Understanding Research Themes and Interactions at Scale within Blind and Low-vision Research in ACM and IEEE

MAXIMILIANO JEANNERET MEDINA[*,†], HEG Arc, HES-SO // University of Applied Sciences Western Switzerland, Switzerland
YONG-JOON THOO[*], University of Fribourg, Switzerland
CÉDRIC BAUDET, HEG Arc, HES-SO // University of Applied Sciences Western Switzerland, Switzerland
JON E. FROEHLICH, University of Washington, USA
NICOLAS RUFFIEUX, University of Fribourg, Switzerland
DENIS LALANNE, University of Fribourg, Switzerland

This article extends our 2023 ASSETS paper, *"A Large-Scale Mixed-Methods Analysis of Blind and Low-vision Research in ACM and IEEE,"* which provided a field-, technology-, and method-agnostic examination of blind and low-vision (BLV) research. Our mixed-methods approach combined quantitative bibliometric analyses with a qualitative analysis of the field, resulting in four high-level research areas. Building on this analysis, we further explore these areas by identifying and characterizing research themes and examining how the notion of *interaction* has been used in BLV research through an analysis of co-located terms. Our results highlight the rich diversity, overlap, and complementarity among these themes while highlighting potential areas for interdisciplinary collaboration. Moreover, our investigation into the terms co-located with *interaction* reveals a predominant focus on the modalities, technologies and actions involved in interaction, rather than on the qualities of interaction. Our paper extends our previous findings by providing: (1) a finer-grained delineation within and between research areas; (2) a better understanding of the notion of interaction within BLV research; (3) an analysis of the research methods used when developing interactive computing systems for BLV users; and (4) a comparative analysis of prior systematic literature reviews of BLV research and possibilities for future survey contributions in our field.

CCS Concepts: • **General and reference → Surveys and overviews**; • **Social and professional topics → People with disabilities**; • **Human-centered computing →** *Accessibility technologies*; *HCI theory, concepts and models.*

Additional Key Words and Phrases: blind; low-vision; visual impairment; systematic review; mixed-methods; qualitative data analysis

1 INTRODUCTION

Blind and low-vision (BLV) research has been a major focus of accessibility research in CHI and ASSETS for the last three decades [114] and spans various applications and empirical investigations, including education

[*]Both authors contributed equally to this research.
[†]Also with University of Fribourg.

Authors' Contact Information: Maximiliano Jeanneret Medina, HEG Arc, HES-SO // University of Applied Sciences Western Switzerland, Neuchâtel, Switzerland, maximiliano.jeanneret@he-arc.ch; Yong-Joon Thoo, University of Fribourg, Fribourg, Switzerland, yongjoon.thoo@unifr.ch; Cédric Baudet, HEG Arc, HES-SO // University of Applied Sciences Western Switzerland, Neuchâtel, Switzerland, cedric.baudet@he-arc.ch; Jon E. Froehlich, University of Washington, Seattle, Washington, USA, jonf@cs.washington.edu; Nicolas Ruffieux, University of Fribourg, Fribourg, Switzerland, nicolas.ruffieux@unifr.ch; Denis Lalanne, University of Fribourg, Fribourg, Switzerland, denis.lalanne@unifr.ch.

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[34, 122, 123], virtual environments for orientation and mobility training [69, 164], assistance for activities of daily living [22], navigation tasks [2, 62, 63] and object recognition [23, 212]. This growing body of research has led scholars to perform a large number of literature syntheses over the last decade. However, systematic research efforts have focused on specific technologies or devices [36, 48, 96, 108, 150, 160], specific applications [48, 121, 130, 186] and, in some cases, did not focus solely on the BLV community [114].

To provide a field-, technology-, and method-agnostic overview of the BLV research, we recently performed a programmatic analysis of 880 papers, published, between 2010-2022, in ACM and IEEE conferences and journals, combined with a qualitative analysis of the 100 most-cited papers [185]. Our mixed-methods analysis delineated the field into four main research areas and highlighted the diversity of denominations used to refer to the BLV community. Additionally, our analysis provided insights into technological trends and the main input/output modalities considered within the studies that presented one or more artifacts.

In this expanded version of our aforementioned 2023 ASSETS paper [185], entitled *"A Large-Scale Mixed-Methods Analysis of Blind and Low-vision Research in ACM and IEEE,"* we further investigate the four high-level research areas identified previously, leveraging similar programmatic and qualitative analysis methods from our previous study. Specifically, we performed an additional qualitative data analysis to refine and expand our thematic understanding of these research areas. Furthermore, to provide deeper insights into the technologies and modalities considered when designing artifacts for the BLV community, we analyze the terms co-located with the word "interaction," its grammatical variants, and synonyms taking inspiration from Hornbæk *et al.* [77]. Moreover, we expand the in-depth analysis of the most-cited subset (N=100) by investigating the research methods considered within the development of interactive computer systems. Finally, we provide suggestions for future work and formalize potential research trajectories for review papers supported by a structured comparison of prior systematic literature reviews (SLRs). This manuscript extends our previous work by providing:

(1) A finer-grained delineation within and between research areas.
(2) A better understanding of the notion of interaction within BLV research through additional programmatic[1] and qualitative analyses.
(3) An analysis of the research methods considered when developing interactive computing systems for BLV users.
(4) A comparative analysis of prior SLRs of BLV research and possibilities for future survey contributions in our field.

2 BACKGROUND AND RELATED WORK

In our previous paper, our related work first presented a synthesis of BLV terminologies found in literature, followed by an overview of past literature reviews, and an introduction into bibliometric methods and techniques. To extend our prior related work, we provide a comprehensive synthesis of SLRs from ACM and IEEE conferences and journals between 2010-2022. We perform a comparative analysis of these SLRs, highlighting their research topics, coverage, sources, number of screened papers, reporting standards, and contribution types. Additionally, we offer further examples of BLV language differences, drawing on examples from these SLRs, and provide further details about the use of bibliometrics to support a survey research contribution.

2.1 BLV Terminology and Language Preferences

The terms used to refer to the BLV community and even what constitutes "blind" *vs.* "low vision" differs between regions, cultures, and scientific fields. In particular, in HCI-focused accessibility research, past BLV research reviews have noted disparities between papers when using terms such as "visually impaired," "blind," "low-vision," and their variants (*e.g.*, "vision disabled," "partially sighted") [35, 114, 185]. Reviews in the computer science

[1]https://github.com/human-ist/BLV-research-analysis-extended

community have either: (1) considered "visual impairments[2]" separately from "blindness" [21, 96, 150, 160, 186]; (2) considered "blindness" as a subset of "visual impairments" [35, 48, 108, 121, 130]; or (3) used the term "blind and low-vision" to denote the two corresponding categories and other commonly used terms (*i.e.*, "differently sighted" or having "vision loss") [36, 114]. This observation extends beyond the realm of research where several national BLV federations use the terms "blind" or "visually impaired" to refer to multiple levels of vision loss (*e.g.*, *American Foundation for the Blind*, *Japan Federation of the Visually Impaired*) whereas others use the terms "blind" or "low-vision[3]" to refer to the severity of the vision loss (*e.g.*, *German Federation of the Blind and Partially Sighted*) per the classification highlighted in the WHO's 2019 *World Report on Vision* [206].

Furthermore, terms also vary across identity-first language (*e.g.*, disabled people) or person-first language (*e.g.*, people with disabilities) [165]. For example, out of the 12 past SLRs described in the following subsection (cf. Section 2.2), six used identity-first language (IFL) [21, 96, 114, 121, 150, 186], four used person-first language (PFL) [35, 48, 108, 130], and two used both [36, 160]. More broadly, Sharif *et al.* [165] recently analyzed the use of IFL and PFL language across multiple disabilities (*e.g.*, mobility, visual, cognitive) in ASSETS and CHI between 2000-2021 highlighting that, overall, PFL is used more frequently (54.4% combined). In contrast, we identified that 211 out of the 216 national federations (excluding regional offices) listed by the *World Blind Union* [188] use identity-first language in their official names.

Whilst the language used to denote BLV people is subject to debate, we draw inspiration from a recent study from Sharif *et al.* [165] who conducted a survey with 519 disabled people from 23 countries to report their language preferences and offer recommendations for researchers when referring to their respective populations. Notably, their results revealed that, while preferences varied across disability categories, age groups and countries, 48.6% of respondents indicated a minor preference for IFL, compared to 33.0% who favored PFL. Moreover, they highlight the recent recommendation of the *National Federation of the Blind* to use the term "blind and low-vision" in place of "visually impaired".

Finally, whilst we use BLV with IFL throughout our paper, we acknowledge that language preferences and our understanding of vision may be subject to change. In particular, while BLV is tightly connected to a wide range of visual impairment categories, other forms of vision loss exist but are not considered as part of BLV. For instance, recent survey research contributions regarding color vision deficiency neither mention nor specify BLV [54, 107, 154]. This is in accordance with the W3C [191] who state that "*color vision deficiencies are not classified as low-vision or disabilities in many contexts*". Moreover, whilst the WHO's classification of *visual impairments* [206] is predominantly based on visual acuity, Kran *et al.* [98] advocate for a change in the definition of *visual impairments* and *blindness* to acknowledge people with cortical visual impairments.

2.2 Related Systematic Literature Reviews of BLV Research

In this subsection, we provide an overview and comparative analysis of prior BLV-focused *survey research contributions* which, as defined by Wobbrock & Kientz, "*review and synthesize work done on a research topic with the goal of exposing trends and gaps.*" [203, p. 42]. In particular, we focused on 12 SLRs obtained by: (1) screening our initial set of 3,378 documents (N=6); (2) adapting and expanding our search query to reach additional SLRs on ACM Digital Library (DL) and IEEE Xplore (N=5); and (3) performing a backward snowballing [204] by examining cited references of the 11 SLRs obtained in preceding steps (N=1). These SLRs were published between 2010-2022 (inclusive) and adopted a *systematic*, and *transparent* review process [146] such as PRISMA [143] or another recognized method (cf. [147, 194]). Seven of these SLRs were published in journals, four in conferences proceedings, and one in a magazine. Further details are provided in the Appendix A and in supplementary materials.

[2] This term was used by the corresponding authors to denote the classification by the WHO [206]

[3] Per this classification, the moderate and severe visual impairment categories are commonly referred to as low-vision [148].

To compare the set of SLRs, we first collected the review scope (*e.g.*, subject, data sources, period covered and the resulting sample). We then relied on the first-order constructs proposed by Paré *et al.* [147]: the overarching goal of the review and its related theoretical review type, the scope of the review questions, the search strategy, the nature of the primary sources included in the review, the explicitness of the study selection, the quality appraisal, and the methods for synthesizing/analyzing findings. An overview of the results can be found in Table 1.

Table 1. Comparison of past SLRs. The table is ordered alphabetically by the surname of the first author. The *Subject* column uses symbols from set theory and the following abbreviations are used: empirical (emp.), evaluation (eval.), programming (prog.), technology (tech.). In the *Period Covered* column, an asterisk (*) denotes SLRs where no start date was reported, and we report the year of the earliest published paper in their set. In the *Primary Sources* column, papers can be empirical, conceptual or both. The primary *overarching goal* of all SLRs is to *summarize* prior literature and all SLRs reported the *study selection*.

Reference	**Subject**	**Data Sources**	**Period Covered**	**Sample**	**Review type(s)**	**RQs Scope**	**Search Strategy**	**Primary Source(s)**	**Quality Appraisal**	**Methods**
Bhowmick and Hazarika [21]	Assistive Tech. ∩ BLV	Meta- and databases	1994-2014	3010	Descriptive	Broad	Representative	Both	No	Frequency; Content
Brulé *et al.* [35]	Quantitative Emp. Eval. ⊂ (BLV ∩ Tech.)	Selected conferences and journals	1988-2019	178	Scoping	Broad	Representative	Both	Yes	Frequency; Content
Butler *et al.* [36]	Touch-based Graphics ∩ BLV	Selected conferences, journals, and metabase	2010-mid 2020	292	Descriptive	Broad	Representative	Empirical	Yes	Frequency; Content
Dos Santos *et al.* [160]	Wearable Devices ∩ O&M ∩ BLV	Meta- and databases	2001*-2020 (June)	61	Descriptive	Narrow	Representative	Empirical	No	Frequency; Content
Façanha *et al.* [48]	Blind ∩ Multimodal Interfaces ∩ O&M training ∩ Virtual Environments	Meta- and databases	-2020	51	Descriptive	Narrow	Representative	Both	No	Frequency; Content
Khan *et al.* [96]	Navigation Assistants ∩ BLV	Meta- and databases	2011-2020 (mid June)	191	Descriptive	Narrow	Representative	Empirical	Yes	Frequency; Content
Li *et al.* [108]	BLV ∩ HMD ∩ (Assistance ∪ Therapy)	Meta- and databases	1999*-2022	61	Scoping	Broad	Comprehensive	Both	No	Content
Mack *et al.* [114]	Accessibility	Selected conferences	1994-2019	836 / 506	Scoping	Broad	Comprehensive	Both	No	Frequency; Content
Mejia *et al.* [121]	BLV ∩ Math. Content Accessibility	Meta-database	-2020	62	Descriptive	Broad	Representative	Both	No	Content; Narrative
Mountapmbeme *et al.* [130]	BLV ∩ Prog. languages ∩ Prog. environments	Databases	2000-2020	70	Scoping	Broad	Comprehensive	Both	No	Content
Plikynas *et al.* [150]	Indoor Navigation ∩ BLV	Meta- and databases	- 2019 (January) / 2013 - 2018 (May 5th)	27 / 15	Descriptive	Narrow	Representative	Both	No	Frequency; Narrative
Torres and Barwaldt [186]	Blind ∩ Diagram	Meta- and databases	2013 - 2018	26	Descriptive	Broad	Representative	Both	Yes (not used)	Frequency

Our analysis highlights that all of these SLRs aimed primarily to summarize prior literature with a specific focus on BLV and either a given technology [36, 48, 96, 108, 150, 160], an application domain [48, 121, 130, 186], or a research methodology [35]. Four SLRs made a substantial effort to delimitate the investigated research object [34, 108, 114, 130], often favoring a comprehensive search strategy. Eight out of ten SLRs answered broad research questions including generic terms (*e.g.*, approaches, barriers, difficulties, gaps, opportunities, solutions) in their respective scope (*i.e.*, subject covered) or mentioned a general research aim. Most of the SLRs used conceptual and empirical papers, but only four studies performed a quality assessment after an eligibility assessment with inclusion and/or exclusion criteria[4]. The presentation of frequencies per category and content within and/or across categories is a common practice as performed by seven papers. However, only a small portion of SLRs detailed the methods used to obtain those categories (*e.g.*, [35, 114, 130]).

Navigation assistance for BLV individuals has been covered extensively across several contexts [48, 96, 150, 160]. More specifically, Khan *et al.* [96] synthesized the underlying technologies, tools, and hardware powering navigation assistants, as well as 20 performance metrics for these computing systems. Similar in-depth analyses were conducted by Dos Santos *et al.* [160] and Plikynas *et al.* [150], focusing on wearable devices for Orientation and Mobility (O&M) and indoor environments, respectively. Notably, Plikynas *et al.* [150] provide a classification of both vision-based and non-vision-based navigation technologies. While these reviews primarily centered on the technical aspects of computer systems, Façanha *et al.* [48] examined O&M virtual environments designed for indoor navigation, aiming to identify techniques for developing and evaluating these applications in terms of usability and cognitive impact. Moreover, their work provides evidence that navigation in indoor virtual environments can support the acquisition or refinement of O&M skills in BLV individuals.

Another research stream focused on the accessibility of varied contents [36, 121, 186] where past SLRs reviewed methods to enable BLV people to perceive and interact with graphical content [36, 186]. Notably, touch-based accessible graphics have found applications in educational settings and O&M tasks involving maps and plans [36]. Moreover, Mejia *et al.* [121] differentiate between content access and content creation whilst examining software tools designed to enhance accessibility in mathematics learning. More recently, Mountapmbeme *et al.* [130] reviewed the accessibility barriers to programming faced by BLV professionals and students and identified solutions to address these barriers.

In addition to the specific technologies and application domains addressed by these SLRs, Li *et al.* [108] conducted a scoping review and present the progress researchers have made using head-mounted displays (HMDs) for visual assistance and therapy. Two-thirds of the articles were classified as assistive technology while the remaining were classified as therapeutic technology. They also provide insights into HMDs across four visual conditions (central vision, visual field, stereopsis, and color vision). Moreover, we identified one methodology-oriented review, performed by Brulé *et al.* [35], on CHI, ASSETS, TOCHI, and TACCESS papers between 1988-2019 (N=178), to determine best practices in quantitative empirical evaluations of technologies for BLV. Their analysis highlights concerns regarding user evaluations, how the BLV participants are reported in these evaluations, and provides recommendations for conducting, reporting, and reviewing evaluations.

Furthermore, we also identified two SLRs with broader scopes within BLV or accessibility research. The first, conducted by Mack *et al.* [114], provides an overview of the growth and extent of accessibility research. They performed a large-scale survey of accessibility papers at CHI and ASSETS published between 1994-2019 (N=836 on a programmatic analysis and N=506 on a manual coding). While their dataset and analysis were not specifically on BLV research, Mack *et al.* found that 40% of all accessibility papers focused on BLV people, thus highlighting the importance of BLV research within the broader accessibility field. The second SLR, performed by Bhowmick and Hazarika [21], provides the largest literature review on assistive technology for BLV people to date. Starting from a critical view of prior *subjective* review papers, that might prioritize themes or subjects aligning with the authors' expertise, they reviewed 16 review papers on 13 diverse categories using a binary coding approach. Moreover, their analysis included 3,010 scientific publications on research relevant to assistive technology for BLV covering the period from 1994 to 2014. While this study offers valuable insight into the landscape of BLV assistive technology, the search strategy is not comprehensive due to their choice of keywords and selected disciplines.

[4]A *by default* quality assessment could be related to selected top-tier venues and document type (*i.e.*, full papers).

Finally, in relation with our work, we identified three SLRs that provide a delineation of BLV research [21, 35] or accessibility research in general [114]. More specifically, Bhowmick and Hazarika [21] delineated the field of BLV assistive technology into four research communities: "multisensory research," "accessible content processing research," "accessible user interface design research," and "mobility and accessible environments research." Moreover, as a secondary research objective of their work, Brulé *et al.* [35] identified 24 application areas, encompassing activities and technical categories, with the most common being "web browsing," "education," "mobility," "interaction with mobile screens," and "access to traditional GUIs." Additionally, Mack *et al.* [114] identified seven issues addressed in their surveyed papers ("digital access," "understanding users," "physical access, "independence," communication," behavior change," and other). However, to the best of our knowledge, no previous survey research contribution has attempted to provide an in-depth understanding of BLV research, its underlying research themes, the corresponding artifacts and the means by which BLV individuals interact with these artifacts. Such a review could help researchers identify similarities and differences across research efforts, uncover knowledge gaps and theoretical biases, and support the development of novel theories [31, 156].

2.3 Bibliometrics for Literature Reviews

Broadus defines *bibliometrics* as the "*quantitative analysis of published or bibliographic units, or their surrogates*" [32, p. 376]. While this form of study has been acknowledged for over six decades [95], the term "bibliometrics" came to light in the late 1960s in the *Journal of Documentation* [32] and is often synonymous with scientometrics and informetrics [75]. Bibliometrics is used to support two main purposes [218]. First, performance analysis seeks to evaluate research activity such as the publication performance of individuals, institutions, or regions [4, 25, 218]. Second, bibliometrics supports the development of science or bibliometric mapping that aims to reveal the structure and dynamics of scientific fields [189, 195, 218]. In the following subsubsections, we first present an overview of common bibliometric workflows, methods, and techniques in SLRs as well as their applications HCI and accessibility research.

2.3.1 Common Bibliometric Workflow. Coarsely, the commonly accepted workflow to obtain science mappings consists of defining the research scope and then to collect, analyze, visualize, and interpret the data [8, 194, 218]. To do so, researchers can rely on a large variety of methods, techniques, and tools [8, 192, 218].

Regarding the collection of bibliographic data, researchers rely on data sources (*e.g.*, ACM DL, IEEE Xplore, PubMed) or meta-data sources (*e.g.*, Scopus and Web of Science) that index scientific publications [193]. Moreover, depending on the research objective, researchers may choose to extract common document metadata (*e.g.*, title, abstract, authors keywords, authors, publication venue, year of publication), citation count, or bibliographic references [8, 193, 218].

Once collected, the dataset can then be analyzed (in its entirety or, more commonly, in subsets) using several bibliometric techniques, including bibliographic coupling, co-citation, co-author, or co-word analysis [8, 189, 193]. Furthermore, each technique can be applied to different units of analysis (*e.g.*, author, document or reference, journal, keyword) [8]. In particular, Documents Bibliographic Coupling Analysis (DBCA) is a well-known bibliometric technique for understanding the intellectual structure of emerging literature [8, 27, 82, 192, 218]. DBCA categorizes technical and scientific literature using bibliographic coupling units [95]. More specifically, when two documents cite the same third document, they are considered to be bibliographically coupled [82] and the strength of their relationship is determined by the number of references they share (*i.e.*, the higher number of shared references, the stronger the relationship). Hence, this technique can be viewed as a measure of document similarity [82]. The main approach for bibliographic coupling involves: (1) identifying a set of recent papers; (2) calculating the similarity between pairs of papers using bibliographic coupling counts and organized the result obtained within a co-occurrences matrix; and (3) assigning citing papers to clusters using the similarity values [82].

As a complement to clustering, mapping techniques are commonly used to investigate the structure of networks, show research streams within a specific scientific topic, and reveal how they relate to each other [195]. Additionally, combining multiple approaches can identify research subjects for specific disciplines, with each bibliometric analysis exhibiting certain advantages [40, 192, 194, 218]. At the end of the bibliometric workflow, the researcher has to interpret the science map [193, 194, 218].

Open-source or proprietary software now support all or a portion of the bibliometric workflow. The most widely used is *VOSviewer* [189], an off-the-shelf tool supporting a wide range of bibliometric methods. Similarly, *bibliometrix* [8], a R package offers similar capabilities and can be used without requiring to code with *biblioshiny*. Finally, ARTIREV is dedicated to support literature reviews while guaranteeing data cleansing in the early stages of the workflow [193].

2.3.2 Bibliometrics-supported SLR. The use of bibliometrics is gradually extending across disciplines [26] and is particularly suitable for science mapping when contributions are producing voluminous, fragmented, and controversial research streams [8]. This is especially relevant within the context of BLV research, where several works over the past decade have highlighted significant growth in research areas such as accessibility [114] and assistive technology [21].

The use of bibliometrics to delineate a research field provides scholars with an additional option for conducting a literature review [192, 218], falling between the traditional qualitative and interpretive approaches and the quantitative meta-analysis technique. Its combination with an interpretative literature review can be illustrated by the flesh and bones metaphor, whereby researchers' interpretation of documents (the flesh) is added on the top of the field structure (the bones) revealed by a bibliometric analysis [192]. More specifically, bibliometric analyses precede the researchers' interpretations, after which both processes become iterative [194].

Building on this idea, Walsh and Rowe [194] recently proposed to combine grounded theory (GT) and bibliometrics (BIB) into a method entitled BIBGT. This approach addresses the limitations of literature reviews based solely on either GT or BIB, leveraging the strengths of both to provide a more comprehensive, systematic, and transparent analysis.

2.3.3 Use of Bibliometrics in HCI and Accessibility Research. Researchers in the HCI community have benefited from a wide range of bibliometric methods and techniques to provide performance analysis and scientific mapping studies. Within the performance analysis group, Bartneck and Hu [17] used bibliometric methods to analyze the countries and organizations that contributed to the CHI conference. Within a similar context, Sandnes [159] recently explored the HCI research activity in the Nordic-Baltic Eight countries.

Regarding science mapping studies, Gurcan *et al.* [68] investigated the research trends in the development stages of HCI studies over the past 60 years utilizing automated text mining with probabilistic topic modeling. Additionally, Sarsenbayeva *et al.* [161] presented a visualization of the intellectual advancement of accessibility research within HCI over the last 20 years. More specific investigations could focus on a single conference, such as Liu *et al.* [112] who mapped two decades of intellectual progress of CHI using a co-word analysis.

Furthermore, Wang *et al.* [196] examined the diversity of citations in accessibility and HCI research. We also note that researchers have used bibliometrics without classifying their works into this literature or range of techniques. For instance, term frequencies have been automatically analyzed through the application of programmatic analytic approaches derived from the fields of *Text Mining* and *Natural Language Processing*, with these terms potentially appearing in the title, abstract, or author keywords (TAK) or in the full paper [68, 77, 114, 165].

More specifically within the context of BLV research, Façanha *et al.* [48] developed a citation relationship matrix between the papers in their set obtained after both identification techniques (database search and forward snowballing). Bhowmick and Hazarika [21] performed a co-word analysis related to assistive technology for BLV. However, surprisingly, in spite of the benefits of using references-based bibliometric techniques to identify a research field's structure [40, 82, 192, 218], we found no study published in a leading HCI or Accessibility venue with the intention of delineating the BLV-related research field.

3 METHODOLOGY

In this section, we first recall the research process adopted in our ASSETS paper followed by the extensions made for this journal article.

3.1 Overview of our SLR Process based on Mixed-Methods

In our original ASSETS paper [185], we aimed to analyze and understand BLV-focused research in ACM and IEEE venues. As illustrated in Figure 1, our review methodology followed the five-step process described by Zupic and Čater [218]: (1) Research design, (2) Compilation of bibliographic data, (3) Analysis, (4) Visualization, and (5) Interpretation. Best practices from the bibliometrics literature [8, 40, 192, 194, 218] were used throughout the entire process, including adhering to an iterative workflow.

3.1.1 Research Design and Compilation of Bibliographic Data. To identify the main areas of research within the boundaries of the review, we relied on DBCA [82] complemented by a programmatic analysis performed on the papers' TAKs [77]. Additionally, we created a conceptual framework that went beyond bibliometrics and our initial research question, focusing on the interaction between the *user* and the *computer system* in addition to the solution's intended context of use. This conceptual framework, developed through deductive and inductive methods, was used to investigate the research field on both a large scale and in-depth.

Without targeting a specific technology, our work concentrated on the wide range of recent research efforts (2010–2022, inclusive) at the intersection of *BLV people* and *computer systems*. To achieve this, we first developed a search query, expanding on prior work [35], including common derivative terms of visual abilities that encompassed not only a wide range but also specific forms of *visual impairments* [206], referring to both identity- and person-first language [165] (*e.g.*, blind people, people with low-vision). Our search yielded computer systems by targeting scientific works published at a (co-)sponsored ACM or IEEE conference or journal. ACM and IEEE are the two largest organizations dedicated to computing and technology, hosting leading HCI and accessibility conferences (ACM CHI, ACM ASSETS) and journals (ACM TACCESS, ACM TOCHI, IEEE Transactions on Human-Machine Systems). ACM and IEEE conference proceedings and journals are the most common venues in the field of BLV and assistive technology [21]. Furthermore, both organizations collaboratively integrated accessibility within HCI as a core component of the body of knowledge in computing education [85]. Applying these criteria, our search on the Scopus database yielded 3,378 results.

Documents were then filtered by several semi-automatic analyses. From the initial 3,378 results, we excluded 185 documents comprising formatting errors, missing abstracts or references, survey research contributions, false positives, and papers wherein the query terms could be found solely in the *Index Keywords*. At the end of this stage, we retained 3,193 eligible papers. A portion of this dataset (N=1,403), selected based on the number of incoming citation and randomly, was then manually verified by two independent researchers.

3.1.2 Describing BLV People and Computing Systems at Large-Scale (N=880). In this subsection, we describe the two bibliometric workflows, used in our previous paper, from data cleaning to interpretation. Each workflow relied on a specific kind of data. More specifically, the first workflow used bibliographic references and citation counts, whereas the second workflow used TAKs. While bibliometrics allows to process automatic analyses, we carefully supervised each workflow.

Workflow A: From Bibliographic References to Distance-based Maps of Documents. While DBCA groups documents by the bibliographic references they share in common [82, 192], distance-based maps are

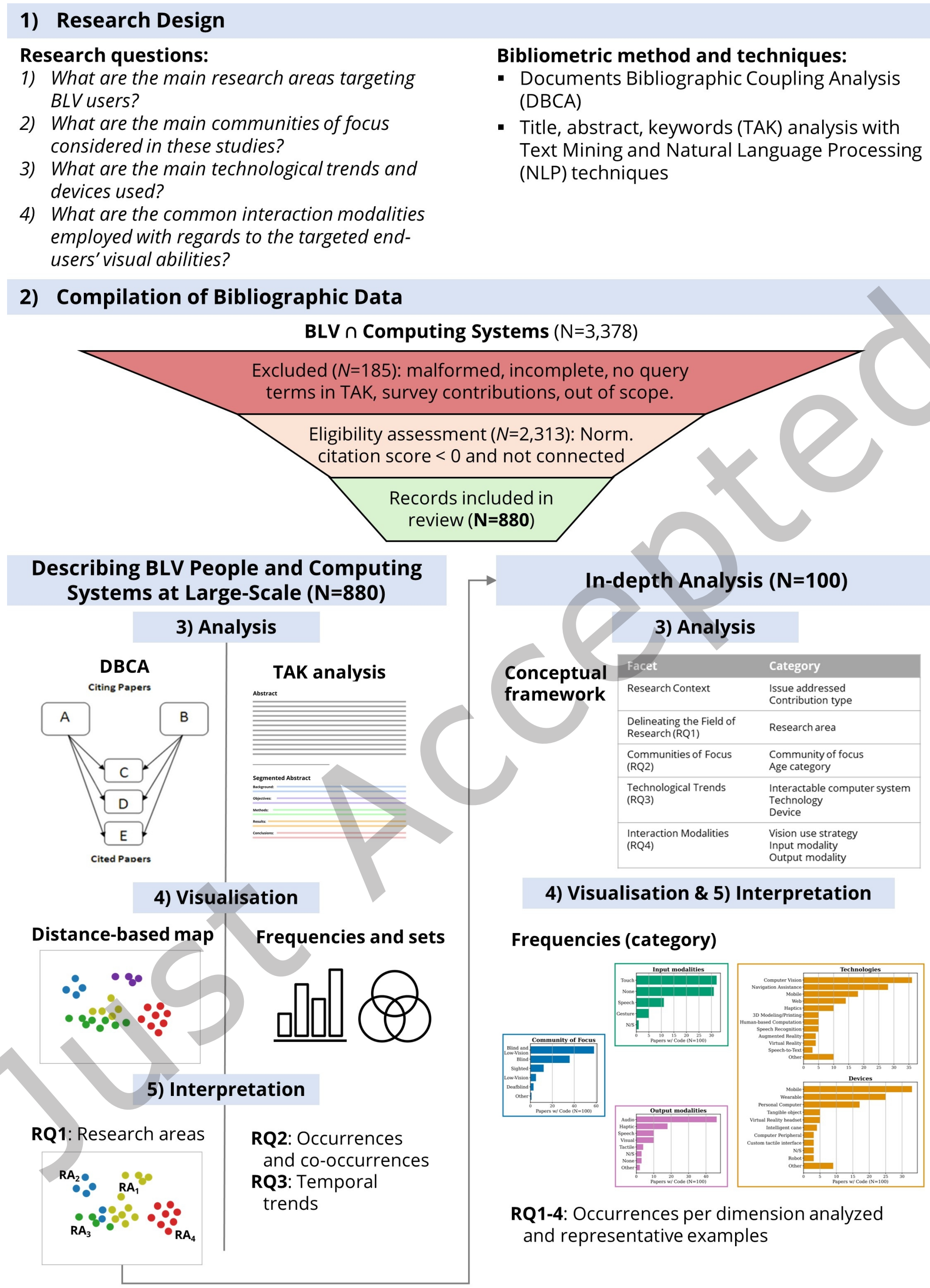

Fig. 1. Overview of the mixed-methods analysis methodology from our previous paper [185], following the 5-step bibliometric workflow [218]. Legend: Documents Bibliographic Coupling Analysis (DBCA); Title, Abstract, and Author Keywords (TAK).

based on the strength of the relationships between documents [195]. Hence, we cleaned bibliographic references by using a semi-automatic process based on a fuzzy string similarity algorithm provided by ARTIREV [193].

Furthermore, to obtain a reliable science mapping, researchers must choose relevant thresholds that cannot be selected *ex-ante* but rather require an iterative trial-and-error approach to determine optimal values [192, 194, 218]. In our case, we relied on a citation count threshold to retain the publications which attracted the most interest from researchers. More precisely, we performed a Z-score normalization taking into account the citation count and the year of publication, resulting in 880 connected papers that were retained for our study.

Finally, to cluster and map the research field, we applied the association strength normalization method and the Leiden clustering algorithm using VOSviewer [195] v1.6.18. This combination of techniques is acknowledged as one of the most suitable for detecting research commonalities [187, 195]. Moreover, to acquire our final mappings, we used an iterative strategy, conducting several trials with different parameters and following best practices in the bibliometric field [194, 195].

Workflow B: From TAK to (Co-)Occurrences Tables and Graphs. To first clean the publications' TAKs, we combined string manipulations, regular expressions, and part-of-speech tagging (similar to [77, 165]). For instance, we removed parts of text that did not contain topical content (*e.g.*, copyright in abstracts) and retained only adjectives, adverbs, nouns, verb, punctuation marks, and other terms [24]. We then counted the frequency of unigrams, bigrams, trigrams, and fourgrams within the publications' TAKs. To do this, we used built-in Python packages as well as the *Natural Language Toolkit* (NLTK[5]). Then, similar to the approach taken by Mack *et al.* [114], we examined the list of terms and their frequencies to create a consolidated list of the most common categories of terms. We then used a custom-made frequency counter based on regular expressions to tally the number of occurrences. To visualize the combinations of terms denoting *people* and their *visual status*, we then used UpSet plots [105] which present the sets, their intersections, and aggregates of intersections when the combinations are numerous.

Interpreting Research Areas. On the basis of the distance-based map, obtained by bibliometric and clustering techniques [187] (*i.e.*, DBCA, Leiden algorithm, VOS map with a precision of 0.7), we performed a qualitative assessment of the composition of clusters, highlighting their commonalities and differences, similar to the approach by Jarneving *et al.* [82]. In particular, the first two authors labeled each cluster using a within-cluster programmatic analysis of documents' TAK, a manual investigation of the most cited and central documents, and the *memoing* technique [194]. The obtained distance-based map was then used as "*a starting point for analytical examination but are not an end in itself*" [218, p. 448]. Given the manageable size of our dataset (N=880), we subsequently manually reviewed each publication's TAK to classify each publication within one research area.

3.1.3 In-Depth Qualitative Analysis (N=100). In this subsequent stage, we selected the most cited papers[6] within each research area based on their normalized citation score. The top-cited papers were retained proportional to the size of their respective research areas, resulting in a subset of N=100 papers for in-depth analysis. Retaining 100 objects for analysis is a common practice in bibliometric investigations. For example, Lin *et al.* [109] summarized the 100 most influential papers on cataract surgery. Similarly, Bhowmick and Hazarika [21] analyzed the 100 most frequent and informative topics in the field of assistive technologies for BLV individuals.

To analyze our subset of 100 publications, we deductively created a conceptual framework (cf. Table 2), reworking within each category, and performed an in-depth qualitative analysis. With the findings from the large-scale analysis in mind, the first two authors independently coded each paper. They subsequently conferred to discuss and resolve coding divergences, resulting in an increase in the convergence rate from α=0.95 to 0.99. Furthermore, their interpretations were presented to the rest of the research team, composed of two professors in

[5]https://www.nltk.org/

[6]According to Aksnes *et al.*, *'citations reflect—with important limitations—aspects related to scientific impact and relevance'* [4, p. 12], representing parts of the multidimensionality of academic quality.

HCI, with over 40 years of combined HCI research experience, and a professor in specialized education with a background in neuropsychology and ten years of clinical experience.

Table 2. High-level view of the conceptual framework used for the coding of our subset of 100 most-cited papers. Please refer to our ASSETS paper [185] for more details.

Facet	**Category**	**Inspired by**
Research Context	Issue adressed (*) Contribution type (*)	[114] [35, 114] based on [203]
Delineating the Research Field (RQ1)	Research area	None (inductive)
Communities of Focus (RQ2)	Community of focus (*) Age category (*)	[35, 114]
Technological Trends (RQ3)	Interactable computer system Technology (*) Device (*)	
Interaction Modalities (RQ4)	Visual use strategy (*) Input modality (*) Output modality (*)	[120] [35, 77] [35, 77]

3.1.4 Additional Descriptive Statistics. To determine the provenance of the papers, we extracted the country of each author's affiliation(s) from our set of 880 papers. Missing or incomplete data were manually retrieved. Additionally, we gathered information on the conferences and journals comprising the set of 100 papers to identify regional conferences.

To better understand the variety of the most-cited set (N=100), we manually coded the research methods in a process-based view encompassing three stages: *Needs Elucidation & Requirement*, *Design & Implementation*, and *Evaluation* as well as the *Number of Cycles* reported in the paper. This coding has been made on the *Primary Artifact* explained in a paper, so each possible *Secondary Artifacts* have been listed but not coded.

3.2 Identifying, Analyzing, and Interpreting Research Themes

To provide a finer-grained delineation[7] of the four major research areas identified in our ASSETS paper (*i.e.*, *Accessibility at Home & on The Go*, *Non Visual Interaction*, *Education*, and *Orientation & Mobility*), we conducted an additional in-depth interpretive qualitative analysis, performed in two cycles and at two scales (cf. Figure 2). We began our analysis by first coding the entire manuscripts of the 100 most-cited papers, then extended our coding to the TAKs of the 880 publications. This qualitative analysis adhered to the methodology described by Gioia *et al.* [55] to ensure rigor. This analysis was conducted with certain preconceptions as the researchers were knowledgeable about the field under investigation (*i.e.*, knowledgeable agents [55]).

More specifically, the two first authors began by performing an initial cycle of open coding of the 100 papers organized per research area while keeping their prior codes in mind. Those code were related to the community of focus, the technology, and the interaction. At the end of this cycle, three researchers then discussed potential second-order themes before performing a second round of coding. At this stage, we encountered the challenge of a high-dimensional problem due to our large-scale investigation. In particular, beyond the community of focus, the technology and the interaction, several codes were related to the *activity* supported by the *technology*, the

[7]While research areas encompass an overarching scope of works, research themes provide a detailed examination of specific themes, within these areas, that share manifest or latent characteristics.

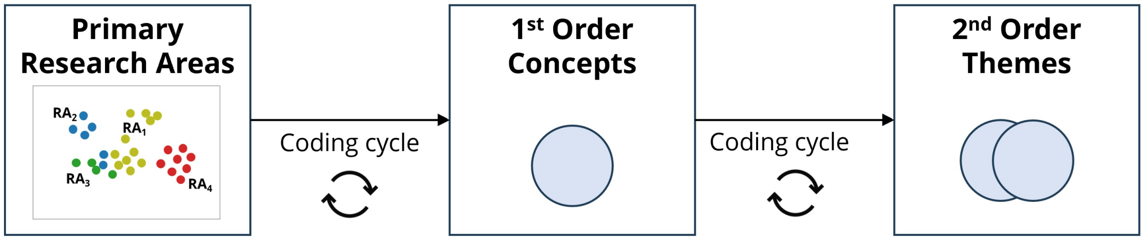

Fig. 2. Illustration of our two coding cycles used to identify concepts and research themes within our four primary research areas.

issues addressed and well-known concepts (*e.g.*, Visual Question Answering, Electronic Travel Aid). Moreover, works focusing on the same activity, could have been divided into social *vs.* technical focus, but were separated into different poles when considering the distance-based map (*e.g.*, answering visual questions). Furthermore, fields with a high technical focus, such as O&M artifacts, could have been categorized by specific technologies (*e.g.*, deep/machine learning), sensors (*e.g.*, cameras), or modules (*e.g.*, inertial measurement units). However, these computer systems are often inextricably linked and can be used for various purposes (*e.g.*, computer vision). This lead us to analyze the research areas by focusing more on the user's perspective (*e.g.*, what service the computer system provides to the user).

To reduce the dimensionality of the problem, we mapped the community of focus onto the distance-based map of 880 papers, confirming that the variety of BLV denominations were blended. We also tried to divide research areas by programmatic analysis using specific terms (*e.g.*, indoor *vs.* outdoor environments for O&M). After thorough discussions, we chose to highlight salient aspects within each research area, commenting on themes that cross the boundaries of our initial delineation. Moreover, while mapping *Issues addressed* to rich *sociotechnical solutions* could have been a satisfactory cutting point, we did not adhere to a problem-solving view [45, 140]. At the end of this second coding cycle, we identified the second order themes provided in Table 3. These research themes contribute to a better understanding of the field. However, our goal is not to conduct four distinct reviews using shared categories and codes.

Our coding of the 100 most-cited papers was then extended to a coding of the 880 papers' TAKs. Moreover, a paper that did not explicitly state the specific purpose of use within their TAK was not attributed a research theme (*i.e., our coding followed a strict coding rather than an implicit or inferred one*). This was typically the case for papers developing an algorithm or a module that could be used in a future interactive computer systems (*e.g.*, a computer vision module to be used in an assistive device for daily living or navigation). As a consequence, the number of coded research themes does not necessarily equal the total number of papers within each research area.

Finally, to provide a narrative summary of each research theme, we first used the most-cited papers. We then extended the summary by citing papers within the same research program (*e.g.*, *VizWiz* [22], *NavCog* [2]) and used meaningful representative examples in the set of 880 papers. Each summary contains the unique characteristic of the theme within the research area. The overlaps and differences between the research themes are also described.

3.3 Understanding Interactions

To understand how the notion of *interaction* has been used within the abstracts of the 880 papers, we adopted a process similar to that used by Hornbæk *et al.* [77], with slight adaptations to suit our specific context.

First, we cleaned the abstracts and divided each into sentences. In line with Hornbæk *et al.* [77], we did not retain the author-provided keywords nor the titles. We then focused on sentences containing the term

Table 3. Dimensions, Themes, and Concepts identified during our interpretative qualitative analysis. The *Navigation paradigm* was solely used to code papers within the *Navigation Assistance* Concept.

Aggregate Dimension	**2nd Order Themes**	**1st Order Concepts**
Accessibility at Home & On the Go	Access to digital media and technology	Assistive technology, Data visualization, Image, Augmented/Mixed/Virtual reality, Mobile, Social media, Video, Web, Other
	Access to activities	Communication, Cultural, Daily living, Leisure, Music, Participate socially, Programming, Shopping, Sport, Using transport, Work, Other
Non-visual Interaction	Non-visual modalities	Touch; Audio/Speech/Sound; Multimodal; Other
Education	Supporting educational development	Learner age category; Subject learned; Support provided; Stakeholders; Design approach
Orientation & Mobility	Assistance & beyond	Navigation assistance; Training; User understanding; Other
	Navigation paradigm	Obstacle avoidance; Turn-by-turn navigation assistance; Both

"interaction" and its variants (*i.e.*, interaction, interactions, interactive, interactional). However, the verb "to interact" was excluded to avoid an excessive number of results about the objects of interaction (*e.g.*, displays, systems) [77]. This parsing resulted in 253 sentences containing at least one occurrence of the word "interaction". While relevant words may precede or follow the term "interaction", we extracted noun phrases with the help of the part-of-speech tagger provided by NLTK [77].

After analyzing the output, we then noticed that the term "interaction" could also sometimes span multiple sentences (*e.g.*, "*this interaction mode...*") or be more complex than our target (*e.g.*, "*two main interaction methods, zooming and element filtering*"). Given the acceptable amount and complexity of extracted sentences and noun phrases, we manually retrieved these data and simplified some noun phrases (*e.g.*, interaction zoom; filtering interaction).

Two researchers then manually classified the *interaction modifiers* into six types defined by Hornbæk *et al.* [77]: *Style*, *Quality*, *Concept*, *Social*, *Statistical*, and *Other*. In a subsequent step, we focused specifically on the *Style* and *Quality* modifier types, due to their importance in understanding interaction [77]. In particular, Hornbæk *et al.* [77, p. 23] state: "*Style is shaped by the technology used in interaction, the modalities and human actions that are engaged, and the type of content or actions in interaction. Quality, in contrast, concerns a user's experience of interaction, their comparison to other forms of interaction, and their emerging attitudes toward the interaction*".

Each modifier was then further assigned to thematic groups. *Style* modifiers were categorized into: *Characteristic*, *Modality*, *Technique*, *Principle*, *Body Part*, *Device*, *Content*, *Artifact*, *Action*, *Widget*, and *Domain*; while *Quality* modifiers encompassed: *Feel*, *Comparison*, *Mode of Use*, *Value Words*, *Resource Use*, *Effectiveness*, *Affective*, *Cognitive*, *Temporal*, *Adaptability*, *Play*, and *Look*. Finally, we conducted separate analyses for these modifiers based on their respective usage types.

4 SYNTHESIS OF BLV RESEARCH AND COMPUTER SYSTEMS IN ACM AND IEEE

In this section, we first provide an overview of our dataset (*N*=880) and our subset of most-cited papers (*N*=100). We then present an overview of the results of our bibliometric and programmatic analyses, as well as our in-depth interpretative analysis, presented in our previous ASSETS paper.

4.1 Overview of the Dataset

Our dataset (*N*=880) contains works published between 2010-2022 (included), in ACM and/or IEEE sponsored conferences and journals. We recall that, at the time of our prior work [185], these publications had been cited more than others within the research field based on their normalized citation score (Z-score).

4.1.1 Sponsor, Document Type, Main Venues, and Authorship. The distribution of sponsors and document types within our dataset revealed that 495 (56.2%) studies were published within ACM-sponsored venues, with conference proceedings comprising the majority of publications (*N*=676, 76.8%). Additionally, the dataset includes papers from 240 different venues, with CHI (*N*=156, 17.7%) and ASSETS (*N*=141, 16%) being the most prevalent. In the subset of the 100 most-cited papers, the proportions of ACM and IEEE publications mirrored those of the full dataset, with 56 ACM papers and 44 IEEE papers. These 100 papers have been published across 40 different venues. The most represented venue was CHI, with 28 papers, followed by ASSETS with 14 papers. IEEE venues such as the *Computer Vision and Pattern Recognition Conference* (CVPR), *Transactions on Human-Machine Systems* (THMS), and *IEEE Access* contributed four papers each while the IEEE *Transactions on Neural Systems and Rehabilitation Engineering* (TNSRE), the IEEE *Transactions on Mobile Computing* (TMC) and the ACM Conference on *Computer-Supported Cooperative Work & Social Computing* (CSCW) have three publications each. The remaining 32 venues included fewer than two papers each. Additionally, two workshop papers were classified as short papers and one full conference paper came from a regional tier venue, the *Australian Conference on Human-Computer Interaction* (OzCHI). Among IEEE publications, journal articles outnumbered conference proceedings, making up 30% of the subset. Notably, no articles from TOCHI or TACCESS were among the top 100.

Furthermore, the 880 papers in our dataset were authored by 2,458 unique individuals, with an average of 4.2 authors per paper (*stdev*=1.9). Notably, only a small number of authors (92, 0.04%) contributed papers to both ACM and IEEE. A total of 62 countries are represented among the 1,731 author affiliations. The United States is the most represented country, appearing in 793 affiliations (45.81%) across the 880 papers. The remaining countries in the top 10 are India (5.31%), Italy (4.97%), Japan (4.79%), United Kingdom (4.62%), Germany (4.33%), China (4.1%), France (3.99%), Canada (2.25%), and Australia (2.14%). The remaining 51 countries have less than 2% of the total number of authors affiliations.

4.1.2 Issue Addressed and Contribution Type. To provide insights into the research context of our dataset, we coded the issue addressed and contribution type of the 100 most-cited papers (Table 2).

Our manual analysis highlighted several issues addressed, including: *increasing digital access* (*N*=38), *increasing independence* (*N*=34), *increasing physical access* (*N*=30), *increasing user understanding* (*N*=25), *increasing safety* (*N*=21), *communication support* (*N*=8), *supporting education* (*N*=6), and *other* (*N*=4). Papers could be coded into multiple categories and often addressed more than one issue (*median*=2, *stdev*=0.67) with the combination of *increasing independence* and *physical access* as most common. Additionally, papers within the *other* category focused on providing access to physical activities [127], training [169] and restoring vision [81, 199].

According to the classification of contribution types based on Wobbrock and Kientz [203], these challenges have been primarily addressed by empirical studies (*N*=93) and artifact contributions (*N*=73). Empirical contributions focus on exploring user preferences or conducting an in-depth investigation of the use of a system whereas artifact contributions focus on the design and the implementation of a software artifact [203]. However, some empirical studies within our subset did not involve a system in use, and not all artifacts enabled interactions.

For instance, some contributions are purely technical and consist of an evaluation of a machine learning model (*e.g.*, [167]) whilst others present novel models or algorithms that were not integrated into an interactive system at the time of the study (*e.g.*, [7]). Algorithms and models were considered as software tools or *toolkits* [203], that could support the development of new interactive systems which could be used in the future by the BLV population (*e.g.*, "*applicable to scenarios encountered when visually impaired users actively elicit visual information*" [7, p. 2425]). Moreover, empirical and artifact contributions frequently co-occurred (N=59).

Furthermore, the remaining contribution types occurred considerably less frequently. Six papers (N=6) provided datasets (*e.g.*, [7, 42]), with one notable example being Gurari *et al.* [67], who collected over 30,000 visual questions from blind individuals using mobile phones, each paired with spoken questions and crowdsourced answers. Moreover, a low number of contributions were theoretical (N=2, *e.g.*, [123, 151]) or methodological (N=2, *e.g.*, [5]), applying to broader research fields such as accessibility research [166, 202].

4.2 Research Areas, Community of Focus, Technological Trends, and Interactions

The initial mixed-methods analysis, conducted in our prior work, aimed to answer the following four research questions:

RQ1 *What* are the main research areas targeting BLV users?
RQ2 *What* are the main communities of focus considered in these studies (*e.g.*, low-vision, blind, not specified)?
RQ3 *What* are the main technological trends and devices used?
RQ4 *What* are the common interaction modalities employed with regards to the targeted end-users' visual abilities?

To provide an overview of our past findings, Table 4 summarizes the results with respect to the research questions and the set of papers (N=880 or N=100). Notably, our iterative process, combining bibliometrics and qualitative data analyses, highlighted four main research areas: *Accessibility at Home & on The Go* (N=280), *Non Visual Interaction* (N=195), *Education* (N=54), and *Orientation & Mobility* (N=331). While in line with prior literature reviews [21, 35, 114], our contribution additionally highlights the proximity between research clusters and provides a high-level delineation of interactive computer systems dedicated to BLV people. We also disclose that seminal BLV research is published in both ACM (*e.g.*, [2, 22]) or IEEE (*e.g.*, [7, 67]) sponsored conferences and journals.

Moreover, in accordance with previous SLRs [35, 114], our findings highlight a large variety of denominations and language preferences used across papers to denote the BLV community. In particular, within the 880 papers, a vast majority of papers used a non-specific BLV term (IFL and PFL) to cover a wide range of visual abilities. Furthermore, these terms were frequently mentioned in tandem with a more precise visual ability definition. However, within the top 100 subset, we found that most artifacts were targeted towards both *blind* and *low-vision* people [57, 173] and/or were inclusive to people with mixed visual abilities [34, 122, 123, 184].

Regarding technological trends and devices, our TAK analysis of the 880 papers highlighted *mobile* as the most prominent, followed by computer vision, wearable devices, navigation assistance technologies, artificial intelligence (AI), and web-based solutions. Notably, there has been a noticeable increase in mixed reality and AI applications since 2015 and 2016, respectively. Additionally, within our top 100 most-cited papers, we observed a predominant focus on *Computer Vision*-based solutions [3, 7, 22, 197, 212] and novel forms of *Navigation Assistance* [2, 62, 92, 93]. Concurrently, we also noted studies focused on technologies available on commercial devices (*e.g.*, touchscreens [91], smartphones [170]).

Finally, to analyze the interaction modalities in our 100 most-cited papers, we first excluded 30 studies that did not present or evaluate interactable computer systems, including datasets and models without interactable components, and surveys not focusing on artifacts. Our analysis then revealed that many of the proposed computer systems, within the 70 remaining papers, did not require or enable specific inputs from users. In particular, we observed artifacts that performed actions automatically without any user intervention (*e.g.*, object detection and/or navigation assistance [92, 93, 212], alt-text generation [57]). Furthermore, whilst a wide range of output modalities have been considered (cf. Table 4), we highlighted the lack of interest for solutions with visual feedback (N=10). This focus on non-visual feedback is further underscored by the fact that 61 studies explored visual substitution rather than enhancement strategies (N=8), with only two studies addressing both depending on the end-user [14, 212]. This trend aligns with past studies [78, 178], which noted a potential oversight of the residual vision of target end-users and their desire to use it.

Table 4. Summary of the results of our ASSETS paper with respect to the research focus and the set of papers.

Research focus	**Analysis Level**	**Main Findings**
Research areas (RQ1)	N=880	*Accessibility at Home & on The Go* (N=280); *Non Visual Interaction* (N=195); *Education* (N=54); *Orientation & Mobility* (N=331).
	N=100	Narrative summary based on top-cited works per research area.
Communities of focus (RQ2)	N=880	**Non-specific BLV terms** (*e.g.*, people with visual impairments, visually impaired people, blind and visually impaired people) are often used to cover multiple visual abilities (N=715). Predominant interest on blind people.
	N=100	*Blind and low-vision* (N=58); *Blind* (N=36); *Sighted* (N=12); *Low-vision* (N=5); *Deafblind* (N=3); *Other* (*e.g.*, motor, sensory and cognitive, N=3).
Technologies and devices (RQ3)	N=880	**Technological trends:** Mobile (N=224), Computer vision (N=116), Wearable (N=106), Navigation assistance (N=106), Artificial intelligence (N=70), and Web (N=67).
	N=100	**Technologies (top five):** Computer vision (N=36); Navigation assistance (N=28); Mobile (N=18); Web (N=14); and Haptics (N=10). **Devices (top five):** mobile devices (N=33); Wearable (N=25); Personal computer (N=17); Virtual Reality headset (N=5); and Tangible object (N=5).
Interaction modalities (RQ4)	N=100	**Output modalities (top five, out of N=70):** Non-speech audio (N=46); Haptics (N=18); Speech (N=10); Visual (N=10); and Tactile (N=4). **Input modalities (top five, out of N=70):** Touch (N=32); None (N=31); Speech (N=11); Gesture (N=5); and Not specified (N=1). **Visual use strategies (out of N=70):** Substitution (N=61); Enhancement (N=8); and Not specified (N=1).

5 RESEARCH THEMES AND INTERACTION

In this section, we present the findings of our extended investigation of the research methods employed within the 100 most-cited papers in our dataset. Next, we present the results of our in-depth analysis of the four high-level research areas, highlighting key themes (*e.g.*, activities, interactions, technologies) involved in BLV research. Finally, we present the terms frequently appearing with "interaction," offering insights into their usage patterns and contextual significance.

5.1 Research Methods and Development Process

The research methods identified with our top 100 most-cited papers include: *usability testing* (*N*=34), *other* (*N*=24), *controlled experiments* (*N*=20), *interviews* (*N*=17), *survey* (*N*=9), *workshop or design session(s)* (*N*=5), *field study* (*N*=4), and *case study* (*N*=2). Other study methods could include a document analysis of guidelines [86, 152] or automatic accessibility testing (*e.g.*, [42]).

When positioning these methods into the development process of an interactive computer system intended to help BLV users, we report the coding of 61 papers and discern several types of approaches. A subset of artifacts (*N*=12) undergo a complete development cycle, commencing from preliminary user or motivational study to the design and implementation, and culminating in evaluation with end users (*e.g.*, [22, 207]). The preliminary user study can be detailed in the same paper as well as another one authored by the same research team (*e.g.*, [12]).

Another set of papers (*N*=8) were primarily aim to deliver a functional artifact, leveraging previous knowledge for design, yet predominantly focus their evaluation on technical aspects (*e.g.*, performance, computing resources uses), with limited or no direct user involvement (*e.g.*, [39, 84]).

Finally, numerous papers (*N*=25) used mainstream interactive systems (*e.g.*, Apple VoiceOver [104], touch screen smartphone running Android [138], tablet PC running Windows [91]) or a prototype created for the occasion to perform a user study (*e.g.*, [74]). They works typically aims to informs user needs and requirements as well as user evaluation of future research.

Moreover, works focusing mainly on technical or computer science aspects, which do result in interactive systems, often used methods relevant to their discipline (*e.g.*, machine learning). However, we also note instances where BLV people were involved or considered during a part of the process. For instance, to identify and address a specific need, Chen *et al.* [42] mined approximately 19,000 Android apps, revealing that over half of the image-based buttons lacked labels. While the absence of labels is recognized as an accessibility issue, the identification of this need was through a proxy. Additionally, Yi *et al.* [211] recruited blind participants to collect an image dataset using a camera mounted on a pair of sunglasses, which was then used to evaluate a text recognition model.

5.2 Research Areas and Research Themes

In this subsection, we first complete our description of the research areas, identified in our previous work, by providing additional information. Then, we detail the research themes within each area. Finally, we explore potential intersections between these themes and areas.

5.2.1 Accessibility at Home & on the Go (N=280). This research area comprises a wide range of efforts focused on the broad concepts of *access* (including *assistive technology*) and *use* of technology (cf. Figure 3). Works in this area have focused on the task of Visual Question Answering by enabling users to ask and receive computer-generated answers about images [7], or by connecting blind people to remote paid workers for assistance [22]. Additionally, studies have assessed the accessibility of wearable devices for BLV people, which facilitate eyes-free interaction methods [209]; reported on web accessibility problems encountered by blind users [151]; investigated existing guidelines and current practices of alternative text, as well as the experiences of BLV users [86]; and explored how BLV individuals use mainstream computing devices [178] or smartphones [155]. Moreover, the terms *access* and *use* are typically more prevalent than *interact* in these works (*e.g.*, Szpiro *et al.* [178], Rodrigues *et al.* [155], Ye *et al.* [209], cf. Supplementary material).

To provide additional insights into the *Accessibility at Home & on the Go* research area, we describe the two main interconnected and complementary themes within this field: *Access to digital media and technology*, and *Access to activities*.

Access to digital media and technology. This research theme focuses on providing and understanding access to various digital artifacts. These objects can be technologies, media or specific specific classes/types within these

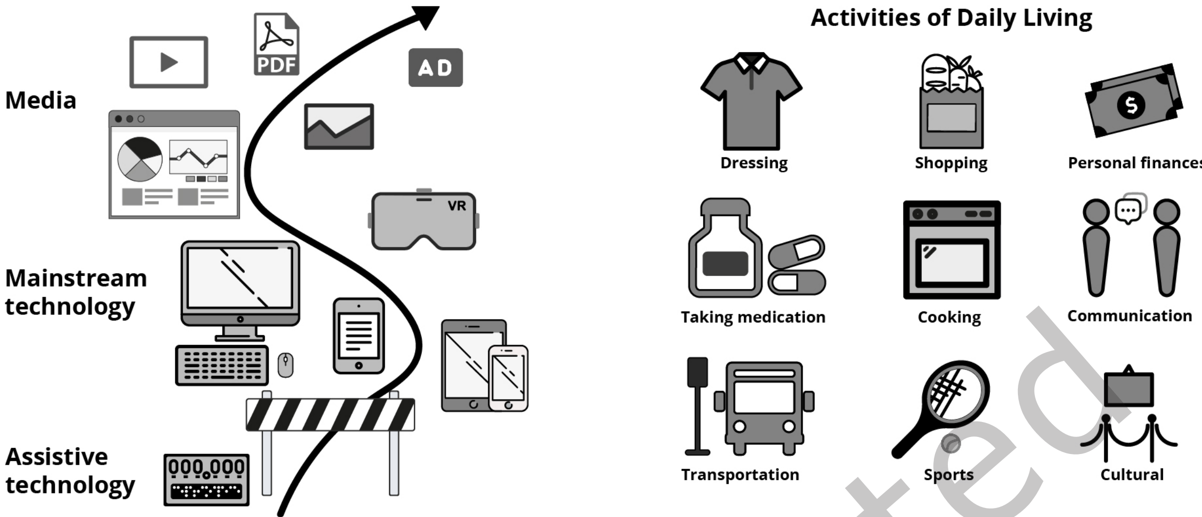

Fig. 3. Illustration of the *Accessibility at Home & on the Go* Research Area and its associated themes.

categories. More specifically, our findings reveal a diverse set of digital objects being studied, including *Assistive technology*, *Data visualization* (*e.g.*, graphs, charts, plots), *Image* (static or dynamic), *Augmented/Mixed/Virtual reality*, *Video*, or *Web* among the most frequent (cf. Table 3 and Supplementary material). Moreover, digital technology and media are typically interconnected. For instance, static images are often integrated within social media or web pages. A typical empirical investigation of the interconnection of computing devices, including assistive technology, is provided by Szpiro *et al.* [178], which focused on low-vision people.

The *Web* is the most frequently coded digital technology in this research theme. However, this rich technology encompasses various other digital media and can be accessed through numerous technologies or devices. Focusing on web accessibility, the seminal paper by Power *et al.* [151] identifies three types of user problems: those not covered by guidelines, those covered by guidelines which are not implemented, and those covered by guidelines with guideline implementations. Given the limitations of web accessibility guidelines to completely address user issues, Power *et al.* [151] suggest investigating effective web usage through usability studies. Additionally, other studies have identified behavioral strategies employed by BLV users to improve access to web content [113].

Mobile technology is another significant area of study, focusing both on understanding the user experience (*e.g.*, [38, 155]) and on providing solutions (*e.g.*, [42]). For instance, Rodrigues *et al.* [155] highlighted major concerns, expectations, challenges, barriers, and experiences by blind smartphones users, while Carvalho *et al.* [38] examined accessibility and usability issues encountered by blind and sighted users on mobile websites and applications. Conversely, in terms of solutions, Chen *et al.* [42] developed a deep learning-based model to automatically predict the labels of image-based buttons within commercial apps on Google Play, aiming to enhance app accessibility via a screen reader embedded in the mobile. More recently, Alotaibi *et al.* [6] developed an automatic approach to detect *TalkBack* failures in Android applications.

Beyond *Web* and *Mobile* technologies, *Virtual* and *Augmented Reality* are proving beneficial for low-vision people [73, 175, 216]. Virtual reality applications for low-vision users often employ visual and audio augmentations, as exemplified by projects like *SeeingVR* [216]. On the other hand, augmented reality technologies, with HMDs (*e.g.*, with the Microsoft Hololens [175]) or mobile devices (*e.g.*, with *Apple iOS* [73]), are being developed and evaluated to explore new possibilities for enhancing accessibility and usability.

Regarding media, automatic image [214] and video [111, 217] description is a well-established field of research with computer science scholars often developing machine/deep learning models for tasks like Visual Question Answering [7, 66, 167] and generating image descriptions [50]. Applications aimed at aiding BLV users are frequently integrated with popular social media platforms like Facebook [207] and Twitter [57, 129]. Moreover, various techniques for generating captions/descriptions, including web crawling, have been evaluated [57, 64]. Additionally, challenges faced by BLV individuals regarding visual content and the detrimental effects of inadequate descriptions are well-documented [115, 173, 190]. Tools designed to investigate captioning errors [101], along with efforts to guide captioning for both novice [126] and experienced workers [131], are also available.

Finally, *Data visualization*, which encompasses graphs, charts, and plots is also investigated extensively. In this context, Ferres *et al.* [51] developed an assistive technology to help BLV individuals interact with graphical representations of line graphs using natural language through key commands and a Text-To-Speech engine. Similarly, Chen *et al.* [41] proposed a model for generating figure captions along with a dataset. More recently, Jung *et al.* [86] tackled this issue from a dual perspective by consolidating guidelines and current practices and conducting interviews with BLV people. Their findings describe the mental images formed by BLV people and provide recommendations to reference the underlying data instead of visual elements, thereby reducing users' cognitive burden.

Access to activities. This research theme focuses on aiding, helping, and understanding access to activities in the physical world (*e.g.*, social relations and communication, textual reading, and mobility [153]).

Activities of *daily living* encompass a wide range of tasks related to the independence of BLV people. These activities are supported by visual assistance technologies (VATs) [174], which use remote human visual assistants (human-powered VATs, *i.e.* remote sighted assistance-RSA [103]), AI algorithms (AI-powered VATs based on visual question answering) [7], or a combination of the two [23, 65]. The pioneering project *VizWiz* [22] enables blind people to recruit remote sighted individuals to assist them with visual issues in almost real-time. Human-powered solutions (*e.g.*, crowdsourcing) have proven to be valuable and scalable [22, 28], while AI-powered solutions have continued to evolve [23, 65]. The initial version of *VizWiz* has since evolved into *VizWiz Social* [28], transitioning from generic crowdsourcing to a friendsourcing strategy, which emphasizes the importance of knowing the asker and addressing privacy considerations. The technology has also progressed from static images to video streams [100]. Additionally, variants of *VizWiz* such as *VizLens* [65], a specialized solution designed to make physical interfaces accessible, have emerged.

In recent years, many research-based projects have evolved into commercial products. For instance, one of the most popular applications on the market is *Be My Eyes* [11][8], which, as of early June 2024, boasts over 7 million volunteers, 650,000 BLV users, and operates in more than 150 countries supporting 180+ languages[9]. The commercialization of these tools has led to the professional practice of remote sighted assistance as a conversational assistive technology [103]. Recent issues with such solutions have centered on privacy concerns [174], prompting the development of solutions focusing on data privacy [66] and privacy by design [174]. Moreover, these solutions are closely related to research on *blind photography* [83], often involving the use of a *mobile* phone. A common daily life activity, such as reading a label on a product, is thus transformed into the task of taking a photo of sufficient quality.

Another important and prominent aid for *activities of daily living* includes personal object recognizers (*e.g.*, *ReCog* [3], *VizWiz::LocateIt* [23]), which can detect a wide range of objects (*e.g.*, [87]) or are trained for specific classes (*e.g.*, medication pills [39], banknotes [71]). These computer vision based systems are typically provided

[8]https://www.bemyeyes.com/
[9]Compared to 25,000 blind users and over 300,000 volunteers in December 2015 [11].

via mobile and wearable technology and are closely linked to predominantly technical contributions focusing on text localization (*e.g.*, [210]) or image quality evaluation (*e.g.*, [84]).

Regarding *non-verbal* and *verbal communication*, prior works have focused on understanding visual cues such as facial expressions, emotions, and eye contact (*e.g.*, [60, 134]). Neto *et al.* [134] developed a wearable face recognition system, while Grayson *et al.* [60] used an advanced computer vision-based AI system that provides BLV people with dynamic, in-situ access to information about the location, identity, and gaze direction of nearby individuals.

Other activities, supported by this research area, include providing access to museums, leisure, sports, work, and hobbies. For instance, Asakawa *et al.* [9] investigated the opinions and expectations of BLV individuals about visiting museums independently, as well as the necessary user interface requirements to support such visits. Finally, closely related to the *Orientation & Mobility* research area, studies also investigate the accessibility of transportation. For instance, Hara *et al.* [70] focus on the role of landmarks in helping BLV people in locating and identifying bus stop locations.

5.2.2 Non-visual Interaction (N=195). This research area centers around enabling BLV people to interact with/through technology without relying on visual input (cf. Figure 4). A related term is *sensory substitution* which pertains to the output modality.

While works in this research area are often connected to those in *Accessibility at Home & on the Go*, they tend to delve deeper into the study of interaction dynamics. Such investigations often involve user studies that assess the effective use of interactive computing systems rather than relying solely on user-reported feedback. For instance, Oliveira *et al.* [138] examined text-entry methods, while Kane *et al.* [91] explored gestures on touchscreen interfaces.

Moreover, the challenges faced and/or the solutions proposed concentrate on the non-visual interaction modality, which could then be used to access the technology. For papers which also focus on a specific media, the interaction modality can then, in most cases, easily be inferred (*e.g.*, touch display–tactile modality [142]). Furthermore, works can be also related to *Education* (*e.g.*, [59]), *Orientation & Mobility* (*e.g.*, [5, 208]) as well as *Accessibility at Home & on the Go* (*e.g.*, [99]) in the application of the interaction.

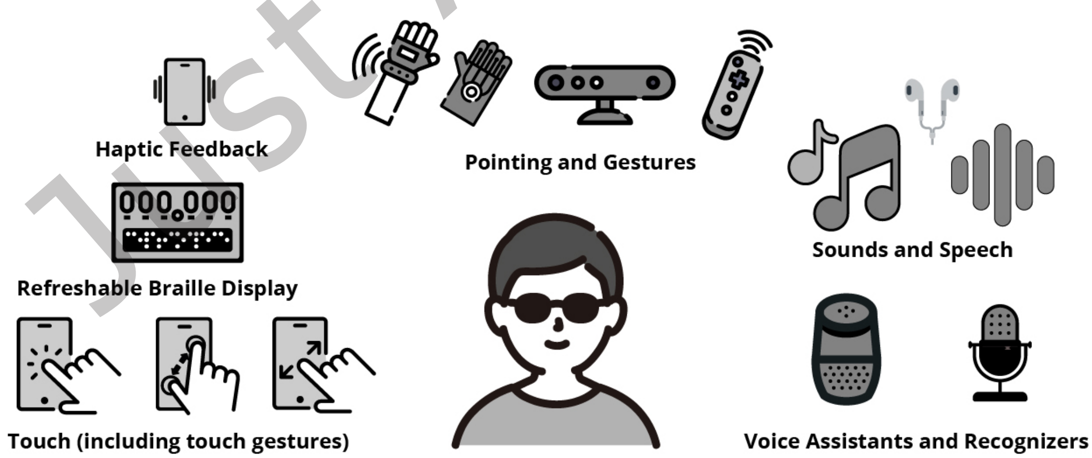

Fig. 4. Illustration of the *Non-Visual Interaction* Research Area and its associated themes.

In particular, within our dataset, the touch [74, 83, 91, 141, 170, 208] and speech [12, 30, 104, 152] modalities received the most interest. Additionally, we identified non-visual multimodal systems that combine various non-visual cues.

Touch. The touch modality is facilitated through mainstream technologies, such as touchscreens [90, 91, 138], and assistive technologies like braille and wearable devices [141]. In particular, touch-based technologies provide a means of communication for individuals who have difficulties communicating via visual/auditory means, with Braille being a popular method for reading and writing within both blind and deafblind communities [141]. Within this scope, Southern *et al.* [170] evaluated *BrailleTouch*, an accessible keyboard for blind users on touchscreen smartphones, demonstrating that participants could transfer their braille typing skills to touchscreens effectively.

The touch modality also plays an important role in the context of spatial maps for O&M. For instance, Yatani *et al.* [208] introduced *SpaceSense*, a handheld system with spatial vibrotactile feedback to present geographical information to BLV users. Moreover, Taylor *et al.* [181] developed a system using 3D printing to create customizable and interactive tactile maps, making them more affordable and accessible. Building on this, Holloway *et al.* [74] compared traditional 2D tactile maps to 3D printed tactile maps for O&M training and found that 3D printed maps facilitated better understanding and recall of spatial information. Additionally, touch-based technologies have been explored in creativity and design. For instance, Siu *et al.* [168] designed *shapeCAD*, a tool that enables BLV users to create and modify 3D models using a 2.5D tactile shape display to enhance the accessibility of 3D modeling. Finally, researchers have also explored touch gestures on tactile surfaces (*e.g.*, touchscreens), investigating the differences between blind and sighted people, both in terms of preference and performance [91].

Audio: Speech and Sounds. The speech modality is investigated through voice personal assistants within mainstream devices, (*e.g.*, Apple Siri, Amazon Alexa, and Amazon Echo) [12, 152], which have rapidly become pervasive in households as smart speakers and on-the-go as mobile applications [30]. These devices provide a voice-user interface that enables human-to-machine and machine-to-human speech communication. While the speech modality is, by default, an accessible means of interaction for BLV individuals [152], studies also highlight its limitations when used by blind users [12], as well as the lack of consideration for this demographic within voice-user interface guidelines [30]. Others focus on speech synthesis integrated into screen readers [29, 43, 104]. Recently, Bragg *et al.* [29] conducted the first large-scale study of human listening rates over a 12-month period. They showed that BLV are the fastest listeners (*i.e.*, compared to sighted people) and in particular those exposed to screen readers at a young age. Moreover, synthetic speech is intelligible to many people at rates much faster than typical human speaking rates, suggesting that there is room to increase and optimize conversational agent speaking rates to save users time. Closely connected to the previous research theme, verbal feedback and gesture sonification are compared to enhance learning of touchscreen gestures [137].

Multimodal Systems. Scholars refers to multimodal interaction when at least two modalities are employed in combination. To provide a non-visual access to graphic material, Giudice *et al.* developed a vibro-audio interface that synchronously trigger a vibration patterns and auditory information when the user touch a visual element on the screen [56]. The research efforts related to multimodal graphics are synthesized by Gorlewicz *et al.* [59] into design guidelines. Recently, and to support data exploration, Fan *et al.* [49] developed two multimodal interfaces using a slider: one with tone sonification, where the pitch changes with the slider's position to represent data values, and another with tilt sonification, where the sound varies based on the angle of the user's fingerpad to convey shape characteristics. Multimodal systems are also employed to encourage physical activities among BLV people. In particular, two exercise games (exergames), tennis [127] and bowling [128], use vibro-tactile and audio cues to inform the user.

5.2.3 Education (N=54). Education research papers focus on the development of technologies and/or studies that aim to support educational support to BLV individuals (cf. Figure 5). While four different learning contexts are discussed—inclusive *vs.* special needs education[10], online learning, and learning at home)—mainstream or inclusive schools are the most prevalent, reflecting a shift towards educating BLV learners in mainstream settings rather than specialized schools [124]. Furthermore, in terms of pedagogy, collaborative learning is frequently put into practice [34, 97, 122, 123, 184] with various technologies and devices including robotics [122], voice user interfaces [123], physical programming languages [184], and multi-sensory interactive maps [34].

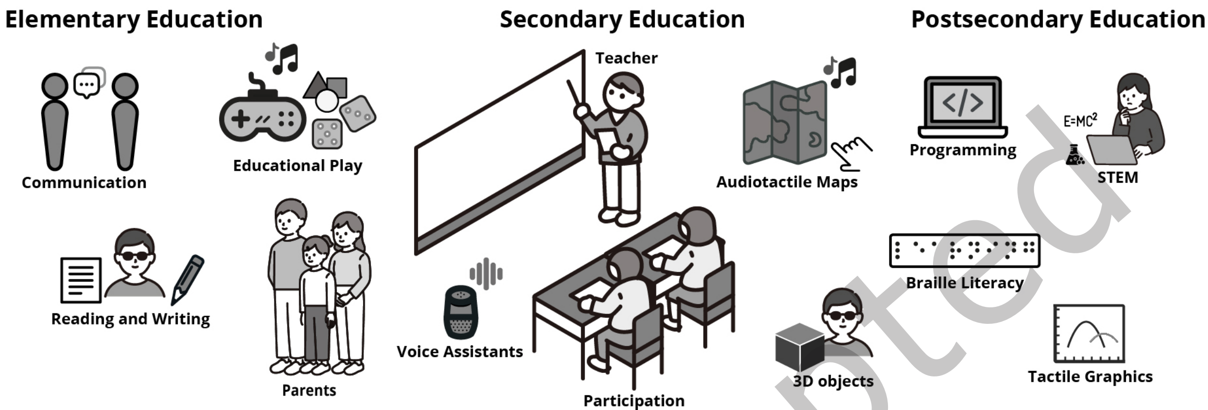

Fig. 5. Illustration of the *Education* Research Area and its associated themes.

Whilst categorizing this research area into distinct themes proved challenging due to significant conceptual overlaps (cf. Figure 5), we identified several themes ranging from the *Learner Age Category* to the *Stakeholders* involved in the educational support (cf. Table 3).

Unlike the other research areas, education research places a significant emphasis on the age of BLV individuals, with a strong focus on children (cf. TAK analysis in Supplementary material) and a selection of papers specifying the *Age Categories* of their end-users (*e.g.*, preschool [172], *"up to 3rd grade"* [171], children aged 7-11 [184]) or study participants (*e.g.*, secondary school students aged 11-18 [123], participants aged 9-10 [122], or interviewees covering ages 7-19 [34]).

While some studies focus on educational play or rather the means to support education that the subject topic, multiple papers focused specifically on science, technology, engineering, and mathematics (STEM) subjects. Due to the abstract nature and intensive reliance on the visual medium of such disciplines, tangible interfaces [89, 97, 184] and 3D printed objects [89] have been proposed to enable BLV students to learn programming languages and create content. Additionally, some papers focused on using audio to support independent mobility and enhance children's play [53], while others focused on literacy by examining co-reading practices between blind parents and their sighted children [177].

Finally, this cohesive research area focuses on educational contexts where a diverse ecosystem of stakeholders (*e.g.*, [34, 97, 122, 123, 172]), including students with mixed visual abilities, students with mixed abilities (beyond BLV), teachers, parents, educators, and caregivers, collaborates to enhance learning and teaching activities. These stakeholders are frequently involved in the development process (*i.e.*, needs elucidation & requirements, design & implementation, evaluation) of interactive computing systems, as evidenced by studies such as those by Brulé *et al.* [34], Koushik *et al.* [97], Metatla *et al.* [122, 123], and others. For instance, in terms of design approaches,

[10]Special needs education is tailored to students and their disabilities, whereas in inclusive education, students with disabilities and their peers receive the same education.

we identified studies that conducted co-design workshops [122, 123] or a formative study [34] with BLV and sighted children, special needs educators, and teaching assistants.

5.2.4 Orientation & Mobility (N=331). The O&M research area aims to improve the independence and safety of BLV people during O&M tasks (cf. Figure 6), with papers differing in terms of approach. In particular, whilst most papers in this research area consider a real-world assistive approach (*i.e.*, *Navigation Assistance*), others consider O&M *Training* or aim to understand needs and navigation strategies of the BLV community to help guide future designs (*i.e.*, *User Understanding*).

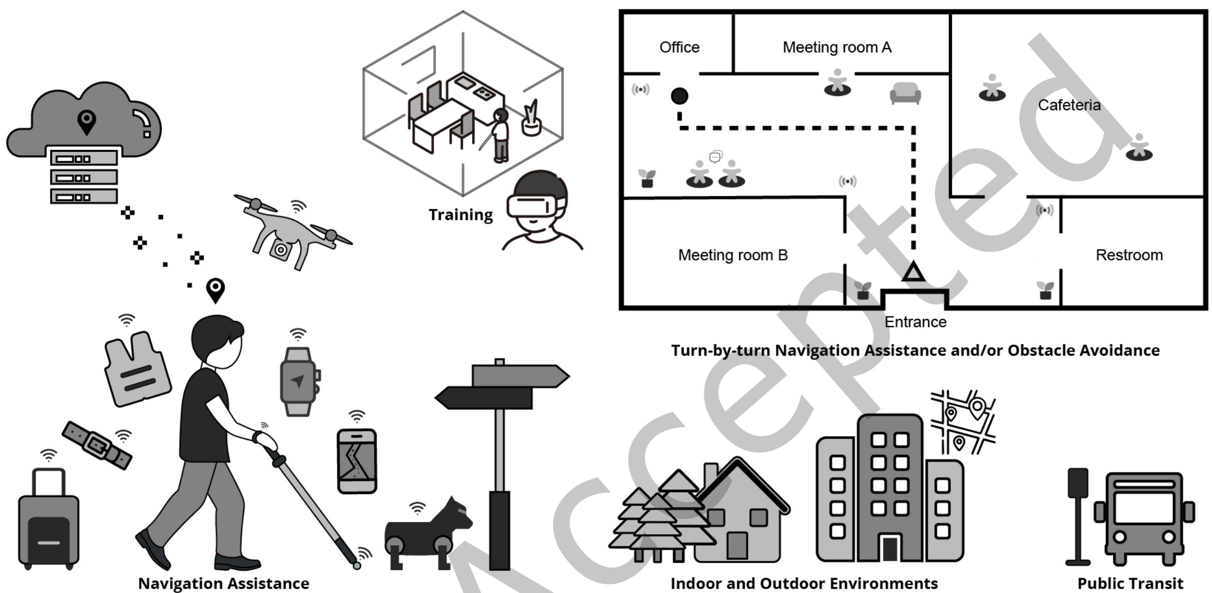

Fig. 6. Illustration of the *Orientation & Mobility* Research Area and its associated themes.

Navigation assistance. Navigation assistance papers focus primarily on the design and evaluation of artifacts which aim to support BLV using during O&M tasks. More specifically, the artifacts contain one or more of the following modules: user localization [2, 106], path detection (sensing eventual obstacles) [16, 106, 212], and/or providing dependable guidance or feedback to help the BLV user (through haptic [16, 106] feedback, or audio [2, 93, 212]). Numerous sensors, devices (*e.g.*, smartphones [2, 162, 180], tablets [106]), and technologies (*e.g.*, Bluetooth low energy [2] or deep learning [212]) are combined to achieve such goals. Furthermore, while some systems focus on navigation in crowded environments [93] or on obstacle detection and/or localization [212], others aim to provide navigation assistance in either (un-)familiar indoor [16, 106, 162], or outdoor [212] environments, or both [2]. Other solutions, related to the accessibility of public transportation, include the *GoBraille* application to help blind and deaf-blind public transit riders [13].

To further delve into the different kind of navigation paradigms, we first distinguish between artifacts which provide *Turn-by-turn* assistance, *Obstacle avoidance*, or both, from the perspective of the BLV user. Artifacts within the turn-by-turn assistance category typically describe systems which, given a map and a destination, provide the users with information to reach their destination. On the other hand, those within the obstacle avoidance category aim to detect obstacles (static and/or dynamic) within proximity of the BLV user, notify them of their presence and guide them safely around the obstacle. In particular, our in-depth analysis of the 24 navigation assistance artifacts from the 38 most-cited papers within this research area, reveals a higher number of obstacle avoidance systems (N=15) than turn-by-turn navigation systems (N=6) or systems that incorporate both (N=3).

User understanding. This theme includes papers focusing on understanding the challenges faced by the BLV community with respect to O&M tasks to provide guidelines and/or recommendations for future designs. For instance, Banovic *et al.* [15] explored the practices and challenges BLV individuals encounter in learning to navigate independently. Müller *et al.* [132] provide a survey-based investigation into the travel behavior of BLV and/or mobility impaired individuals in indoor environments their results highlighting the lack of available high-quality indoor maps. Furthermore, Williams *et al.* [200] examined the perceptions of sighted people regarding BLV navigation, revealing that well-meaning assistance often stems from a lack of understanding of how BLV individuals navigate, which can lead to inappropriate and even dangerous feedback.

Complementing these findings, other studies focus on investigating how BLV people use assistive technology to provide insights into usage patterns and recommendations for future assistive tools [88, 201]. In particular, as navigation technology is prone to errors, Abdolrahmani *et al.* [1] explore how BLV users respond to errors from navigation assistance systems in various scenarios. Interestingly, their results indicate that, whilst error acceptance depended on its type and context, 42% of errors were acceptable to users.

Moreover, Williams *et al.* [201] emphasize the importance of understanding the unique navigation needs and behaviors of BLV individuals, advocating for designs that cater to these specific requirements. Accordingly, Saitis & Kalimeri [157] additionally consider a context-aware approach and advocate for emotionally intelligent mobility-enhancing systems which not also adapt to the environment but also to the emotional state of the users. As such, their study proposes a multimodal framework that integrates brain activity signals and peripheral biosignals from BLV users with the goal of understanding the environmental factors that increase their stress and cognitive load [157].

Finally, with the rise of autonomous vehicles, Colley *et al.* [44] consider the issue of vehicle-pedestrian communication (VPC) between autonomous vehicles and BLV people. They highlight the lack of inclusion of the BLV community in past designs and present an inclusive user-centered design for VPC considering both sighted and BLV people.

Training. Studies within this theme focus on O&M training, utilizing various technologies such as virtual reality [69, 164, 169, 183, 215], audio-based simulators [158], haptic feedback [169, 179, 215], and mobile position-based games [116].

Within studies that focused on virtual environments, Seki and Sato [164] and Sánchez *et al.* [158] primarily explore auditory orientation training where BLV trainees can navigate through a virtual world using sound cues. Notably, Sánchez *et al.* [158] adapted their game to be used within an fMRI scanner to study brain activity during navigation and discuss their future goal of understanding how and if acquired spatial information can be transferred from virtual to real environments in future work. In addition to the auditory channel, Han *et al.* [69] investigated the impact of walk-in-place using an omnidirectional treadmill in virtual reality, compared to actual walking with a virtual reality tracker, on spatial information acquisition. Interestingly, their results indicated that whilst their BLV participants retained routes better when using the treadmill, they remembered obstacles more easily when walking with the virtual reality tracker. Additionally, Thevin *et al.* [183] developed X-Road, an accessible virtual reality system providing both visual and audio feedback to support O&M training, designed to be inclusive for both sighted and low-vision users. Furthermore, to also enable BLV white cane users to physically navigate virtual worlds/environments whilst training their real-world cane skills, Siu *et al.* [169] and Zhao *et al.* [215] developed haptic cane controllers taking inspiration from real-world cane interaction strategies.

Extending beyond virtual environments, Tanabe *et al.* [179] proposed a training system featuring an optical motion capture system and a handheld device that uses illusory pulling cues through asymmetric vibration stimuli to teach white cane techniques. Additionally, Magnusson *et al.* [116] designed a location-based mobile pervasive training game, in collaboration with O&M specialists and BLV children, to make navigation training more engaging.

Other. Within this theme, we include artifacts or components of computer systems which could be used to develop interactive systems. For instance, these encompass deep learning-based computer vision models that detect various generic objects (not necessarily related to O&M), which could be used in contexts such as obstacle avoidance [10, 117]. Additionally, we also identified papers which focus on implementing and evaluating navigation-related algorithms/models (*e.g.*, localization [110] and pedestrian crossing detection [37]), but do not explicitly address user assistance methods [37, 110].

5.3 Understanding Interactions

HCI places significant emphasis on understanding "*how the interplay between humans and computers is structured*" [77, p. 2]. Consequently, interaction emerges as a critical focus within our dataset (N=880), with the term "interaction" appearing 244 times across 176 abstracts (20%). To illustrate the use this term across our dataset, we further showcase its contexts of use and categorized modifiers, with a focus on the *Quality* and *Style* types (cf. Section 3.3). In descending order, *Style* modifiers occur 148 times, followed by *Concept* with 67 occurrences, *Other* with 40 occurrences, *Quality* with 36 occurrences, *Social* with 36 occurrences, and *Statistical* with one occurrence.

Further focusing on the modifiers classified under the *Style* (N=148) and *Quality* (N=36) types (cf. Section 3.3), Table 5 showcases the frequencies of each modifier and provides examples of how they are used. However, we note that we also identified 17 occurrences where the modifiers were categorized under both types (*e.g.*, "enhanced, seamless interaction" [133], "accessible on-body interaction" [136], "usable touchscreen interaction" [125]). Moreover, we note that, whilst the remainder of this analysis focuses solely on the *Style* and *Quality* themes, the full results of our analysis are provided in our supplementary materials.

5.3.1 Styles of Interaction. The *Style* modifiers (N=148) were categorized into 10 out of the 11 themes presented in Hornbæk et al. [77]: *Characteristic*, *Modality*, *Technique*, *Principle*, *Body Part*, *Device*, *Content*, *Artifact*, *Action*, and *Widget*.

Artifact emerged as a the most prominent theme (N=41), encompassing interactive computing systems, such as mobile phones [104] or tabletops [90], in addition to tangible objects (*e.g.*, 3D printed models [181]) and non-digital assistive technology (*e.g.*, white cane [215]). Interestingly, while some abstracts used generic terms such as "application" or "system," others used more specific and descriptive terms like "multi-sensory interactive maps" [34] or "*VoiceOver iMove* user interaction" [88]).

Modality also emerged as a frequent theme (N=35), encompassing various input modalities such as "tactile interaction", "touch-based interaction," "zero-touch interaction," "voice interaction," "gesture-based interaction" or "gestural interaction," and "hands-free interaction". Within the output modalities, the terms "haptic interaction," "eyes-free interaction," and "visual interaction" were identified, alongside complex combinations such as "eyes-free wearable interaction" or "hands and eye free interaction". For instance, Jain *et al.* [80] discuss how touchscreen phones, which tend to demand constant visual attention, limit the possibility of "eyes-free interaction". Ye *et al.* [209] state that "eyes-free wearable interaction" means are particularly appealing for BLV people who do not always require the visual display of a mobile phone. Moreover, Fiannaca *et al.* [52] highlight the potential of wearable devices with cameras to support "hands-free and eyes-free interaction".

Characteristic themes were also common (N=28) with terms that can provide additional information about the technology, type of actions and modalities involved in the interaction. Notably, we found multiple instances of the term "multimodal" interaction, but also identified terms such as "seamless," "physical," or "spatial" interaction. For instance, Bartolome *et al.* [79] explored a voice interactive "multimodal guide" that uses tactile gestures and voice commands to trigger audio descriptions and sounds while navigating a 2.5D tactile representation of visual artworks. Similarly, Brock *et al.* [33] promote "multimodal" interactive maps as a solution for providing blind people with access to geographic information, using tactile maps on multitouch displays with sound output, outlining device requirements, presenting a prototype, and proposing future developments. On the other hand, regarding the term "seamless interaction," Nanayakkara *et al.* [133] discuss how a finger-worn interface enables "seamless" interaction with environmental information, benefiting both BLV and sighted users alike. Moreover, Panëels *et al.* [145] developed a spatial awareness application using smartphones, geographic databases, and spatialized audio rendering, and emphasize the importance of appropriate design when considering "physical" interaction.

The remaining *Style* modifiers explored themes like *Content*, *Principle*, *Widget*, *Device*, and *Artifact*, providing insights into the technologies involved in the interactions and their contents (*e.g.*, "games," "immersive," "virtual," "touchscreen," "smartphone," "tabletop," "audio label"). Additionally, themes such as *Action*, *Body Part* and

Table 5. Frequencies of the Modifier Types and Themes with examples.

Modifier Type (#)	**Theme (#)**	**Examples**
Style (148)	Artifact (41)	audio-tactile map; tabletop; mobile phone; smartphone; ring
	Modality (35)	haptic, tactile, vibratory, speech-audio; eyes-free
	Characteristic (28)	multimodal, physical, proximity-based, spatial, passive
	Content (12)	audio game; mobile tool; braille window system; map; visual content
	Device (11)	touchscreen; cane; keyboard surface; visual displays
	Body Part (9)	manual; foot-based; on-body; two-hands; hands and eye free
	Principle (6)	immersive; virtual; wearable; ubiquitous
	Action (5)	zoom interaction; element filtering
	Widget (4)	menu; audio label; visual element
	Technique (1)	mid-air gesture
Quality (36)	Comparison (10)	future; modern; novel; popular; unique
	Value Words (8)	robust; satisfactory; enhanced; innovative; powerful
	Feel (6)	user-friendly; natural; complex
	Effectiveness (5)	effective; usable; efficient; performance
	Resource Use (2)	speed; longer
	Affective (1)	challenging
	Temporal (1)	synchronous
	Adaptability (1)	accessible
	Look (1)	well-designed

Technique provided insights into the human actions that are engaged in the interaction and/or those performed by the interface (*e.g.*, "mid-air gesture," "zoom interaction," "foot-based").

5.3.2 Qualities of Interaction. The *Quality* modifiers (N=36) were categorized into nine out of the 12 themes presented in Hornbæk *et al.* [77]: *Comparison*, *Value Words*, *Effectiveness*, *Feel*, *Resource Use*, *Affective*, *Temporal*, *Adaptability*, and *Look*.

Among these themes, *Comparison* forms the largest group of modifiers (N=10) primarily serving as comparison to other forms or standards of interaction (*e.g.*, "future," "new," or "novel"). For instance, Gollner *et al.* [58] introduced a mobile communication and translation device for deaf-blind people in the form of a glove, highlighting a "novel system of interaction". Stearns *et al.* [175] discuss the potential of "new" augmented reality visualizations and interactions for assistance, presenting an iterative design process using Microsoft HoloLens (v1) to develop augmented reality magnification ideas. Furthermore, following the trend of developing accessible systems (as opposed to assistive technologies), Patil *et al.* [149] introduced a "new touch-free" mode of interaction wherein BLV individuals can perform gestures on their white canes to trigger tasks on their smartphones.

Similarly, the remaining *Quality* modifier themes (*Value Words*, *Effectiveness*, *Feel*, *Resource Use*, *Affective*, *Temporal*, *Adaptability*, and *Look*) then explored topics such as emerging attitudes toward the interaction (*e.g.*, "satisfactory," "efficient," "robust," "challenging") or the user's experience of the interaction (*e.g.*, "user-friendly," "natural," "accessible," "well-designed").

Furthermore, while accessibility is a prominent concept in our dataset, we found only one mention of this term (*i.e.*, "accessible on-body interaction") within an interaction context, categorized under the *Adaptability* theme. Specifically, Oh and Findlater [136] explored preferences and design considerations for "accessible on-body interaction," within contexts where BLV users do not necessarily require a visual display (*e.g.*, Imaginary Interfaces).

6 DISCUSSION AND OPPORTUNITIES FOR FUTURE WORK

In this section, we first summarize our main findings, followed by potential future trends in BLV research and opportunities for future work.

6.1 Current Foci in BLV Research

Our findings—when combined to those of our ASSETS paper (cf. Section 4)—illustrate the diversity of research areas, technologies and themes within BLV research. In particular, the findings in this paper provide further depth to the research areas identified previously as well as a broader view of how interactions are characterized in BLV research. The following subsections recall our extension and discuss our findings.

6.1.1 Research Themes. In our prior work [185], we used a three-step approach: (1) bibliometrics to cluster and map the research field; (2) developing research areas based on these clusters; and (3) assigning each work to one primary research area while maintaining as best as possible the initial distance calculated programmatically. In this work, we leveraged this prior knowledge to explore research themes and their meaningful relationships. Through an open coding cycle, we uncovered a multidimensional problem (cf. Section 3.2) that was initially hidden by bibliometric analysis. However, by integrating a mixed-methods approach, we obtained cohesive research themes that complement prior research efforts in HCI and Accessibility research, which often covered a specific dimension of the field (*e.g.*, [21, 35, 114]).

Specifically, our results highlight a wide range of sociotechnical solutions designed to assist users in their daily lives, as well as user understanding studies to guide future designs of computer systems. Moreover, whilst the themes uncovered contribute to our understanding of their respective research areas, we notice overlaps not only within each research area but also between them. For instance, within the *Accessibility at Home & on the Go* research area and its *Daily life* and *Images* themes, we observe an overlap between Remote Sighted Assistance, where help is provided by human workers (crowdsourcing), and Visual Question Answering, commonly discussed in machine learning papers, where assistance is provided by a model. Additionally, between the *Accessibility at Home & on the Go* and *Non-Visual Interaction* research areas, there is an overlap in the context of visiting museums [9] and interacting with art objects, which is mentioned in the *Non-Visual Interaction* area, while providing access to museums as an activity or place is mentioned in the *Accessibility at Home & on the Go* research area.

Moreover, we identified overlaps between the *Accessibility at Home & on the Go* and *Orientation & Mobility* research areas, particularly in the realm of transportation accessibility for BLV users. Notably, while both Hara et al. [70] and Azenkot et al. [13] leverage online crowdsourcing to gather bus stop information, Hara et al. [70], from the *Accessibility at Home & on the Go* research area, focus on the method for acquiring this data, while Azenkot et al. [13], in the *Orientation & Mobility* area, emphasize the importance of independence and safety of the user during travel in their artifact's design and evaluation.

Such examples highlight both the complementarity and overlaps between research areas and illustrate shared issues addressed and solutions. Furthermore, while these overlaps enrich our understanding of complex societal challenges, they also suggest opportunities for interdisciplinary collaborations—such as with researchers in ophthalmology, vision care, or related fields—to jointly address issues faced by BLV people and/or co-design solutions.

6.1.2 Style and Quality of Interactions. In our previous paper, we provided an in-depth analysis of the input/output modalities considered in our subset of 100 most-cited papers. We highlighted the prevalence of non-visual output modalities—in particular non-visual audio—and visual substitution systems. Our current work extends our prior findings by providing a higher-level analysis of how the notion of interaction is used in BLV research. Whilst only 20% of the abstracts in our dataset (N=880) included the term "interaction," our analysis highlights the variety of its use in BLV research. Notably, our results reveal that papers tend to focus more on the *Style* (N=148) of the interaction rather than its *Quality* (N=36). In particular, most occurrences of the term "interaction" were co-located with either the *Artifact* or the specific input/output *Modalities* considered between the user and the computer system (*e.g.*, "haptic," "tactile," "touch-based," "eyes-free").

The modalities highlighted in our study align with those of Hornbæk *et al.* [77] who showed that "touch," "gesture," "hands-free," and "eyes-free" are the most common modalities within HCI research over the last decade, a trend partially explained by the increasing focus on accessibility within the HCI research community [114, 196]. Additionally, the emphasis on non-visual modalities may be driven by the heavy focus on both "blind" and "low-vision," or "blind" people, as well as the potential overlook of residual vision of target end-users and their desire to use it [185].

In addition to these modalities, other *Style* modifiers also provided insights into the technologies and actions involved in the interactions, while the *Quality* modifiers played a crucial role in highlighting specific attributes (*e.g.*, "novel," "robust," "effective," "natural") of the described interaction paradigm and/or its associated artifacts. This distinction suggests the potential for a deeper investigation into *what* the interaction with a technology achieves *vs. how* the technology (*i.e.*, artifacts, devices, and widgets) supports the interaction. Moreover, an analysis of these patterns over time, similar to the approach by Hornbæk *et al.* [77], could shed light on the evolution stages of our field, revealing research directions that were eventually abandoned and those that have sustained interest.

Finally, the low amount of unique modifiers within several themes of both *Style* and *Quality* categories indicates an overall limited diversity of vocabulary related to the term "interaction" and its variants. While this could be partly attributed to the limited frequency of such terms, another contributing factor could be the significant focus on the "access*" and "assist*" terms within those abstracts (cf. Appendix B, Figure 7). By applying a similar methodology to the one used in this paper, future work could delve deeper into understanding *what* specific objects or environments have been made accessible, as well as the means (computer and/or human) through which assistance is provided. This approach will provide further insights into the distinction between accessible *vs.* assistive technologies [166, 203], contributing to a more comprehensive understanding of the field. Furthermore, analyzing the accessibility of mainstream computing systems would require to enlarge the scope of our review [118, 144].

6.2 Potential Research Trajectories for BLV Research

In Table 6, we summarize potential research trajectories based on the facets explored in our work. In the following subsections, we specify the types of contributions these trajectories could yield.

Table 6. Potential Research Trajectories Organized per Facet

Facet	**Potential Research Trajectories**
Research Disciplines, Areas, or Themes	How have different research disciplines or fields contributed to the development of computing systems for BLV people? and how should they collaborate? Why have researchers focused on specific research areas or themes? How can deductive investigations of activities of daily living complement or align with existing inductive research findings?
Communities of Focus	Is the focus on particular topics disproportionate to or disconnected from the needs of BLV individuals? How do different BLV sub-populations vary in the themes they would like to see prioritized in research?
Technology	To what extent can recent advancements in artificial intelligence and computer vision address challenges faced by BLV individuals? To what extent do mainstream technologies integrate accessibility features for BLV people? To what extent will the boundary between accessible and assistive technologies become increasingly blurred?
Research Approaches	What design approaches are being used to develop/adapt interactive computer systems for BLV people? and how are such approaches being used/operationalized inside or outside of academia? Could deductive investigations help provide systematic comparisons of user interfaces for BLV people?
Interaction / Overall	How has BLV research evolved over time (*e.g.*, in terms of human-computer interaction dynamics)? How have geographical factors influenced the development of computing systems for BLV people?

6.2.1 Novel Interactive Technologies. While, over a decade ago, Manduchi and Coughlan [119] mentioned that, very few computer vision systems and algorithms had been used to aid BLV people, our study highlights the widespread adoption of such technologies in BLV research today. Moreover, the use of AI and computer vision—two intimately intertwined technologies—has continued to grow. Recent technological advancements, within computer vision and AI, have been integrated into various other applications, including personal object recognition and Visual Question Answering. For instance, Lee *et al.* [102] recently used the Microsoft HoloLens 2 with OpenAI's GPT-3 to create a context-aware voice assistant for wearable augmented reality that leverages eye gaze, pointing gestures, and conversation history to enhance natural interaction. Moreover, recent multimodal large lanuage models (LLMs) such as OpenAI's GPT-4 [139] or Google Deepmind's Gemini [182] offer novel opportunities for research and the development of commercial solutions such as *Be My AI*™ [18], which uses OpenAI's GPT-4 [139] as a visual assistance tool. We believe that these technological advancements will lead to prominent artifacts and socio-technical evaluations in BLV research as well as foundational understanding studies (*e.g.*, how/if BLV people use such systems and for what), paving the way for further innovations in accessibility and HCI. This would also open vibrant discussions about the acceptance [76] of such technologies.

6.2.2 Methodologies to Develop, Adapt, and Understand Computing Systems. Concerning methodological aspects, we observed that while some studies exemplify best-in-class approaches to conducting comprehensive development processes—engaging users at multiple stages and iterating on computer systems and features—we found limited reference to specific accessibility design approaches (*e.g.*, Ability-Based Design [202], Design for Social Accessibility [166]). This can be explained by the relatively recent formalization of such frameworks and their even more recent operationalization [135]. Future research could examine how these methods *have been applied* and *can be effectively utilized* in empirical studies, or how they might serve as analytical lenses to better characterize accessibility research practices.

6.3 Future BLV-focused Survey Research Contributions

Our analysis of *systematic* and *transparent* survey research contributions provides a comparative overview of prior literature synthesis efforts with a comprehensive typology [147]. In the following subsections, we discuss the main characteristics of previous surveys and outline several areas for future contributions.

6.3.1 Critical, Aggregative or Integrative Reviews. Our work—like the majority of prior SLRs—focuses on providing the structure of a research field, including its areas and themes. Descriptive reviews have detailed a snapshot of the literature (*e.g.*, [21, 36, 48, 121, 130, 150, 186]), while scoping reviews have made a substantial manual effort to define the boundaries of a research object (*e.g.*, [35, 114]). We believe that the exploration of research areas, themes, and topics has been conducted with sufficient breadth and depth to provide a solid foundation for researchers entering the field. This foundation can guide newcomers, while we encourage senior researchers to leverage the large, curated datasets provided by prior SLRs (*e.g.*, [114]) to "*set their sights beyond existing mines*" (Breslin and Gatrell [31, p. 153]) and develop more critical analyses. Shifting from a *mining* to a *prospecting* approach could foster the creation of new narratives and conceptualizations [31].

During the screening stage of our review, we identified over 3,000 papers that align closely with our research focus and excluded 70 survey research contributions. Given the rapid growth in accessibility research [114] and assistive technology for BLV individuals [21], synthesizing the field presents significant challenges. An effective approach to managing this complexity is to conduct an *umbrella review*, also known as an overview of reviews [147], such as the one recently performed by Stefanidi *et al.* [176]. Such an overview could expand our work by including *narrative* reviews of quality (*e.g.*, [46, 61, 163]) that have been excluded due to a lack of transparency in the early steps of the research process, such as in reporting the results of the search query. In the realm of BLV research, an *umbrella review* could consolidate previous *survey research contributions* offering a comprehensive synthesis of the existing literature not only from HCI-focused or Computer Science-focused accessibility venues, but also from disciplines like Information Systems [118], Ophthalmology [47], Psychology [163], or Vision [94] as well as fields of Computer Science such as Software Engineering [144]. Moreover, other syntheses aiming to *aggregate* or *integrate* prior empirical findings [147] would help to determine the impacts of computer systems for BVL people in different contexts (*e.g.*, [94]).

6.3.2 Comparative, Evolutionary, and Geographical Analyses at Scale. While our work provides an integrative view of the field (*i.e.*, ACM and IEEE), our investigation of research methods employed within most-cited studies reveals two distinct complementary branches investing significant efforts in developing interactive computing systems for BLV people. In particular, ACM SIGACCESS and SIGCHI contributions primarily emphasize user understanding combined with sociotechnical solutions, while IEEE contributions in our dataset focus on technical aspects such as models, datasets, and algorithms. Despite these differences, both branches share the common goal of improving the lives of BLV individuals through complementary work. For instance, Saitis *et al.* [157] provide a technical contribution that can further the understanding of users, while ACM solutions like Bigham's *VizWiz* platform [22] enable data collection from BLV users, which can then be used to train future models and algorithms. To gain further insights into this field, a comparative analysis of research methods, technological trends, and evaluation approaches (*e.g.*, ML testing [213], software testing [20]) across BLV research communities (*e.g.*, ACM vs IEEE) could highlight complementary research and areas for collaboration.

Temporal aspects, meanwhile, have focused mainly on examining the evolution of the quantity of research over time (*e.g.*, [21, 35, 96]). To the best of our knowledge, no works have attempted to describe the evolution of BLV research at a large scale. Exploring this temporal dimension could offer valuable insights into the shifting research foci of the community over time (*e.g.*, target end-users, computer systems, interactions).

The geographical dimension has been addressed only superficially (*e.g.*, [160]). According to the WHO, eye conditions and vision impairment vary significantly across countries, with "*the burden tending to be greater in low- and middle-income countries and underserved populations [...]*" [206, p. 11]. Geographical differences may have shaped research interests and influenced the development of accessible and assistive technologies for BLV individuals. One way of approaching this type of analysis might be to focus on regional (*e.g.*, [159]) or carefully selected conferences and/or journals by analyzing the issues researchers addressed.

6.3.3 Towards Deductive Investigations.

Among the SLRs that detailed their data analysis process, we note a frequent use of inductive methods, both qualitative (*e.g.*, [35, 108, 114, 130]) and quantitative (*e.g.*, [21, 114]). In line with this, when it comes to research areas, our work identified four of them through inductive analysis—*Accessibility at Home & on the Go*, *Non-Visual Interaction*, *Education*, and *Orientation & Mobility*—as well as the wide variety of activities coded within their respective research themes (*e.g.*, daily life, sports, leisure, culture). In a deductive approach, future works could map the literature to *Activities and Participation component* of the *International Classification of Functioning, Disability and Health* (ICF) [205, Annex 3] to provide additional insights into the foci of BLV research with respect to the end-user's needs and highlight areas which are not yet covered in HCI. Another, more focused approach on BLV would be to use the domains of life covered by validated statistical scales aiming to assess the impact of "vision impairment" (*e.g.*, [72, 198]). To support the comparability of computing systems for BLV people, the model *Devices*, *Interaction Techniques*, *Representations*, and *Assemblies* (DIRA) can be used to "*analyze existing and new types of user interfaces in terms that capture their central characteristics*" (Bergström and Hornbæk [19, p. 2]).

6.3.4 A focus on Low-Vision People.

Our comparative analysis of prior SLR (cf. Section 2.2) reveals that only two out of 12 reviews have specifically focused on a distinct sub-population of BLV individuals—blind people [48, 186]. Despite our efforts to categorize the field based on visual ability criteria, either holistically or within specific research areas, we encountered challenges in achieving clear delineations. In particular, as each sub-population within BLV is characterized by unique preferences, needs, and challenges [178], the field would greatly benefit from a comprehensive review that synthesizes the diversity of studies aimed at low-vision individuals. In designing such a review, particular emphasis should be placed on defining "low-vision," either strictly adhering to the WHO classification based on visual acuity [206], another recognized standard, or adopting a broader scope with rigorous full-text screening to identify the target population.

7 CONCLUSION

In this article, we expanded on the analysis presented in our ASSETS paper entitled *"A Large-Scale Mixed-Methods Analysis of Blind and Low-vision Research in ACM and IEEE"* [185] by delving further into our analysis of the previously identified research areas to investigate research themes, how the notion of *interaction* is used in BLV research, and a comparative analysis of prior *systematic* and *transparent* survey research contributions. Our results further highlight the diversity, overlap and complementary nature of research themes to address challenges faced by the BLV community as well as opportunities for interdisciplinary collaboration. Furthermore, our analysis of the notion of *interaction* reveals a primary focus on delineating the modalities (input and/or output), technologies, and actions that characterize the interactions, with a notable focus on non-visual modalities, rather than the aspects qualifying these interactions. Whilst our findings extend our prior analysis, they also offer ideas for future work such as an analysis of the distinct, but interwoven, notions of accessible and assistive technologies. We encourage future research to address remaining challenges and hope our review will serve as a basis for future works in accessibility, HCI, and beyond.

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A PRIOR SYSTEMATIC LITERATURE REVIEWS DETAILS

A.1 Identification

Similar to the approach of our own systematic review, we focused exclusively on survey research contributions (SRC) published between 2010 and 2022 in ACM and IEEE conferences or journals. We employed the following queries in ACM DL and IEEE Xplore, respectively:

ACM DL (*N*=49, last update 05/01/2024): `"query": Title:("review" OR "survey" OR "state of the art" OR "meta analysis") AND Abstract:(((eye OR vis*) AND (impair* OR disab* OR disorder*)) OR "partially sighted" OR "partial vision" OR "low vision" OR blind*) "filter": E-Publication Date: (01/01/2010 TO 12/31/2022), ACM Content: DL`

IEEE Xplore (*N*=170, last update 05/01/2024): `("Document Title":"review" OR "Document Title":"survey" OR "Document Title":"state of the art" OR "Document Title":"meta analysis") AND ("Abstract":"visually impaired" OR "Abstract":"vis* impair*" OR "Abstract":"vis* disabilit*" OR "Abstract":"eye disorder*" OR "Abstract":"vis* disorder*" OR "Abstract": "partially sighted" OR "Abstract":"partial vision" OR "Abstract":blind OR "Abstract":"low vision")`

A.2 Screening and Eligibility

Inclusion Criteria. Papers published in English between January 2010 and December 2022 that met the following criteria were included for analysis.

(1) Survey research contributions published as a peer-reviewed conference paper, journal article, or magazine article. Conference papers must be indexed in the main conference and not in the adjunct, companion, extended abstracts, workshop, or poster session.
(2) Survey research contributions citing at least one reference help guide the execution of a review paper (*e.g.*, can be a method or a tool)
(3) Survey research contributions citing at least one prior survey research contribution in a relevant topic.

Exclusion Criteria. The following types of paper were excluded.

(1) Paper outside of the scope of our work (*i.e.*, not focusing on BLV people and Interactive Computing Systems). It is typically the case of false positive without any references about BLV research in computing systems.
(2) Not a survey research contribution [203].
(3) Survey research contributions published as a conference short paper (*i.e.*, < 6 pages for IEEE conference papers[11]).
(4) Survey research contributions published in national or regional ACM or IEEE conferences.
(5) Survey research contributions that do not follow a *systematic* and *transparent* [146] review process (*i.e.*, that leads the reader to make assumptions about *what was done* and *how* it was realized, Paré *et al.* [147, p. 193]). We particularly consider the *rigor* of the review process by analyzing two out of three criteria[12]: (1) the search terminology, data sources and the period covered; (2) the decision rule that is associated with a selective, representative or comprehensive inclusion of articles [147, p. 192]). Studies that do not report the result of initial search query and the final sample of document were excluded. This is typically the case for narrative reviews [147] but we also excluded systematic literature reviews.
(6) Survey research contributions included/cited in another more complete or more recent survey research contribution

[11] https://conferences.ieeeauthorcenter.ieee.org/become-an-ieee-conference-author/types-of-ieee-conference-papers/

[12] We do not consider (3) a clear statement on whether the quality of the included articles was appraised (and if so, the criteria used for appraisal) due resulting too low [147, p. 192]

Table 7 provides an overview of the identification, screening, eligibility, and inclusion steps of past survey research contributions. Those reported in the *# eligibility* column are provided as supplementary material.

Table 7. Overview of the survey research contribution selection process. With the exception of the *# identified* column, the counts reported correspond to the sample obtained at the end of the step.

Set	# identified	# screening (candidates)	# eligibility	# included	Comment
Initial	3,378	41	26	6	-
Extended	219	184	24	5	35 documents were already included in the *Initial* set.
Snow-balling (backward)	1,254	40	20	1	Identified papers corresponds to the total number of citation of the 11 documents included in step 1 and 2.

B ACCESS* AND ASSIST* TAK TERMS

The UpSet plot [105] presented in Figure 7 was obtained by searching for regular expressions (strict term) based on the following keywords *assist**, *access**, *help**, *aid**, *support** in the titles, abstracts and keywords of our set of 880 publications.

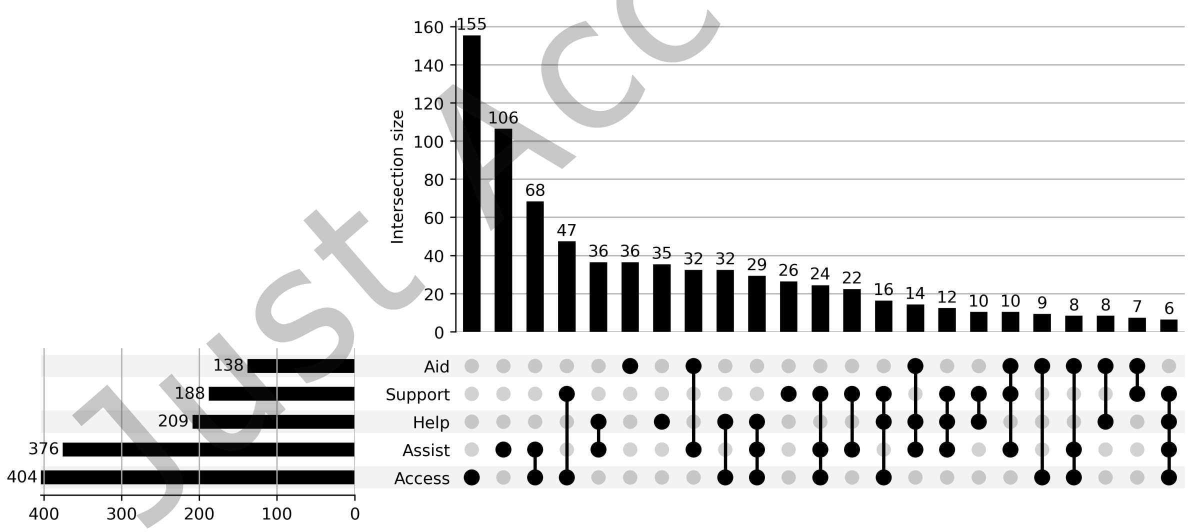

Fig. 7. An UpSet plot [105] highlighting (co-)occurences of the terms *assist**, *access**, *help**, *aid**, *support** in the titles, abstracts and keywords of our set of 880 publications.

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