to title, abstract, and keywords to ensure that the results obtained were closely related to the paper's subject matter.

Moreover, concerning the inclusion and exclusion criteria, a total of 5 filters (F) were defined:

- *F1*: Discard duplicated papers after executing a search in a certain digital library.
- *F2*: Discard papers that were not written in English.
- *F3*: Discard papers whose source, i.e., journal or conference, are not indexed within the Journal Citation Report (JCR) [43] and GII-GRIN-SCIE (GGS) Conference Rating [44] rankings respectively. These indexes were taken as a reference to set up the quality assurance criteria that will corroborate the scientific rigor of the study.
- *F4*: Discard papers that, after reading the title and abstract, are not within the topic of this proposal, i.e., those that are not explicitly focused on the discussion or proposal of ATs or that do not address disabilities or ATs comprehensively (e.g., those related to surgical aspects and interventions in the prosthetic field, good practice manuals, or psychological/social interventions related to the disabilities considered, among others).
- *F5*: Discard papers related to systematic reviews, comparative studies, surveys, or discussions, among others. A selection of the most relevant ones will give rise to the related work section.

Finally, after applying inclusion and exclusion criteria, each primary study is analyzed by a specific researcher of this study to determine its classification considering

Table 2. Queries by digital library

Digital Library	Query
ACM	(Title:("disabled" OR "disabilities") AND Title:("person" OR "people" OR "user") AND Title:("assistive technology")) OR (Abstract:("disabled" OR "disabilities") ANDAbstract:("person" OR "people" OR "user") AND Abstract:("assistive technology")) OR (Keyword:("disabled" OR "disabilities") AND Keyword:("person" OR "people" OR "user") AND Keyword:("assistive technology"))
IEEE Explore	((("Document Title":"disabled" OR "Document Title":"disabilities" OR "Abstract": "disabled" OR "Abstract":"disabilities" OR "Author Keywords":"disabled" OR "Author Keywords": "disabilities") AND ("Document Title":"person" OR "Document Title":"people" OR "Document Title":"user" OR "Abstract":"person" OR "Abstract": "people" OR "Abstract":"user" OR "Author Keywords":"person" OR "Author Keywords": "people" OR "Author Keywords":"user") AND ("Document Title":"assistive technology" OR "Abstract":"assistive technology" OR "Author Keywords":"assistive technology")))
Scopus	(TITLE-ABS-KEY(("disabled" OR "disabilities") AND ("person"OR "people" OR "user") AND "assistive technology")) AND (LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ENGI"))
Science Direct	Title, abstract, keywords: ("disabled" OR "disabilities") AND ("person" OR "people" OR "user") AND ("assistive technology")
PubMed	(("disabled"[Title/Abstract] OR "disabilities"[Title/Abstract]) AND ("person"[Title/Abstract] OR "people"[Title/Abstract] OR "user"[Title/Abstract])) AND ("assistive technology"[Title/Abstract])

the type of disability, technology, etc. (cf., Section 4.1). After executing this stage, it is possible that some doubts arise about the adequacy and cataloging of some primary studies. Faced with this situation, our review method proposes holding face-to-face meetings between the researchers of this study in order to minimize the biases of each investigator and avoid subjective decisions, as well as establishing consensual agreements on which primary studies are relevant and their cataloging.

4. Execution

This section describes activities 1 to 4 of the SMS, carried out until the results to be analyzed later are obtained.

The first activity aims to define the research questions. In that sense, the main research question that aimed to understand the current literature on technological and software assistive proposals for empowering people with disabilities was divided into four sub-questions (cf. Table 3).

Once the research questions were defined, the queries defined in Table 2 were exe-

Table 3. Research Questions

Research Question	Motivation
RQ1. How is the research area of AT proposals structured? What are trends concerning the publication quantity and focus of AT proposals? What are the leading publication channels for this area?	Categorize by topics according to the focus of the proposals and identify where each proposal is published as a quality metric. For this purpose, international rankings are taken as reference (JCR for journals and GII-GRIN-SCIE for conferences), as well as a disability typology (Section 4.1.1) and a technological typology). The disability typology is based on two internationally recognized classifications (International Classification of Functioning, Disability and Health (ICF) [45]; and International Classification of Diseases (ICD) [46]), whereas the technological typology is based on 35 types grouped into 6 main categories as Section 4.1.2 shows.
RQ2. What are the main research types and methods found in the proposals of AT? What have scientific methods been applied to evaluate and validate each study?	Identify the types of research that have been carried out and the scientific method that has been used to evaluate and validate each primary study. These typologies are respectively described in Section 4.1.3 and Section 4.1.4 in detail.
RQ3. What disability categories are treated using ATs?	Categorize each analyzed AT proposal according to the type of disability group by the used assistive technology. In addition, this RQ aims to analyze trends in technologies that have been applied to support each disability.
RQ4. What is the scientific or technological typology presented in the ATs?	Categorize the ATs according to scientific or technological typology in order to analyze the temporal trends on each of the ATs (Section 4.1.2) and their evolution over time.

cuted as activity two states. It is essential to highlight that the search was executed in February 2021, covering those papers published between 2000 and the execution date. The results obtained from 2021 were omitted since they would have introduced a small and potentially misleading sample of data, which could obscure the overall findings.

In this context, the results obtained from the execution of the queries in ACM, IEEE Explore, Science Direct, Scopus, and PubMed were: 441, 235, 213, 2086, and 296 papers, respectively. In addition, it was added 24 expert recommendations, adding up to a total of 3295 studies. Once the queries were executed, the filters defined in Section 3 were executed. It is imperative to underscore that the papers were divided into two sets, each containing 50% of the total papers. Each set was assigned to two researchers who conducted the classification process by applying the predefined inclusion and exclusion criteria. When conflicts arose, both researchers arrived at a mutual agreement regarding the inclusion or exclusion of the study. As a general rule, the paper was included in the group under consideration in cases of disagreement.

The objective of *F1* was to discard those papers that could appear more than once for each digital library. In this sense, 731 papers were discarded: 23 from ACM, 20 from IEEE Explore, 80 from Science Direct, 474 from Scopus, and 134 from PubMed leaving a total of 2564 papers to be filtered. *F2* raised as relevant the papers written in English. Consequently, a total of 26 papers from all digital libraries were discarded. After applying this filter, a total of 2538 papers remained to be filtered. *F3* sought to discard those papers that did not meet specific quality criteria. All papers that were not published in high-impact indexed journals (i.e., JCR ranking) or conferences (i.e., SCIE ranking) were discarded. This filter represents the most significant number of papers discarded: 273 from ACM, 116 from IEEE Explore, 1104 from Scopus, and 42 from PubMed. After applying *F3*, a total of 1003 papers were left to be filtered out.

At this point, the remaining papers were unified, and those that appeared duplicated among the different digital libraries were discarded. No specific criteria were used since this paper is focused on the quality of the papers, not on making an in-depth analysis of the digital libraries. 60 duplicates were discarded, leaving a total of 943 papers to be filtered. *F4* and *F5* filters were executed simultaneously. A total of 448 papers that did not fit the subject matter of this paper were discarded. Besides, 106 papers classified as systematic reviews, surveys, or comparisons were also discarded. A selection of these papers makes up the section of related work.

Finally, after applying all the filters, a total of **389 primary studies** were obtained to be analyzed in depth. Figure 2 summarizes the entire executed process and Figure 3 show the PRISMA flow diagram [47].

4.1. Categorization Criteria

To answer the research questions, a concept-centric review has been performed, focusing on categories related to disabilities and AT. A first survey of the analyzed papers allowed us to select the most suitable categories in each section.

4.1.1. Disabilities and diseases classification

During the analysis of the type of disability or disease on which each research work is focused, two internationally recognized classifications have been studied: The ICF [45] and the ICD [46]. The former has been established by WHO in 2001. It is a framework for measuring health and disability at both individual and population levels. The latter is a globally used diagnostic tool for epidemiology, health management,

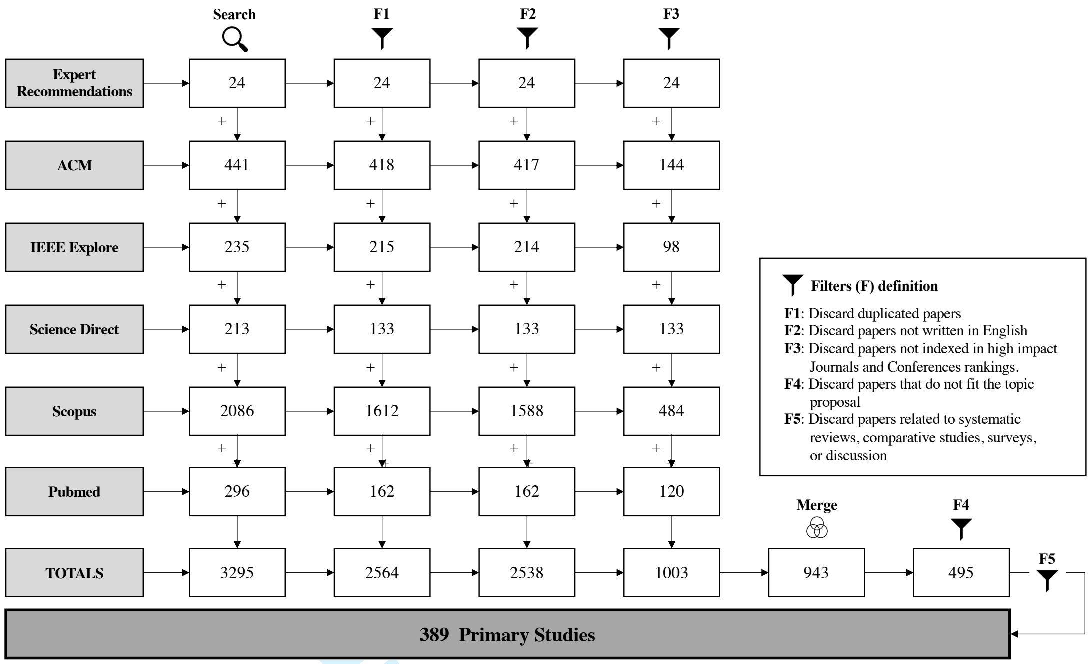


Figure 2. Execution process summary

and clinical purposes, including the classification of electronic health applications and information systems. The ICF complements WHO's ICD and both constitute the core classifications in the WHO Family of International Classifications (WHO-FIC). Both classifications are continuously evolving, but ICD is more mature, given it was born in 1948 and is being updated and reviewed continuously [48,49] by 18 Topic Advisory Groups [50].

Currently, the 11th version is being validated. ICF description is used to complement the diagnosis, helping to describe the day-to-day problems in functioning that an individual with a health condition experiences. For example, ICF explains the next: *"Two people with the same diagnosis could have very different functioning profiles and therefore different needs"*. Given the specificity of ICF, ICD was decided to be used. Furthermore, several analyzed studies focused on specific diseases, so the ICD fits better in categorizing the papers.

The categories shown in Table 4 have been selected from ICD-11 to describe the diseases. Multiple/Cross disability has been added to classify some works that propose tools for multiple disabilities or diseases. The selected categories were grouped according to the code used in ICD-11. Code 6 correspond to **mental disorders** including development disorders (6A00, 6A01, 6A03, 6A04), **dementia** (6D8x,6D80 and 6D85.0) and **specific diseases** (6A02 Autism or 6D71 mild neurocognitive disorder). Code 8 accord with **nervous system diseases** including parkinsonism, choreiform, dystonic, ataxic or tremor disorders disorders (8A0x), **Alzheimer** (not the dementia associated with) or **Lewy body disease** (8A2X), genetic disorders characterized by progressive weakness secondary to **degeneration of the lower motor neurons** (8B6x) and **Cerebral palsy** (8D2x). More general categories were associated with codes 9: visual system diseases, including **blindness**, 10: ear process such as **deafness**, 15: **musculoskeletal system** such as arthropathies, osteopathies or spine disorders, 20: developmental anomalies such as **down syndrome**, 21: **"Other" category**, 22:

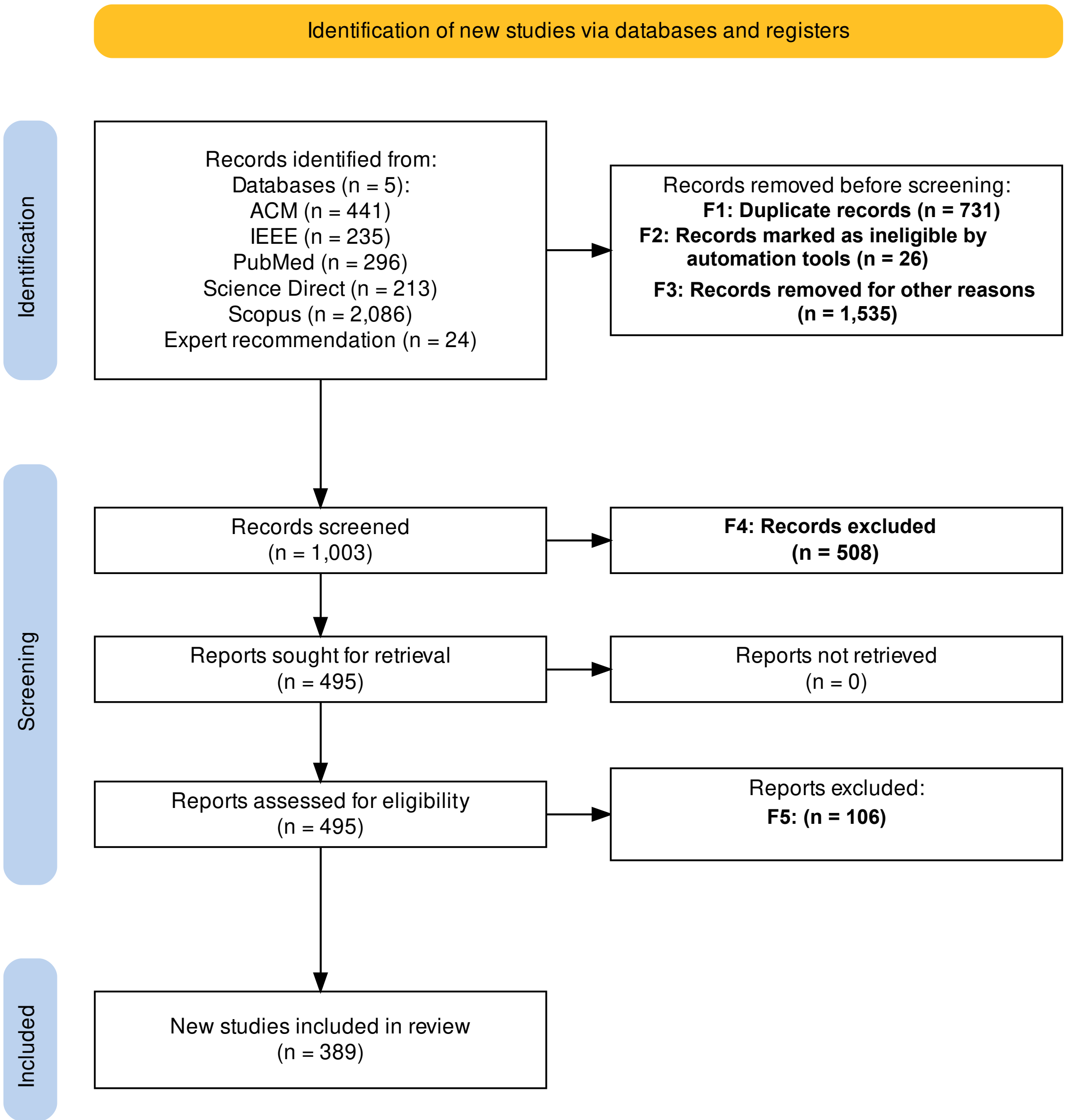


Figure 3. PRISMA flow diagram

injuries, burns and other consequences of external causes, and finally, an added category not included in ICD-11, **Multiple/cross disability**, used when a work describe a technology focused on several diseases (more than 3 in our classification).

Table 4. ICD-11 categories selected for the study.

ICD-11 category	Identifier
06 Mental, behavioral or neurodevelopmental disorders	06
6A00 Disorders of intellectual development	6A00
6A01 Developmental speech or language disorders	6A01
6A02 Autism spectrum disorder	6A02
6A03 Developmental learning disorder	6A03
6A04 Developmental motor coordination disorder	6A04
6D8x Neurocognitive disorders - Dementia	6D8x
6D71 Mild neurocognitive disorder	6D71
6D80 Dementia due to Alzheimer disease	6D80
6D85 Dementia due to Parkinson disease	6D85
08 Diseases of the nervous system	08
8A0x Movement disorders	8A0x
8A2x Disorders with neurocognitive impairment as a major feature	8A2x
8B6x Motor neuron diseases or related disorders	8B6x
8D2x Cerebral palsy	8D2x
09 Diseases of the visual system	09
10 Diseases of the ear or mastoid process	10
15 Diseases of the musculoskeletal system or connective tissue	15
20 Developmental anomalies	20
21 Symptoms, signs or clinical findings, not elsewhere classified	21
22 Injury, poisoning or certain other consequences of external causes	22
Multiple/Cross disability (not ICD-11)	Cross

4.1.2. AT categories

Concerning the categorization of AT, there are international and national standards that categorize ATs. For instance, the "United States Classification System for Assistive Technologies Devices and Service" [51]; and ISO 9999 (technical aids for people with disabilities - classification and terminology) [52], among others. These categorizations are focused on categorizing assistive products and assistive requirements from the end-user point of view [53]. In addition, they address the gamut of service provision steps, including client intake, assessment, training, and device maintenance and repair [54], but do not provide information on specific technologies. Although these previously mentioned standards are interesting, they are not framed in the context of our research paper.

This paper aims to categorize technologies (software and/or hardware) that allow the design and development of assistive solutions to improve the autonomy of people with disabilities. In this context, the AT categorization used in our paper includes 6 categories (cf. Table 5), which have been identified and refined during the categorizing process of primary studies (re-evaluating the original categories). For instance, a general category of Robotics was the starting point, but, when reading the papers, it was redefined to several subcategories: Assistant robots, assisted rehabilitation, exoskeleton and control software for robotics. This categorization allows the research community to know the technologies that are used to propose assistive solutions.

The first one is related to **computer vision** and includes augmented reality; description of the environment; machine learning techniques (given the advances with deep learning, several works are describing the architectures used [55,56]); obstacle detection (for wheelchairs or blind people), sign language recognition and virtual reality.

Another common category is **Human-computer Interface** or HCI, where the user communicates with a computer through diverse methods. In this class, several subclasses have been obtained: balance detection such as Wii balance; electroencephalography (EEG) sensor, measuring the brain activity; eye-tracking (very related to computer vision); communication using Morse code; motion recognition such as recognize some gestures; myography or electromyography (EMG) that allows performing actions in the computer when some muscles are activated; neurostimulation useful for output interaction process; object detection using computer vision or other sensors; sign language recognition; tongue motion input identifying the movement of the tongue as a computer input device; touch/keyboard or haptic interfaces again as an input device; and voice recognition with two options, vocal or habitual input (speech recognition); and non-vocal such as sounds that people that are not capable to speak can do.

Another category that has been included is vibrations as an **output device**. This case is used when the output is not related to the HCI class.

In the **Robotics** category, wheelchairs and humanoids that can help the user in some tasks, technology for rehabilitating him/her, and exoskeleton and prosthesis have been included. The description of the software control for these robots has also been taken into account.

Software class includes the subclasses of application (description of a mobile or desktop one), environment description, navigation support technology, useful to avoid getting lost; Serious games, helpful in achieving adherence to some treatment; simulators; smart homes including multiple protocols to improve the life of the user; task automation; text-to-speech synthesis and Web and Cloud software. **Wearable** class is used when the technology has enough battery to be used for several hours, and it can be worn without effort (helmet, glasses, or other devices).

4.1.3. Research category

To categorize the paper, 10 possibilities related to the main contribution have been considered. Furthermore, two possible types have been included if needed for each paper.

In this context, the contribution could be classified into the following categories: *algorithm*, which refers to the presentation or description of an algorithm that can be used to support AT proposal; *methodology*, which refers to the description of methodological guidelines for the specification or analysis of AT solutions and proposals; *framework*, which refers to the publication of guidelines or frameworks that improve or facilitate the building or development of AT proposals; *hardware*, which refers to the publication or description of AT proposals that only include hardware components; *hardware + software*, which refers to the description of software and hardware components that jointly support the AT proposal; *software*, which refers to the publication of AT proposals based on software components; *method*, which refers to systematic guide for the design of AT solutions; *models*, which refers to the description of conceptual models associated with AT solutions and proposals; *software architecture*, which refers to the description of software architectures that could be used to develop new AT proposals and solutions; and *others*, which refers to any other typology not previously considered.

4.1.4. Validation category

Since the last decades, empirical validations have been applied in Software Engineering to enrich and validate this area's knowledge and develop or improve processes, methods, and tools for software development and maintenance [57]. In that sense, this paper considers it interesting to identify and categorize the validation method followed in each primary study. The purpose is to know the maturity of formal validation methods on a research paper focused on the AT area.

The categorization used to classify each primary study is based on four values: *scientific experiment*, which refers to the use of formal experimental methods for software engineering [58,59]; *case of study in a project*, which means the validation of the proposal in a practical project in real and uncontrolled conditions and with the participation of multiple users; *proof-of-concept*, which refers to the definition of a small application scenario to verify the behavior of ATs under controlled conditions; and *non validation*, which means no validation method has been used in the primary study.

5. Threats to validity

Following the recommendations proposed by Kitchenham and Brereton [60], it is relevant to identify the risks or weaknesses detected during the execution of this systematic review. In this sense, the following are threats to the validity of the present research:

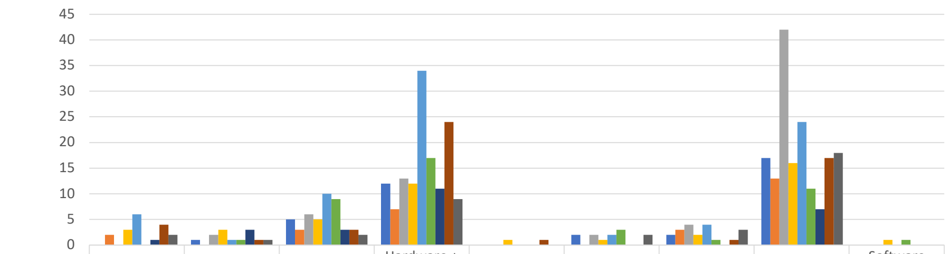
- **Diseases/disabilities categorization**: to avoid the risk of a non-useful or wrong classification of diseases or disabilities, two international categories (ICD and ICF) have been analyzed. Several categories of ICD have been used to classify the disability/disease focused on. ICF has also been analyzed and finally discarded, given the difficulty of considering each category (i.e., body functions, activities and participation, environmental factors, and body structures) or subcategories. For instance, b2 subcategory ("sensory functions and pain") includes not only seeing and hearing subcategories but two pain categories that are complex to consider given that the studies are focused on a specific disability or disease, but no pain is described for each subject. Furthermore, some works are focused on specific diseases such as cerebral palsy or autism, and the categorization using ICF will include several subcategories for each one and will hardly represent these diseases. Another threat to this process is the idea of including different categories than those selected in our study. Although the process of selecting the ones included in Table 4 has been defined a priori and refined during the categorization process to include all the papers with the most similar category, another categorization could be acceptable.
- **Technologies categorization**: given the number of possible technologies, multiple categorizations can be applied to the analysis. The ATs categories (cf. Table 5) have been established in parallel with the review process of primary studies. Furthermore, these categories have been refined during the categorizing process of primary studies (re-evaluating the original categories). Finally, it is important to mention that the selected categorization allows a hierarchy and embraces all the categories analyzed in the studies.
- **Inclusion and exclusion criteria**: some proposals focused on a topic that could be considered tangential to the use of AT for people with disability. In the

confusing cases, a consensus decision was made among all the authors to include or exclude it. In this regard, the criterion for inclusion was the description of a novel technology that assists people with disability in their daily lives. In addition, evaluations of existing technologies on groups of people with disability were considered as an exclusion criterion, given that they did not provide a novel solution but an evaluation. Furthermore, it is important to emphasize that the PICO principles (Patient/Population, Intervention, Comparison, and Outcomes) were not utilized in our study, as we adopted the SMS method, which is commonly employed in software engineering research. Nevertheless, we encourage future researchers to consider employing the PICO approach in similar investigations to enhance the precision and specificity of their research questions.

- **Language bias**: F2 proposed discarding papers that were not written in English. English's predominance in the scientific community and its widespread use in international conferences and journals facilitated access to a diverse range of relevant studies and reduced language bias. The abundance of English-language literature enabled a comprehensive and robust analysis, leading to a more reliable and meaningful study. Nonetheless, the authors recognize the significance of exploring non-English sources in future research to understand the subject matter comprehensively.
- **Publication bias**: In this case, no previous publications from the authors or co-authors have been cited, avoiding emphasizing some of the analyzed works. Furthermore, some experts colleagues in this area have analyzed the study to guarantee the criteria defined in Section 3.
- **Definition of the RQs**: RQs were formed in the most comprehensive way possible concerning publications and dates. Therefore, this research was performed as completely as possible since it does not privilege particular papers.
- **Search strings**: the quality of the selection of primary studies can be affected by the search strings (cf. Table 1) since the studies are obtained from its execution. The inaccurate definition of keywords that make up these strings may cause a significant bias in the results obtained. Two iterations of the SMS process were executed to mitigate this threat, the first to obtain preliminary results and the second to implement the complete study after refining keywords if necessary.
- **Mapping process**: when it was unclear how to classify a paper in the different categories (type, validation, technology, and disability), the authors met and discussed until a consensus was reached.

6. Results and discussion

This section aims to structurally answer the research questions posed in Section 3 and present an analysis of past and present ATs based on the previously described indicators. This analysis will provide a snapshot of the current state of ATs and show the evolution that it has undergone over the last 20 years (which allows identifying trends in this area over the next few years).



	Algorithm	Framework	Hardware	Hardware + Software	Method	Methodolgy	Model	Software	Software architecture
Class 1	0	1	5	12	0	2	2	17	0
Class 2	2	0	3	7	0	0	3	13	0
Class 3	0	2	6	13	0	2	4	42	0
Class WIP	3	3	5	12	1	1	2	16	1
Q1	6	1	10	34	0	2	4	24	0
Q2	0	1	9	17	0	3	1	11	1
Q3	1	3	3	11	0	0	0	7	0
Q4	4	1	3	24	1	0	1	17	0
WIP	2	1	2	9	0	2	3	18	0

Figure 4. Papers included in the analysis and categorized according to the quartile (Q) of the journal (JCR ranking) or class of the conference (GII-GRIN-SCIE ranking). *Note: WiP stands for Work in Progress category for conference ranking.*

6.1. *RQ1. How is the research area of AT proposals structured? What are trends concerning the publication quantity and focus of AT proposals? What are the leading publication channels for this area?*

This RQ aimed to categorize by topics according to the focus of the study and identify where each study is published as a quality metric.

On the one hand, Figure 4 shows the categories of the journal/conference. As mentioned in the inclusion and exclusion criteria (cf. section 3), the international rankings taken as a reference are the JCR for journals and the GII-GRIN-SCIE for conferences. The JCR ranking establishes four quartiles (i.e., Q1, Q2, Q3, and Q4, ordered by importance from highest to lowest) to rank the journals. A quartile is a unit used to measure the position of a journal. It is used to separate groups of journals in a given specialty, sorted by impact factor. Similarly, the GII-GRIN-SCIE ranking establishes four classes (i.e., Class 1, Class 2, Class 3, ordered by importance from highest to lowest, and WiP (i.e., Work in Progress)) to classify conferences. The conference class ranking is done through an algorithm —description available at [61]— that performs a series of calculations on data imported from other international rankings (i.e., The CORE 2018 Conference Rating [62], Microsoft Academic [63] and LiveSHINE (Google Simple H-Index Estimator) [64]. Conferences classified as WiP are those for which insufficient information is available for classification into classes 1, 2, or 3, but are recognized by the ranking.

As can be seen in Figure 4, the case of software architecture cannot be considered as a representative, since the number of related works found during the bibliographic search has been very small. Regarding the software and framework typology, the most significant number of primary studies are in Class 3 and WiP. This is justified since many of the papers categorized in these typologies have had little formal validation, in many cases necessary for journals with a high impact factor or at top-level conferences. The opposite is true for the model, methodology, and algorithm typologies. In these cases, the largest concentration of papers is found in first-level conferences (class 1) and journals, mainly in Q1. Finally, the hardware+software and hardware typologies deserve special mention since the concentration of related work in the field

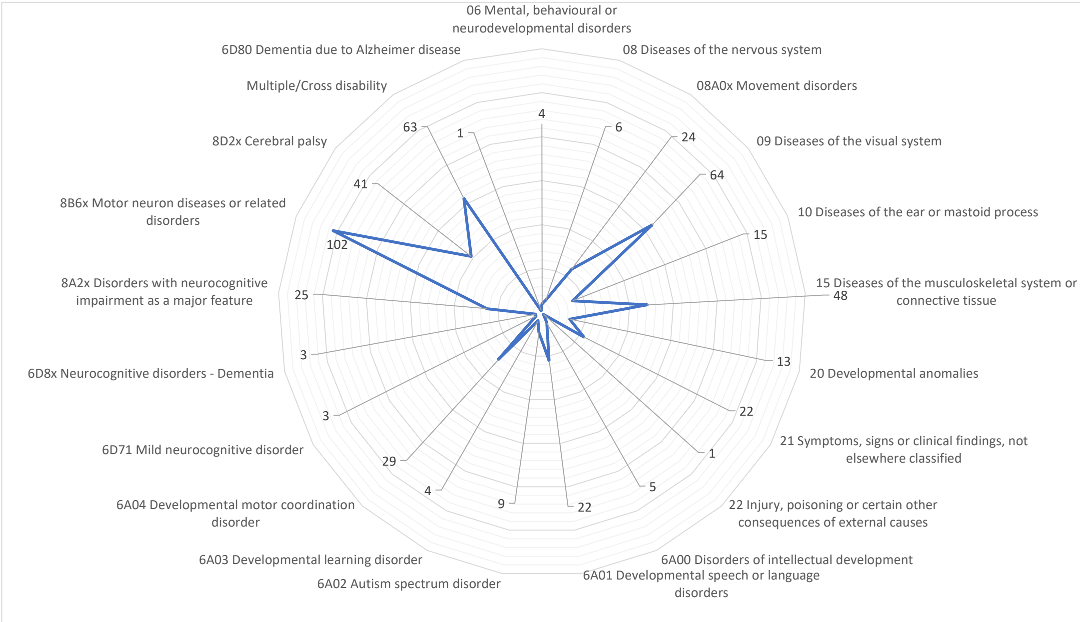


Figure 5. Number of papers under analysis associated with each type of disability

of AT has been noteworthy. Both categories contain more than 50% of the identified works, so their analysis is quite representative. Since these are the most widespread typologies in the literature, their publication in high-impact journals (Q1) and conferences, regardless of their classification, is significantly high, as can be seen in Figure 4.

On the other hand, Figure 5 shows the proportion of papers related to the different types of disabilities identified in this analysis, following ICD-11 categorization as explained in Section 4.1.1, for which relevant contributions have been found in the bibliography. To these disabilities, as previously described, the category "Cross" has been added for those solutions that apply transversely to several disabilities. It should be said that the sum of the studies associated with each disability is greater than the ones considered in this analysis, given that during the analysis of the papers, up to 3 types of disability were assigned to each paper. The same occurs in Figure 6 (up to 2 types of technology per paper). The decision to make these multiple assignments was due to the difficulty of grouping jobs into a single disability or technology category. To avoid losing information and biasing the results due to difficulties during the validation process, this solution was applied.

As it can be seen in Figure 5, data is unbalanced towards three specific disabilities: Motor neuron diseases or related disorders (8B6x), Cross (54), and Diseases of the visual system (09), with a total of 102, 63 and 64 papers classified in these categories respectively.

These categories are related to the highest concentration of people with disability in the categories 8B6x and 09, where 42 [65] and 285 million [66] of people in the world present these disabilities. In this sense, the efforts of the scientific community and companies are especially focused on these disabilities. However, after analyzing the results of our study, there are disabilities with a high incidence in the population that have been less considered by the scientific community taking into account our selection process for primary studies of our systematic review. For example, the number

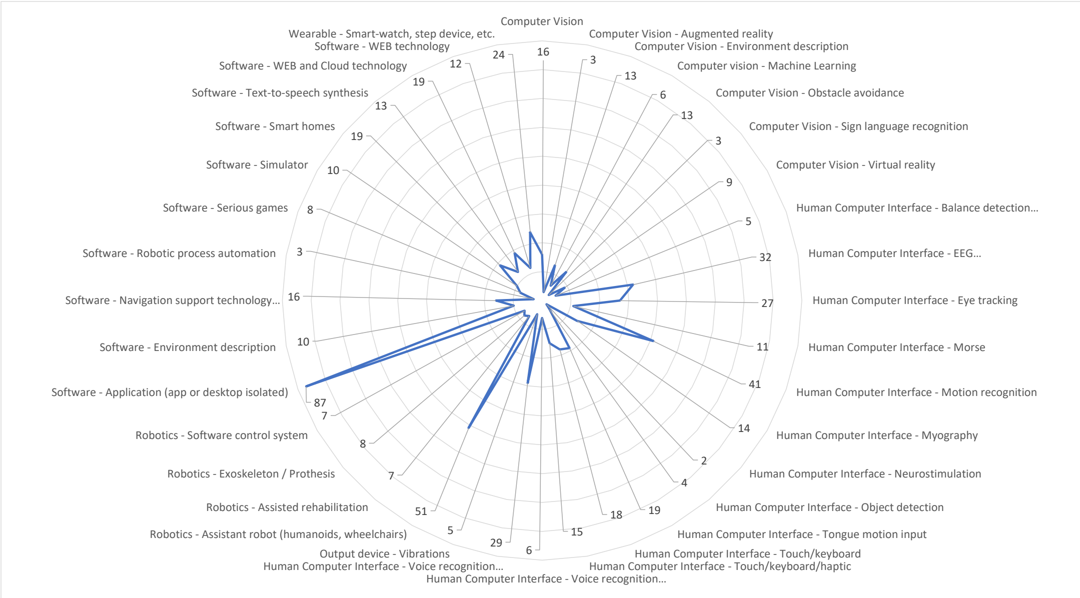


Figure 6. Number of papers under analysis associated with each type of technology

of people living with dementia worldwide is currently estimated at 50 million [67] according to WHO. However, we have only found 4 primary studies which describe ATs focused on people with dementia (6D8x Neurocognitive disorders - Dementia; 6D80 Dementia due to Alzheimer disease) as shown in Figure 9 and Table of supplemental material.

Concerning the "Cross" typology, it was also to be expected that the number of primary studies would be high, as a large number of the solutions proposed are cross-cutting and have therefore been considered in this category.

Among the other categories, Diseases of the musculoskeletal system or connective tissue (15) and Cerebral palsy (8D2x) stand out with an also considerable number of contributions.

Finally, Figure 6 shows an analysis similar to the previous one except that, instead of disabilities, it considers the categorization of developed AT. AT refers to the different technologies considered in the classification and identified during the primary studies analysis. For the classification, 36 different technologies have been identified, grouped into 6 macro-categories. In this case, the greatest amount of work is again distributed into 3 categories: Application (S-APP), Assistant robot (S-AR), and Motion recognition (HCI-MR). Again, this is related to the prevalence of data on disabilities worldwide. Application-based solutions are often targeted at visual disabilities, while assistive robots and motion recognition are largely associated with disabilities related to motor system disorders. Therefore, mentioning the same justification as in the previous case, the most significant interest of the research community (considering published papers) is focused on these areas.

The information illustrated in Figure 6, however, lacks an essential factor in making a perspective analysis of the proposed solutions: the time factor. The technologies mentioned above are well-established in the scientific field, and for many years they have produced many remarkable results. However, the emerging technologies in recent years, for example, computer vision or machine learning techniques, are relegated to the background because of their short past history. For this reason, the following answers to the research questions will consider, in addition to the number of primary studies, the time component, thus being able to identify technological trends (and declines).

The macro-category Human-Computer Interface presents most of the proposed solutions, being Computer Vision, the one with the lowest concentration. Although it could be assumed that people with vision impairments need AT from Computer Vision, the reality is that they almost need more to facilitate their interaction with the environment or computers via HCI. Therefore, it is not surprising that more application-oriented solutions or Assistant Robots surpass the computer vision category in the number of items.

According to the leading conferences for this area, we find the following four terms of their periodicity, the number of papers they present, and the researchers who participate. We indicate the number of articles evaluated in brackets before applying the filters discussed in Section 3: International ACM SIGACCESS Conference on Computers and Accessibility - ASSETS (87), Conference on Human Factors in Computing Systems - CHI (65), International Web for All Conference - W4A (40), IEEE Engineering in Medicine and Biology - EMBS (15). These conferences are highly recommended for researchers working with AT to improve the lives of people with disabilities. Concerning the journals, as explained above, only those indexed in the Journal Citation Report (JCR) are included in this study; however, we consider highly recommendable the journal ACM Transactions on Accessible Computing (TACCESS), which, although not on this list, has a subject matter closely related to this work. Another channel for dissemination and advancement of the state-of-the-art are competitions. In this sense, CYBATHLON [68] should be highlighted as it aims to break down barriers between the public, people with disabilities, and technology developers and promote the inclusion of people with disabilities.

6.2. RQ2. What are the main research types and methods found in the assistive proposals? What have scientific methods been applied to evaluate and validate each study?

This RQ aimed to identify the types of research carried out and the scientific method used to evaluate and validate each primary study. To check the maturity of a technology, a good indicator is the analysis of the results and the conditions under which those results have been evaluated. After discussing the results of RQ1 and considering the high volume of primary studies published in conferences and journals, the research community has generated a high volume of AT-based proposals practical to improve the autonomy and independence of people with disabilities. Below, the research typology of these proposals and how they have been validated according to the category of the journal or conference is analyzed.

On the one hand, Figure 7 shows an analysis of validation type, representing the validation carried out in the works analyzed, being, from more to less exhaustive: experiment, case study, proof of concept, and without validation. Contribution type refers to the typology of the proposed solution, which, in essence, determines the solution generated by the primary study (see Section 4.1.4). This analysis shows that journals classified as Q1 have the highest proportion of seriously validated papers. That is, experiments, case studies and, to a lesser extent, proofs of concept are very significantly present in this category. In contrast, lower-level conferences (class 3) present a higher percentage of papers not validated or validated by proofs of concept.

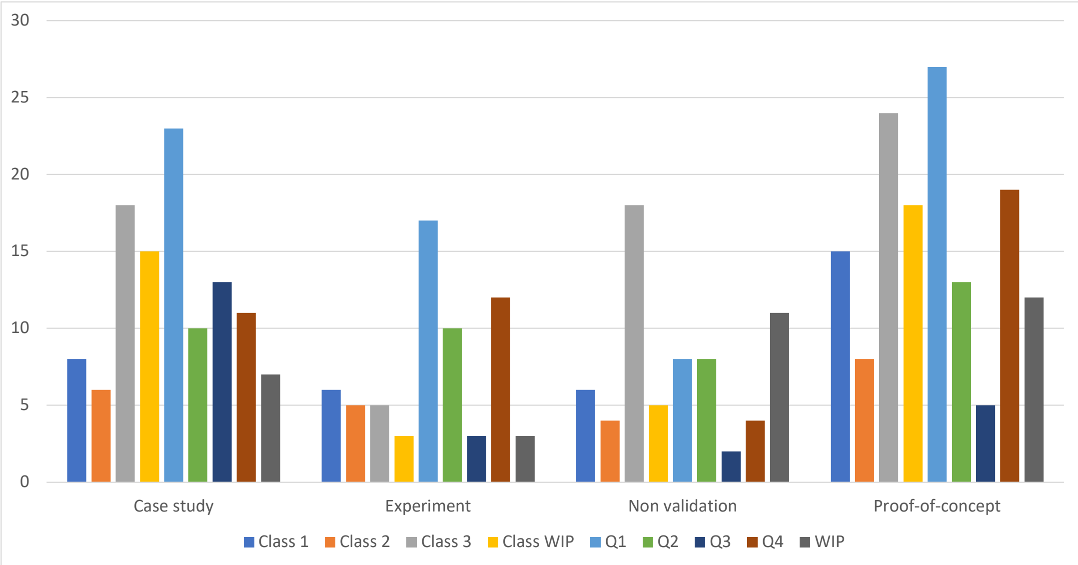
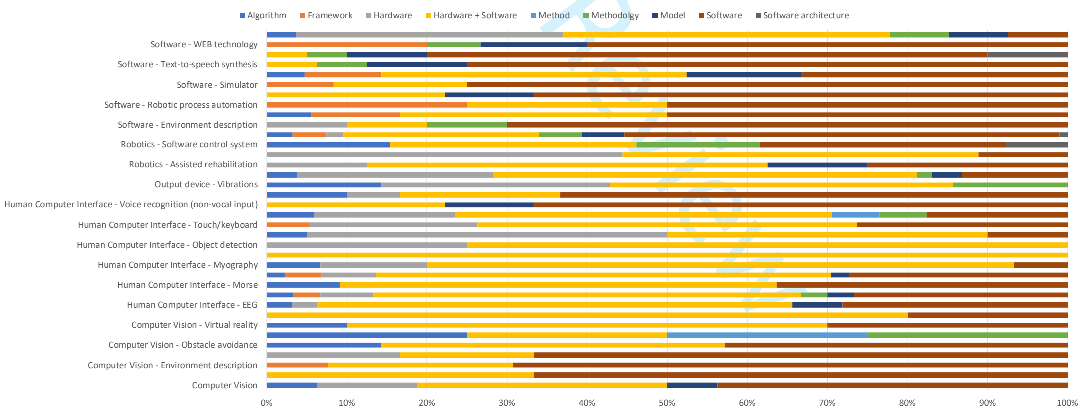


Figure 7. Number of papers grouped by type of validation in each category of journal or conference



	Computer Vision	Computer Vision - Augmented reality	Computer Vision - Environment description	Computer vision - Machine Learning	Computer Vision - Obstacle avoidance	Computer Vision - Sign language recognition	Computer Vision - Virtual reality	Human Computer Interface - Balance detection	Human Computer Interface - EEG	Human Computer Interface - Eye tracking	Human Computer Interface - Morse	Human Computer Interface - Motion recognition	Human Computer Interface - Myography	Human Computer Interface - Neurostimulation	Human Computer Interface - Object detection	Human Computer Interface - Tongue motion input	Human Computer Interface - Touch/keyboard	Human Computer Interface - Touch/keyboard/haptic
Algorithm	1	0	0	0	2	1	1	0	1	1	1	1	1	0	0	1	0	1
Framework	0	0	1	0	0	0	0	0	0	1	0	2	0	0	0	0	1	0
Hardware	2	0	0	1	0	0	0	0	1	2	0	3	2	0	1	9	4	3
Hardware + Softw	5	1	3	1	6	1	6	4	19	16	6	25	11	2	3	8	9	8
Method	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Methodolgy	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1
Model	1	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
Software	7	2	9	4	6	0	3	1	9	8	4	12	1	0	0	2	5	3
Software architect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Human Computer Interface - Voice recognition (non-vocal input)	Human Computer Interface - Voice recognition (vocal input)	Output device - Vibrations	Robotics - Assistant robot (humanoids, wheelchairs)	Robotics - Assisted rehabilitation	Robotics - Exoskeleton / Prothesis	Robotics - Software control system	Software - Application (app or desktop isolated)	Software - Environment description	Software - Navigation support technology (pedestrian)	Software - Robotic process automation	Software - Serious games	Software - Simulator	Software - Smart homes	Software - Text-to-speech synthesis	Software - WEB and Cloud technology	Software - WEB technology	Wearable - Smart-watch, step device, etc.
Algorithm	0	3	1	2	0	0	2	3	0	1	0	0	0	1	0	0	0	1
Framework	0	0	0	0	0	0	0	4	0	2	1	0	1	2	0	0	3	0
Hardware	0	2	2	13	1	4	0	2	1	0	0	0	0	0	0	0	0	9
Hardware + Softw	2	6	3	28	4	4	4	23	1	6	1	2	2	8	1	1	0	11
Method	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methodolgy	0	0	1	1	0	0	2	5	1	0	0	0	0	0	1	1	1	2
Model	1	0	0	2	1	0	0	5	0	0	0	1	0	3	2	2	2	2
Software	6	19	0	7	2	1	4	51	7	9	2	6	9	7	12	14	9	2
Software architect	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	0	0

Figure 8. Papers grouped by technology belonging to each of the classification categories

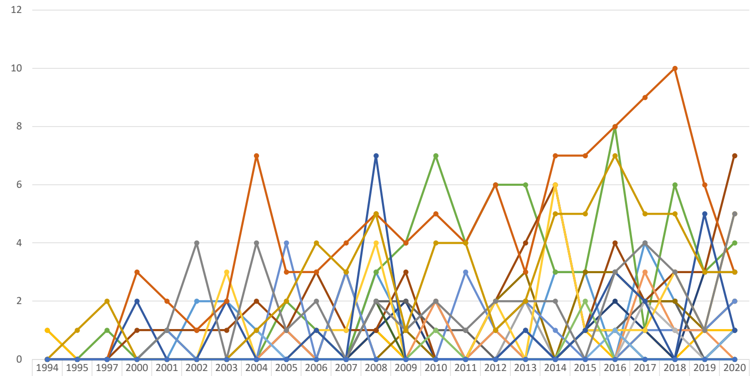
On the other hand, Figure 8 illustrates the analyzed works grouped by technology belonging to each type. This fact will answer the question of what types of technology are used in the field of AT and how they are classified. According to the results obtained and presented in the previous figure, the most widespread typology is software and hardware, and the combination of both ones. This means that software and hardware works prevail over models, methodologies, and algorithms. This concentration of works in these categories is perfectly visualized in the technologies Voice recognition with non-vocal input (HCI-VRNV), Text-to-speech synthesis (S-TTS), and Environment description (S-ED), where 80% of the works considered belong to the category "software".

6.3. RQ3. What disability categories are treated using assistive proposals?

This RQ aimed to categorize each analyzed proposal according to the type of disability. In this sense, the categories of disability for which ATs have provided solutions and have made significant progress in the state-of-the-art have been identified. To this end, the primary studies have been analyzed from a timeless perspective, through the correlation between technologies and disabilities, and from a temporal point of view, through the evolution of work on AT over the last 2 decades.

Figure 6.4 displays the number of analyzed papers tied to a specific technology and a specific disability. The point height indicates the number of papers at each intersection so that those technologies applied mostly to a specific disability will have a higher value than those technologies that have not been applied to that disability. Four main peaks can be seen. The first and highest appears with the technology assistant robots (R-AR) on the disability "degeneration of the lower motor neurons" (8B6x). Most of the works grouped in this category propose assistive solutions (at home and outdoors, such as the use of motorized wheelchairs) for people with reduced mobility. For this reason, this association between technology and disability is not strange, reaching a total of 23 related papers. Moreover, also related to the disability "degeneration of the lower motor neurons" (8B6x), we can see in the same figure that Human-Computer Interface - EEG (HCI-EEG), Human-Computer Interface - Eye tracking (HCI-ET) and Application (S-APP), where the contributions to this disability have also been relevant. Specifically, the number of contributions understudy with the previous technologies applied to this disability is 21, 15, and 12, respectively. Although with a lower number of contributions, the Application Technologies (S-APP) also offer solutions for the following disabilities: Diseases of the visual system (09) with 12 related papers and Cerebral palsy (8D2X) with 9 studies. In addition, assistant robot (AR) technology also makes significant contributions to the following disabilities: Cross disabilities with 10 related papers and Diseases of the musculoskeletal system or connective tissue (15) with 13 related studies.

Continuing the above analysis, in Figure 9 a temporal vision is offered that will enable the analysis of the trends identified through the study of the evolution in the number of related primary studies in the different technologies and applied to the identified disabilities. The figure shows how the technology applied to Motor neuron diseases or related disorders (8B6x) has been increasing over the last few years, reaching 10 considered primary studies in 2018. Although this increase is particularly significant, for most disabilities it can be seen how the number of related papers has grown steadily over the last decade. Contrary to the previous trend, there are disabilities where the impact of technology is not particularly significant. For instance,



	1994	1995	1997	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
06 Mental, behavioural or neurodevelopmental disorders	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0
08 Diseases of the nervous system	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1	1
08A0x Movement disorders	0	0	0	0	0	2	2	1	0	0	0	3	1	2	0	1	0	3	3	0	4	2	0	0
09 Diseases of the visual system	0	0	1	0	1	0	0	0	2	1	0	3	4	7	4	6	6	3	3	8	1	6	3	4
10 Diseases of the ear or mastoid process	0	0	0	0	0	0	0	0	1	0	0	1	2	0	0	0	1	0	1	2	1	0	3	3
15 Diseases of the musculoskeletal system or connective tissue	0	0	0	1	1	1	1	2	1	3	1	1	3	0	0	2	4	6	1	4	2	3	3	7
20 Developmental anomalies	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	0	0	0	1	1	2	2	0	1
21 Symptoms, signs or clinical findings, not elsewhere classified	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	2	3	0	3	3	2	2	1	2
22 Injury, poisoning or certain other consequences of external causes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6A00 Disorders of intellectual development	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	1	0	0	0	1
6A01 Developmental speech or language disorders	0	0	0	0	1	0	0	0	4	0	3	0	0	0	3	1	2	1	0	0	1	1	1	2
6A02 Autism spectrum disorder	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	1	0	0	0	0	3	1	1	0
6A03 Developmental learning disorder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	0	0
6A04 Developmental motor coordination disorder	0	0	0	0	0	0	3	0	0	1	1	4	0	0	0	2	0	6	1	1	1	3	1	5
6D71 Mild neurocognitive disorder	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
6D8x Neurocognitive disorders - Dementia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0
8A2x Disorders with neurocognitive impairment as a major feature	0	0	0	2	0	0	2	0	0	1	0	7	0	0	0	0	1	0	1	3	2	0	5	1
8B6x Motor neuron diseases or related disorders	0	0	0	3	2	1	2	7	3	3	4	5	4	5	4	6	3	7	7	8	9	10	6	3
8D2x Cerebral palsy	0	0	0	0	1	4	0	4	1	2	0	2	1	2	1	2	2	2	0	3	4	3	1	5
Multiple/Cross disability	0	1	2	0	0	0	0	1	2	4	3	5	1	4	4	1	2	5	5	7	5	5	3	3
6D80 Dementia due to Alzheimer disease	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

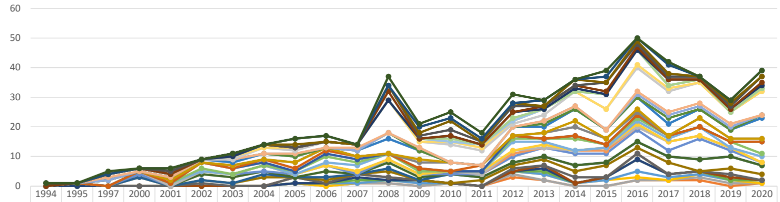
Figure 9. Analysis of the temporal trend of the papers understudy on each of the disabilities present in the classification

on "Diseases of the nervous system" (08), "Mental, behavioral or neurodevelopmental disorders" (06), and "Movement disorders" (8A0x). As it can be seen in Figure 9, the presence of related jobs in these disabilities is not particularly significant. Special mention should be made of "Symptoms, signs or clinical findings, not elsewhere classified" (21). This category groups together pathologies not included in any of the previous classifications and, therefore, they are usually associated with rare diseases.

6.4. RQ4. What is the scientific or technological typology presented in the assistance proposals?

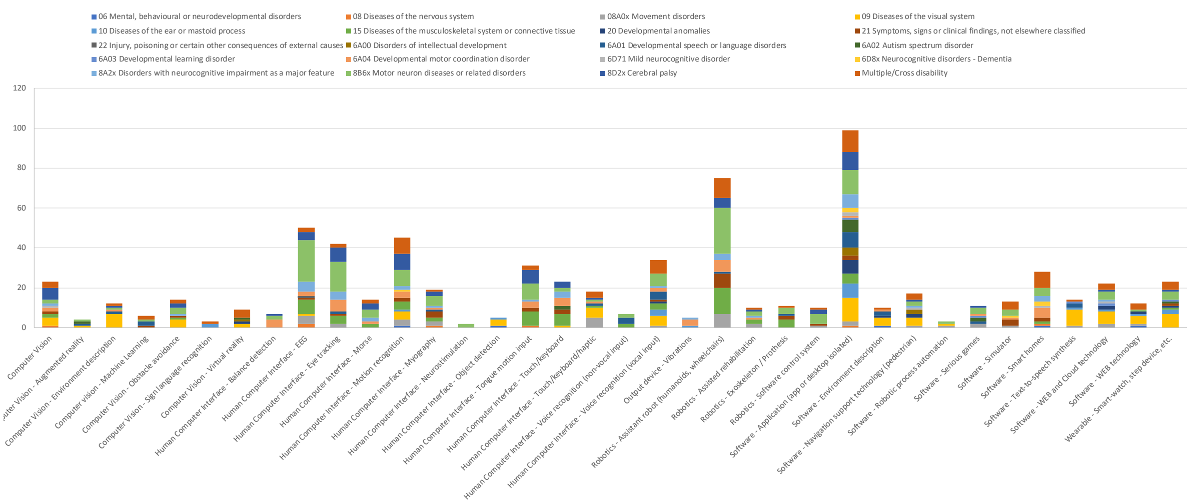
This RQ aimed to categorize the assistance proposals according to scientific or technological typology. In this paper, this RQ is perhaps the most ambitious of all as it seeks to outline the future of ATs. Based on the processed works and their technological and temporal categorization, Figure 10 shows the technological evolution in this area of research. Both figures have been generated from the same information, but through the two visualizations, it is possible to appreciate nuances for the elaboration of the trend hypotheses.

In Figure 10, the temporal evolution of the identified technologies is projected. Although it appears that all technologies have evolved, increasing the number of identified works, some have done so more clearly. For example, applications (S-APP), Human-Computer Interface - Tongue motion input (HCI-T) or Human-Computer Interface - Voice recognition (HCI-VRNV and HCI-VRV) have shown an average year-on-year growth of more than 40% since 2012. Special mention should be made of computer vision-related technologies where, in virtually all subcategories, the overall number of



	1994	1995	1997	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Wearable - Smart-watch, step device, etc.	0	0	1	0	0	0	0	0	0	0	0	3	1	2	2	3	0	0	2	0	1	0	0	0
Software - WEB technology	0	0	0	0	0	0	0	0	2	2	0	0	2	1	1	0	2	0	2	1	3	0	1	2
Software - WEB and Cloud technology	0	0	0	0	1	0	0	0	1	0	0	0	1	3	0	1	0	2	0	1	1	0	1	0
Software - Text-to-speech synthesis	1	0	0	0	1	0	0	0	0	0	0	2	1	2	1	2	0	0	3	1	1	1	1	2
Software - Smart homes	0	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	1	1	1	1	0	0	0	1
Software - Simulator	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	1	0	0	2	0	1	1
Software - Serious games	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Software - Navigation support technology (pedestrian)	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	5	5	1	1	0	1
Software - Environment description	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	1	2	0	0	1	1	0	0	0
Software - Application (app or desktop isolated)	0	0	1	1	1	0	0	2	1	2	1	11	2	6	5	1	2	5	7	8	7	7	4	8
Robotics - Software control system	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	0
Robotics - Exoskeleton / Prothesis	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	1	1	1	1	0
Robotics - Assisted rehabilitation	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	1	0	0	0	2	0	0	1
Robotics - Assistant robot (humanoids, wheelchairs)	0	0	0	0	1	1	1	2	2	0	2	5	3	0	0	3	2	4	3	4	4	3	3	7
Output device - Vibrations	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	1	0	0	0	0
Human Computer Interface - Voice recognition (vocal input)	0	0	2	0	1	0	1	0	2	1	0	0	2	3	0	0	2	3	2	1	0	3	1	1
Human Computer Interface - Voice recognition (non-vocal input)	0	0	0	0	0	0	0	1	1	1	1	0	0	0	2	0	0	0	0	0	0	0	0	0
Human Computer Interface - Touch/keyboard/haptic	0	0	0	0	0	2	2	1	0	1	1	0	1	0	0	1	0	1	0	1	0	0	0	4
Human Computer Interface - Touch/keyboard	0	0	0	0	0	1	0	0	1	2	1	0	0	0	0	1	1	4	1	1	1	0	2	1
Human Computer Interface - Tongue motion input	0	0	0	0	0	0	0	0	0	1	2	2	1	0	0	3	1	0	0	1	1	3	0	2
Human Computer Interface - Object detection	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0
Human Computer Interface - Neurostimulation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Human Computer Interface - Myography	0	0	0	1	0	0	0	2	0	0	1	0	0	1	0	1	0	1	1	1	3	1	1	0
Human Computer Interface - Motion recognition	0	0	0	0	0	1	1	0	1	2	0	1	1	0	1	2	3	4	3	4	2	7	2	1
Human Computer Interface - Morse	0	0	0	1	0	2	2	1	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0
Human Computer Interface - Eye tracking	0	0	0	0	0	0	0	1	0	1	0	1	0	3	1	1	1	2	1	2	2	4	4	3
Human Computer Interface - EEG	0	0	0	3	0	1	1	3	0	1	0	2	0	0	2	1	2	2	4	2	4	0	2	2
Human Computer Interface - Balance detection	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	1	0
Computer Vision - Virtual reality	0	1	0	0	0	0	0	0	2	0	1	1	0	0	0	0	1	0	0	2	0	0	0	0
Computer Vision - Sign language recognition	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0
Computer Vision - Obstacle avoidance	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	4	1	1	0	0
Computer vision - Machine Learning	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0	1
Computer Vision - Environment description	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	2	1	2	1	0	1	1	0
Computer Vision - Augmented reality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0
Computer Vision	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	3	2	0	0	2	2	2	0	1

Figure 10. Linear chart of the temporal trend of the papers under study on each of the technologies present in the classification



	Computer Vision	Computer Vision - Augmented reality	Computer Vision - Environment description	Computer vision - Machine Learning	Computer Vision - Obstacle avoidance	Computer Vision - Sign language recognition	Computer Vision - Virtual reality	Human Computer Interface - Balance detection	Human Computer Interface - EEG	Human Computer Interface - Eye tracking	Human Computer Interface - Morse	Human Computer Interface - Motion recognition	Human Computer Interface - Myography	Human Computer Interface - Neurostimulation	Human Computer Interface - Object detection	Human Computer Interface - Tongue motion input	Human Computer Interface - Touch/keyboard	Human Computer Interface - Touch/keyboard/haptic	Human Computer Interface - Voice recognition (non-vocal input)	Human Computer Interface - Voice recognition (vocal input)	Output device - Vibrations	Robotics - Assistant robot (humanoids, wheelchairs)	Robotics - Assisted rehabilitation	Robotics - Exoskeleton / Prothesis	Robotics - Software control system	Software - Application (app or desktop isolated)	Software - Environment description	Software - Navigation support technology (pedestrian)	Software - Robotic process automation	Software - Serious games	Software - Simulator	Software - Smart homes	Software - Text-to-speech synthesis	Software - WEB and Cloud technology	Software - WEB technology	Wearable - Smart-watch, step device, etc.
06 Mental, behavioural or neurodevelopmental disorders	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0
08 Diseases of the nervous system	1	0	0	0	0	0	0	0	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
08A0x Movement disorders	0	0	0	0	0	0	0	0	4	2	0	3	2	0	0	0	0	5	0	1	0	7	2	0	1	2	0	1	1	2	1	0	1	2	1	0
09 Diseases of the visual system	4	1	7	0	4	0	2	0	1	0	0	4	0	0	3	0	1	5	0	5	0	0	0	0	0	12	4	4	1	0	0	0	8	6	4	7
10 Diseases of the ear or mastoid process	0	0	0	0	0	2	0	0	0	0	0	1	0	0	1	0	0	0	0	3	1	0	0	0	0	7	0	0	0	0	0	0	1	1	1	2
15 Diseases of the musculoskeletal system or connective tissue	2	0	0	0	1	0	0	0	7	4	2	4	2	0	0	7	6	1	2	3	0	13	2	4	0	5	0	0	0	0	0	1	0	0	0	1
20 Developmental anomalies	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	7	1	2	0	0	0	0	0	2	1	1
21 Symptoms, signs or clinical findings, not elsewhere classified	1	0	0	1	1	0	0	0	1	1	0	2	3	0	0	2	2	0	0	1	0	7	0	2	1	2	0	0	0	0	3	2	0	0	0	1
22 Injury, poisoning or certain other consequences of external causes	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6A00 Disorders of intellectual development	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	0	0	0	0	0	0	0	0
6A01 Developmental speech or language disorders	0	1	1	2	0	0	0	0	0	1	0	0	1	0	0	0	0	1	3	4	0	1	0	1	0	8	2	0	0	1	0	0	2	0	0	0
6A02 Autism spectrum disorder	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	6	0	0	0	2	0	0	0	0	0	1
6A03 Developmental learning disorder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1
6A04 Developmental motor coordination disorder	2	0	1	0	0	0	0	4	2	6	1	3	1	0	0	3	4	1	0	2	3	6	1	0	0	1	1	0	0	1	1	5	0	0	0	0
6D71 Mild neurocognitive disorder	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	1	0	0
6D8x Neurocognitive disorders - Dementia	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	2	0	0	0	0
8A2x Disorders with neurocognitive impairment as a major feature	1	0	0	0	1	0	0	0	5	4	2	2	1	0	0	1	3	0	0	1	1	3	1	0	0	7	0	1	0	0	0	3	0	1	0	0
8B6x Motor neuron diseases or related disorders	2	1	1	1	3	0	0	2	21	15	4	8	5	2	0	8	2	1	2	6	0	23	2	3	5	12	0	2	1	3	3	4	0	4	1	4
8D2x Cerebral palsy	6	0	1	0	2	0	0	1	4	7	3	8	2	0	0	7	3	1	0	0	0	5	1	0	2	9	0	1	0	1	0	0	0	1	0	1
Multiple/Cross disability	3	0	1	2	2	1	4	0	2	2	2	8	1	0	0	2	0	3	0	7	0	10	1	1	1	11	1	3	0	0	4	8	1	3	3	4

Figure 11. Cross table with the primary studies under study corresponding to each disability in each of the technological categories described

related jobs has increased. This is in line with the global rise of this technology not only in the healthcare field but also in different contexts such as safety, autonomous driving, and disease diagnosis among others using Deep Learning techniques.

In 2008 and 2016, despite the evolution of each technology individually, two very pronounced peaks can be observed. Moreover, these peaks occur independently of technology, so their explanation does not seem to lie in the development of disruptive technology or/in the evolution of individual technologies. If the historical context is analyzed, in 2008 the decision 742/2008/EC of the European Commission [69] takes place through which the use of ATs in domestic environments and the use of these for the assistance of people with disability and dependent elderly people is regulated. In addition, in July 2008 the AppStore [70] for iOS and in October 2008 the Android application store (Google Play - [71]) were presented worldwide, representing a before and after in the proliferation and use of mobile applications for any purpose. This fact may be fundamental for the number of publications categorized as S-APP to grow drastically this year, reaching 11 papers in 2008 compared to the maximum of 2 published during the previous decade. On the other hand, at the end of 2015, the WHO will publish the "Health technology assessment" (HTA) [72], the systematic evaluation of properties, effects, and impact of ATs. This document provides the institutional framework for regulating these technologies and, therefore, the impact the following year on the number of related publications does not seem to be a simple coincidence.

Finally, and as a summary of the process carried out in this paper, Figure 6.4 —described as a table in the supplementary files— is shown. This figure shows the primary jobs classified by type of disability and by technology. As commented previously, it was decided to allow the same primary study to be classified into up to three types of technology and two types of disability. Therefore, the sum of all of the values of the Table presented in the supplemental material does not coincide with the number of selected primary studies. As can be observed, regarding the distribution of technologies, there are five categories where the number of contributions is higher. In decreasing order, S-APP (mobile applications), R-AR (assistive robots), HCI-MR (motion recognition), HCI-VRV (voice recognition with vocal input), and HCI-ET (eye-tracking). These categories were already commented on previously, so in Figure 6.4, it is possible to appreciate that not only the number of studies is interesting, but also the heterogeneous distribution in which these studies are distributed when contributing to various types of disability. In this sense, although there is indeed a certain dispersion in the contributions, most of them are concentrated in the previous technologies and three disabilities, in particular, 8B6x, Cross, and 09. These disabilities are not only one of the most considered in terms of the number of primary studies, but they are also disabilities that have contributed approximately 80% of the technologies identified so they could be considered "transversely technological". Conclusively, the leading technologies in the care sector have been analyzed. In addition, those disabilities that, due to the number of persons affected or their impact on the scientific community is especially relevant, have been considered. This process has led to some curious conclusions, both from the assistance and technological point of view, providing a snapshot of the advances made in the last decade in the area of ATs. Moreover, the study, having been framed in a temporal progression, has allowed us to identify trends based on the evolution of contributions over the last few years.

7. Conclusion and future work

The purpose of this study is to review the ATs state-of-the-art proposed to support the empowering of people with disability. To fulfill this objective, a rigorous and systematic process (i.e., SMS [24]) has been followed. Considering the objective of the research, four RQs were established to identify some key issues, including: (1) research area structure in terms of metrics (i.e., trends, publication channels, or quantity of publication, among others), (2) type of approaches proposed, (3) type of disabilities treated based on assistive proposals and (4), the technological typology of the proposals. Once defined and planned the SMS, it was conducted, resulting in 3295 studies. After applying the inclusion and exclusion criteria, 389 primary studies remained to be analyzed in-depth. Afterward, the mapping process was applied to the studies to generate the information needed for answering the RQs.

This paper has led to some curious conclusions, both from the assistance and technological point of view, providing a snapshot of the advances made in the last two decades in the area of ATs. Furthermore, having been framed in a temporal progression, this paper has allowed us to identify trends based on the evolution of contributions over the last years. ATs to support people with disability is an actual and engaging research area. It has become a trending topic over the years, raising the number of publications in the field.

Although it appears that all ATs have evolved, increasing the number of identified works, some have done so more clearly. There are five categories with a higher number of contributions. In decreasing order, S-APP (mobile applications), R-AR (assistive robots), HCI-MR (motion recognition), HCI-VRV (voice recognition with vocal input), and HCI-ET (eye-tracking). It is possible to appreciate the heterogeneous and dispersion distribution in which these ATs are distributed when contributing to various types of disability. In this sense, most of the studies are concentrated on the previous ATs and three primary disabilities: 8B6x (Motor neuron diseases or related disorders), Cross (Multiple/Cross disability), and 09 (Diseases of the visual system). These disabilities are not only one of the most considered in terms of the number of primary studies. The number of disabilities supported by technologies is unbalanced, but the previous three disabilities have contributed approximately 80% of the ATs identified.

After analyzing the results of our study, there are disabilities with a high incidence in the population that have been less considered by the scientific community taking into account our selection process for primary studies of our systematic review. For example, code 10 (Diseases of the ear or mastoid process), have been less explored despite the affected world population —According to the WHO, 466 million people worldwide have hearing loss, either from congenital or acquired deafness [73]. In this sense, systems such as sign language recognition or improved techniques for cochlear implants can improve the life quality of the deaf community. Also, the number of people living with dementia worldwide is currently estimated at 50 million according to WHO [67]. However, we have only found 4 primary studies which describe ATs focused on people with dementia (6D8x Neurocognitive disorders - Dementia; 6D80 Dementia due to Alzheimer disease; 6D85 Dementia due to Parkinson disease) as shown in Figure 9 and Table provided in supplemental material).

Regarding future works, we propose to investigate Model-Driven methods and mechanisms to systematize the design and development of ATs from the definition of technology-independent models. Furthermore, these mechanisms would allow proposing tools to define and execute tests from the early stages of these technologies' design. Also, all the primary studies analyzed propose very concrete and specific technological proposals to provide support to the day-to-day challenges of people with specific disabilities. In this sense, it is planned to investigate mechanisms that facilitate the design and development of assistive and customizable technologies. Moreover, an analysis and discussion about ATs in terms of effectiveness, cultural aspects, affordability, sources of payment, or government policies, among others, will be performed as future work. The use of ATs could depend on these factors, which could become decisive for end users.

Finally, some threats to the validity of the present research were identified, which were related to the categorization of disabilities and categorization of ATs, as well as factors that could affect our systematic review (such as publication bias, definition of the RQs, search strings, and inclusion and exclusion criteria). All these factors were analyzed and their risk was mitigated as described in Section 5.

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Table 5. AT Categories considered

Category	Identifier
Computer Vision - Augmented reality	CV-AR
Computer Vision - Environment description	CV-ED
Computer Vision - Machine Learning	CV-ML
Computer Vision - Obstacle avoidance	CV-OA
Computer Vision - Sign language recognition	CV-SL
Computer Vision - Virtual reality	CV-VR
Computer Vision - Others	CV
Human Computer Interface - Balance detection	HCI-BD
Human Computer Interface - EEG	HCI-EEG
Human Computer Interface - Eye tracking	HCI-ET
Human Computer Interface - Morse	HCI-M
Human Computer Interface - Motion recognition	HCI-MR
Human Computer Interface - Myography	HCI-MYO
Human Computer Interface - Neurostimulation	HCI-NEURO
Human Computer Interface - Object detection	HCI-OD
Human Computer Interface - Tongue motion input	HCI-TMI
Human Computer Interface - Touch/keyboard/haptic	HCI-HAP
Human Computer Interface - Voice recognition (non-vocal input)	HCI-VRNV
Human Computer Interface - Voice recognition (vocal input)	HCI-VRV
Output device - Vibrations	OD-V
Robotics - Assistant robot (humanoids, wheelchairs)	R-AR
Robotics - Assisted rehabilitation	R-REHAB
Robotics - Exoskeleton / Prosthesis	R-EX
Robotics - Software control system	R-SCS
Software - Application (app or desktop)	S-APP
Software - Environment description	S-ED
Software - Navigation support technology	S-NST
Software - Serious games	S-SG
Software - Simulator	S-SIM
Software - Smart homes	S-SH
Software - Robotic process automation	S-RPA
Software - Text-to-speech synthesis	S-TTS
Software - Web technology	S-WEB
Software - Cloud technology	S-CLOUD
Wearable	WEAR

Two Decades of Assistive Technologies to Empower People with Disability: a Systematic Mapping Study

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ARTICLE HISTORY
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1. Supplementary table with the primary studies under study corresponding to each disability in each of the technological categories described

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Table 1. Disabilities vs. technological categories classification scheme

	06	6A00	6A01	6A02	6A03	6A04	6D71	6D8x	08	8A0x	8A2x	8B6x	8D2x	09	10	15	20	21	22	Cross
CV-AR			[1]	[2]								[1]		[3]						
CV-ED			[4]									[5]	[6]	[7–15]		[5]				[16]
CV-ML			[17, 18]									[18]						[19]		[20,21]
CV-OA								[22]			[23]	[24–27]	[24,25]	[12,28–30]		[23,31]		[26, 27]		[32,33]
CV-SL															[34, 35]					[36]
CV-VR		[37]		[38]										[39,40]			[37]			[36,36,41,42]
CV						[43,44]	[45]		[46]		[47]	[48,49]	[43,46, 48–51]	[45,52–54]		[51,55]		[44]		[56,57]
HCI-BD						[58–60]						[58,61]	[62]							
HCI-EEG						[63,64]			[65, 66]	[67,68]	[64,65, 69–71]	[63,67–69,72–89]	[66,82, 85,90]	[91]		[72,74, 76,78,79, 84,92]		[77]	[93]	[42,94]
HCI-ET			[95]			[95–100]				[98, 101]	[96,97, 99,102]	[100,101,103–114]	[107–111,115]			[55,103, 104,116]		[117]		[118]
HCI-MYO			[119]			[98]			[120]	[98, 121]	[122]	[82,87,121–123]	[82,115]			[31,119]		[124, 125]		[36]
HCI-HAP			[126]	[38, 127]		[128–132]				[68, 133–136]	[129, 137, 138]	[68,139,140]	[140–142]	[53,91, 143–146]		[92,116, 130,138, 139,147, 148]		[131, 149]		[150–152]
HCI-VRNV			[153–155]									[154,156]				[157,158]				
HCI-VRV			[159, 160]			[63,161]				[162]	[161]	[63,163–167]		[162,163, 168–170]	[171–173]	[92,164, 167,174]	[170]	[175]		[41,176–179]
HCI-NEURO												[180,181]								

	06	6A00	6A01	6A02	6A03	6A04	6D71	6D8x	08	8A0x	8A2x	8B6x	8D2x	09	10	15	20	21	22	Cross
HCI-MR	[182]		[119]			[100,161,183]		[184]		[185–187]	[161,188]	[48,100,112,140,166,183,185,189–192]	[48,50,62,140,193–196]	[39,40,182,197]	[198]	[148,190,193,199]		[117,119,195]		[21,56,176,178,200–203]
HCI-M						[204]					[205,206]	[204,207–209]	[90,208,210]			[207,210]				[211–213]
HCI-TMI						[183,214,215]			[46]			[49,166,216–220]	[46,51,85,221]			[51,174,221]		[222]		[223,224]
HCI-OD	[225]													[91,225,226]	[227]					
OD-V						[59,60]					[228]		[107]		[229]					
R-AR			[95]			[44,95,230]				[187,231–235]	[23,102,122]	[5,24–27,84,89,113,122,140,165,230,231,233,235–244]	[24,25,140,236,237,244]			[5,23,84,232,242,243,245–251]		[26,27,44,175,247,252,253]		[94,150,202,224,254–259]
R-REHAB						[230]				[232,260]	[47]	[230,260]	[261]			[232,246]				[259]
R-EX			[262]									[262–264]				[31,247,263,265]		[124,247]		[203]
R-SCS										[266]		[107,264,266,267]	[195]		[107]					[124,195]
S-APP		[268–271]	[119,154,272–276]	[2,127,277–280]	[281]	[214]	[282,283]	[22,184]	[284]	[67,121,162,266,285]	[205,206,268,286–288]	[67,121,139,181,191,266,275,285,285,289,290]	[108,109,142,221,261,291–293]	[13,162,286,288,294–300]	[172,198,229,301–304]	[119,147,157,221]	[276,305–309]	[284,310]		[118,212,213,256,283,311–318]
S-NST		[270,271]					[282]			[235]	[228]	[24,235]	[24]	[13,29,30,319]			[320,321]			[32,33,315,322]
S-RPA										[323]		[190,323]		[324]		[190]				
S-SG			[18]	[325,326]	[325]	[43]					[185,186]	[18,185,327]	[43]							[328]
S-SIM						[204]		[83]		[285]		[27,204,285]						[27,83,253]		[42,329–332]
S-SH						[58,64,97,129,131]	[283]	[22,83]			[64,97,129]	[58,81,167,192]				[167]		[83,131]		[179,201,259,283,313,322,333–335]
S-TTS			[274,336]		[337]					[162]				[162,168,337–342]	[171]					[151,343]
S-WEB	[344]							[345]		[323]		[323]		[298,324,346,347]	[348]		[309,344]			[349–352]
S-CLOUD					[353]		[45]			[67,266]	[137]	[67,75,192,266]	[291]	[10,45,170,354–356]	[357]		[170]			[358–360]
S-ED	[225]		[272,361]			[362]								[225,226,363–365]			[366]			[151]
WEAR				[280]	[281]							[112,190,263,289]	[196]	[12,143,197,226,367–369]	[370]	[190,251,263]	[281]	[371]		[41,118,203,358,372,373]

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