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Web Accessibility Barriers and their Cross-disability Impact in eSystems: A Scoping Review

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Highlights

- A review of Web accessibility barriers in eSystems and their impact across disabilities.
- We identify mental and functional gaps in design attitudes towards accessibility.
- We report human, technical and Web content component barriers in the Web accessibility lifecycle.
- We propose the first framework to assess access barriers' impact across disabilities.

Web Accessibility Barriers and their Cross-disability Impact in eSystems: A Scoping Review

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ABSTRACT

Accessibility is an important component in the implementation of Web systems to ensure that these are usable, engaging, and enjoyable by all regardless of the level of ability, condition, or circumstances. Despite manifold efforts, the Web is still largely inaccessible for a plurality of reasons (*e.g.* poor navigation, lack of/unsuitable alternative text, complex Web forms) with significant impact on disabled users. The impact of Web accessibility barriers varies per disability, but current measures for the impact of barriers treat disabilities as a homogeneous group. In this work, we present a scoping review of the Web accessibility research landscape. Following a structured approach, 112 studies were reviewed, and findings are reported on common Web accessibility barriers and practices within the Web Accessibility Lifecycle. An assessment framework is further proposed to measure the impact of such barriers across disabled groups. Finally, the need for extensive qualitative research into organizational change and multinational studies on Web activity and disturbance by barriers per disabled user group are discussed as future avenues for accessibility research.

Keywords: Accessibility, standards, disability, Web, review, impact assessment

1. INTRODUCTION

Designing for accessibility is a widely recognized practice which is underpinned by legal directives such as the European Disability Act 2019, [1], the 1998 Rehabilitation Act in the USA [2], and the Equality Act of 2010 in the UK [3]. Accessible products are in fact 35% more usable by everyone and are typically cheaper to run and maintain [4]. However, a recent survey has found that 98.1% of the top 1 million home pages and 97.8% of more than 100,000 interior pages within a wide sample of Websites had detectable accessibility failures [5]. Despite recent acknowledgements in research on Web accessibility about the importance of inclusive Web design and development [6],[7],[8],[9],[10],[11],[12], there is still a plurality of reasons such as dissonance in accessibility understandings [13],[14] (see also sections 2.1 and 2.3.1), overreliance on solutions devoid of user nuances [15],[16],[17],[18],[19],[20],[21], insufficient resource allocation towards accessibility [22], reluctance to engage with training on Web accessibility [19],[23],[24], and a general mismatch between the perspectives of content creators and content consumers about what makes Web content accessible [25],[26],[27], that have contributed to the emergence and persistence of *Web accessibility barriers* which hamper efforts aimed at improving the current state of Web accessibility. Moreover, there is currently a gap in scholarly knowledge on the **impact** of Web accessibility barriers and any specific ways each barrier can inhibit users' preferred modes of functioning on the Web across *eSystems,* which is a term used in this work to describe "the full range of interactive electronic products, services and environments including operating systems, personal computers, applications, Websites, handheld devices" [19],[28],[29],[30],[31],[32],[33],[34],[35]. Accordingly, this survey work focuses on those types of eSystems that are directly impacted from the emergence and persistence of barriers in accessing and using Web content.

Past research [31],[32],[33],[36],[37],[38] has produced a much-needed review of measures reflecting the impact of Web accessibility barriers by taking into account disability-specific considerations [18],[19],[20],[22],[39],[40]. However, it has been intimated that existent measures are most often limited to one group of disabled people [41],[42],[43],[44], or are reporting the general prevalence of each barrier on the Web [5],[45]. This lack of a holistic view of impact on a wider range of disabled groups is also evident in state-of-the-art tools for authoring and evaluating Web content [46],[47], which are largely limited to only reporting compliance with internationally recognized Web accessibility guidelines and standards [17],[43],[48],[49],[50],[51],[52],[53]. This is despite the fact that there is now sufficient evidence to proffer that one of the most pivotal reasons for such tools' underperformance, especially considering the diversity of disabilities, is their overreliance on conformance with Web accessibility guidelines and standards [38],[43],[54],[55],[56],[57], which although constitute an invaluable first step towards delivering more accessible Web content [14],[27],[31],[54],[58],[59], are by no means the full picture of Web accessibility. In effect, authoring and evaluation tools more closely resemble how progress in Web accessibility is approximated [15],[16],[57], rather than leveraging user-documented data, which remain largely untapped [18],[43],[60], and which can be fed into Web accessibility guidelines and standards to foster resource allocation prioritization in a more inclusive manner.

In order to understand the holistic impact of Web accessibility barriers on the wider range of disabilities, it is vital to first know the current state of Web accessibility efforts, any reported barriers, and the inherent components of the Web Accessibility Life Cycle, which refers to the process of designing and developing Web products [38]. It must be noted at this stage that there is a large and diverse body of literature pertaining to Web accessibility that is spanning decades of work. It therefore makes it difficult to carry out a systematic review for the above purpose due to the sheer number of papers involved. Accordingly, in this work a scoping review of the Web accessibility research landscape is performed instead. It is acknowledged that this approach may not provide the same level of detail as a systematic review, however, it will allow to provide a roadmap and overview of current work within a multidisciplinary topic. To the best of the authors' knowledge, there is no recent scoping review of Web accessibility work across eSystems including the diversity of disabilities. There have been past similar efforts (*e.g.* [61],[62],[63],[64]), but they were largely restricted to specific sectors and disabilities, such as healthcare and audiovisual disabilities, and their criteria for Websites being accessible were limited to compliance with official guidelines and standards (see section 2.4), which, as detailed throughout this study, is by no means a full picture of Web accessibility. Despite such guidelines and accessibility tools having been around for more than 20 years [60],[65], advancements in accessibility have been largely outpaced by advancements in eSystems and relevant technologies [66],[67]. The goal of this work is to summarize and present a much-needed review and overview of commonly reported Web accessibility barriers in relevant eSystems and their impact across disabled groups, as well as a review of relevant state-of-the-art tools and practices across all components involved in the design and development process of accessible Web products. Accordingly, the contributions of this work are:

A. A *much-needed review* and overview of commonly reported Web accessibility barriers in eSystems and their impact across disabled groups, as well as a review of relevant state-of-the-art tools and practices across the Web Accessibility Life Cycle.
B. Expanding on previous work on the Web Accessibility Life Cycle by *integrating a Web content* component which is associated with barriers that directly impact accessibility, usability and user experience.
C. The identification of a *mental* and a *functional* gap in current Web accessibility design efforts and attitudes towards accessibility, as well as between users' requirements and expectations and their hands-on interactive experiences with Web content, respectively.
D. An *Impact Assessment Framework*, which is the first, to the best of the authors' knowledge, attempt to measure the impact of Web accessibility barriers by taking into account disability-specific considerations.

This paper is structured as follows. Section 2 discusses the background, definitions and relevant concepts resulting in the identification of a mentality gap in design efforts and attitudes towards Web accessibility. Section 3 then presents the literature search methodology that was utilized to produce the scoping review, whilst Section 4 discusses Web accessibility and the relevant human and technical components involved in the life cycle for the delivery of accessible Web content. Section 5 presents a Web accessibility impact assessment framework, and finally, Section 6 includes a concluding discussion of the findings and proposed gaps for future work.

2. BACKGROUND, DEFINITIONS AND RELEVANT CONCEPTS

Before exploring the barriers and their impact on Web accessibility, it is imperative that disability is first discussed. Disability is part of the human condition, but many people with disabilities do not have equal access to services that are taken for granted, such as equal access to the Web, and are therefore excluded from everyday life activities. In this section, the key definitions and models of disability, as well as key policies, regulations, and accessibility design approaches are discussed.

2.1. Disability definitions and models

Despite the importance of this issue, there is no agreed definition of disability. In response, the World Health Organization (WHO) put forward the notion that:

> "disability results from the interaction between individuals with a health condition….with personal and environmental factors including negative attitudes, inaccessible transportation and public buildings, and limited social support." [68].

This is also the definition adopted in this work and it identifies three dimensions that characterize disability, which are a person's impairment (i.e., body structure or function, or mental functioning), an activity limitation (i.e., difficulty seeing, hearing or walking) and restrictions to participation in daily activities (i.e., working, socializing, healthcare) [69]. There are also many types of disability, such as those affecting a person's vision, hearing, mobility, and cognitive functioning, which are also the types considered in this work (see also Table 5). Disability can also be invisible as it may not be immediately apparent to others. It can be therefore agreed that disability is complex, dynamic, and multidimensional.

The above definitions also highlight the role of medical and social barriers in a person's disability. There are in fact two prevailing models of disability - the medical and the social model. The former argues that "a person's functional limitations (impairments) are the root cause of any disadvantages experienced and these disadvantages can therefore only be rectified by treatment or cure", whilst the latter discusses that people are disabled by societal barriers rather than their bodies [70]. Therefore, disabilities are different to impairments and are framed as a limitation of a person in the medical model and a barrier in the social environment in the social model. Research views on these two models vary, as the social model is often considered as too utopic in practice [71], whilst others argue that disability is indeed described as a social prejudice [93]. Historically, both of these models have been presented as distinct; nevertheless, recent efforts by the WHO resulted in the International Classification of Functioning, Disability and Health (ICF) that instead presents that functioning and disability are interrelated and are characterized by a dynamic interaction between health, personal and environmental factors [69], which is described as the 'bio-psycho-social' model [72], and has now replaced the medical and social models as the prevailing model of disability.

2.2. Disability policy and legislation

In addition to the shift from the medical and social models to the 'bio-psycho-social' model of disability, legal policies and laws are also in place, giving people with disabilities important rights not to be discriminated against. One of the first laws to take effect was the *Rehabilitation Act of 1973* in the US, which prohibited organizations that had received government funding from discriminating against people with disabilities [37]. *Section 508* was later included within the Rehabilitation Act to cover accessibility aspects in electronics and in Information and Communication Technologies (ICTs), which was revised in January 2018 to comply with the latest accessibility requirements [73]. Another pivotal law for accessibility in the US is the *American Disability Act* (ADA) [37].

Similarly, in the UK the *Disability Discrimination Act* (DDA) was established in 1995 classifying discrimination as the unjustified and unfavorable treatment of certain individuals within the population [74]. The *Special Educational Needs and Disability Act* (SENDA) later extended the DDA to address discrimination in an educational context, which was followed by the *Equality Act 2010* amendment to encompass neglected indirect discrimination cases [3]. More recently, the *EU Web Accessibility Directive*[1] and the *European Accessibility Act* (EAA)[2] were introduced in the European Union in 2016 and 2019, respectively, to focus more closely on ensuring equal access to the Web and the built environment. However, it is argued that both of these EU regulations face a 'knowing-doing gap', that is, "the gap that traditionally occurs when people 'know' what should be done but there [are] a number of challenges and barriers in place that prevent action being taken" [75]. This can also hold true for similar laws and policies in the US and the UK, as well as to the rest of the world, which calls for the much-needed scoping review of barriers and their impact presented in this work.

[1] https://digital-strategy.ec.europa.eu/en/policies/Web-accessibility
[2] https://ec.europa.eu/social/main.jsp?catId=1202

2.3. Accessibility design approaches

The previous section highlighted that equal access for people of all abilities is supported by many legal acts and policies. In a similar vein, the academic community and the industry have put a larger focus on accessibility and, specifically, the design of accessible applications to support people with various disabilities [76]. Since then, a range of approaches, methods and tools have been developed to enable the design of accessible technologies [77]. In this section, accessibility is discussed and the main design approaches are described.

2.3.1. Defining accessibility

Historically, despite efforts to define accessibility tracing back to the 1950s, the plurality of perspectives on its essential components have delayed the development of an unambiguous conceptual framework of accessibility [13],[14],[34],[37],[66]. It is however noted in scholarly work that the terms *property* ("the right to benefit from things") and *access* ("the ability to derive benefits from things") were at the heart of discussions about accessibility [78]. Traditionally, both physical and digital environments have been susceptible to Lawton's *environmental docility hypothesis*, that is, "the less competent the individual, the greater the impact of environmental factors on that individual" [79], which is in fact lacking encompassment of *population diversity* [61],[62] that is evident in disability. However, drawing on the recent disability models discussed in Section 2.1, the less competent the environment in encompassing behavior and diverse ability, then the greater the divide between those whose activities are supported and unsupported by the environment will inevitably be. More recently, it has been argued that modern definitions of accessibility should acknowledge the concept of *population diversity*, which considers a multitude of abilities and contexts [32],[33],[37],[82],[83]. It is, therefore, important to consider alternative perspectives on accessibility, particularly those that aim for the recognition of a diverse pool of activities and their interplay within the environment. Such perspectives should encompass population diversity and should also recognize the interrelatedness between accessibility, and its opposite, disability. It can be hence conjectured that a contemporary unified definition of accessibility may only emerge through acknowledging such components alongside digital advancements, which can entail multiple benefits for deepening the discourse around novel and proper accessibility practices [13],[37],[66]. Despite scholarly perspectives on accessibility being disparate and multidimensional, there is now great acquaintance with the term accessibility [14], and the related design approach of *accessible design* which relies on extending standard design principles to people with some type of functioning limitation [84]. In a similar fashion, *barrier-free design* is a related design approach focusing mainly on lifting barriers for specific individuals in order to perceive an environment as barrier-free [14], which is arguably considered as a highly-subjective notion [37]. It is notable that in both approaches there is, again, an over-reliance on the environment, and they seem to both fail to acknowledge population diversity, which should be key in more contemporary definitions.

2.3.2. Web accessibility

More relevant to this work, Web accessibility is defined as the ability of:

> "all people, particularly disabled and older people, to use Websites in a range of contexts of use, including mainstream and assistive technologies; to achieve this, Websites need to be designed and developed to support usability across these contexts." [13]

This definition is chosen, as it agrees well with inclusive design approaches that aim to reasonably encompass population diversity (see section 2.3.6) and puts emphasis on design for delivering accessibility to the user rather than the opposite. Additionally, the definition considers various reported inconsistencies in accessibility-related terminology. This promotes clarity for setting consumer demands and provides a common framework for discussing issues, past approaches, and solutions. However, Persson *et al.* discuss that such a definition needs to be concise if it is to be at all effective, whilst in contrast, Petrie, Savva, and Power advocate that completeness over conciseness, in this context, is key [13]. Web accessibility has been treated by industry as a low priority consideration that is traditionally limited to compliance with a set of official guidelines and legal mandates [19]. This in fact aligns well with recent survey results from AbilityNet indicating that there is a low allocation of resources towards Web accessibility, owing primarily to the lack of awareness of the importance of Web accessibility [22]. Nevertheless, research has shown that content creators with demonstrable appreciation of the benefits involved in designing for accessibility will not necessarily prioritize design efforts towards accessibility [19],[23],[24].

2.3.3. Usability

Previous work by Carlsson, Iwarsson and Ståhl suggests that accessibility should be anchored to thorough knowledge of population diversity, which should be a foundational component of any contemporary definition of accessibility [85]. However, accessibility seems to lack what Iwarsson and Ståhl note as the *activity component*, i.e., a "description of activities to be performed by the individual or group at target, in the given environment" [14]. In addition, accessibility is strongly tied to disability and is rather frailly based on knowledge about population diversity, deferring to the experiences and perspectives of disabled populations [86], which are essential to increase understanding of population diversity itself

[14],[21],[32],[39],[43],[60]. There is, thus, an evident overreliance on disability, functional ability and population knowledge when discussing accessibility. However, Shneiderman suggested that "access is not sufficient to ensure successful usage" [87], which points to the need to consider designing eSystems that are widely *usable* irrespective of disability or peoples' abilities [88]. In this vein, accessibility is preconditioned by usability, which allows for extending beyond a specific disability. The close connection between accessibility and usability has been studied before [16],[28],[63],[65]. Previous work by Kaur and Kumar suggested that accessibility conformance is in fact a first step towards ensuring usability in the Web [49]. Along the same lines and in a Web context, Dattolo and Luccio discuss that accessibility prerequires usability instead, as the former may flexibly draw on usability measures to more holistically address user experience on the Web [90].

2.3.4. Universal design

The limitations observed in accessibility definitions and the need to ensure usable eSystems, irrespective of disability or peoples' abilities, identified in discussing usability earlier resulted in the universal design approach. The term was coined by Mace who presented it as "a way of designing a building or facility, at little or no extra cost, so that it is both attractive and function[al] for all people, disabled or not" [91]. Similar definitions are evident in the literature with the most prevailing being "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" [37],[92],[93],[94]. Importantly, at the heart of such definitions is the close connection of universal design to population diversity and the less emphasis on disability, as also noticed when discussing usability.

Interestingly, the theoretical foundation of universal design is rarely discussed [92],[93]. However, its number one principle is striving for *universal access* and avoiding discriminatory design [92]. In accessibility studies, universal access is typically understood as the ability to flexibly design and develop, highly customizable and adjustable, per individual needs, products and environments [37],[67]. In Human-Computer Interaction (HCI) studies, however, universal access is not only an approach to design, but also a way of thinking that aims for inclusivity and utility in addition to accessibility and usability [37]. Although rooted in accessible and barrier-free design (see section 2.3.1), universal design has grown from an approach to design that seeks an individualistic end-result to a fixed, yet customizable and adjustable design process [95]. Whilst there is no cure-all as regards individually experienced barriers in an environment, conversely, there is a necessity to constantly and flexibly allow for adjustability of said environment within every step of the design process. This agrees with recent research assimilating universal design to the term design for all [14],[32],[83],[92].

2.3.5. Design for all

Design for all describes a process that takes the individual into account at every step rather than an end-result [96]. Despite it being the most popular term in Europe [14], Stephanidis describes and attributes its interchangeable use with universal design to their common origin in built environment and Web design, as well as to their common principles and purpose in universal access [97]. However, both approaches accept Waller *et al.*'s notion that it is pragmatically impossible to always adequately and irrespectively represent the entire population through design [82]. Instead, they strive to include the widest possible range of the population by acknowledging the lack of a one-size-fit-all approach, and as such to apply design principles that are tailored to meet diverse individual preferences. Nevertheless, the abundance of such interchangeably used approaches has been shown to hinder the overall measurability of accessibility beyond conformance with established standards [37], and additional questions have been raised as to whether designers share a common understanding of universalism [92]. Foremost, the fixed nature of the universal design principles lacks the flexibility to address a wider range of accessibility barriers relating to pragmatic socioeconomic and/or geopolitical factors [28],[67].

2.3.6. Inclusive design

Similarly to design for all and universal design, inclusive design is another popular design approach, which unlike the former two, it has its roots in product design [32]. The term has grown in significance, particularly across the UK [37], albeit it is often mistakenly employed to encompass design for all and universal design as an umbrella term. Despite the scales being tilted in favor of the similarities between the three afore-mentioned approaches rather than their differences, inclusive design is comparatively not a fixed set of principles [98]. Instead, Persson *et al.* describe inclusive design as an attitude to design that seeks to evolve based on reliable and continuous gathering of insights about population diversity, diverse experiences, and interactions within the environment [37]. In other words, inclusive design can be described as an attitude to design that seeks to include as many people as possible where the resulting design can be used by all people [27]. This is in line with similar views about the goal of inclusive design being to design products or services that are accessible and usable widely without the need for special adaptation [99]. Whilst all afore-mentioned design approaches fundamentally share the same goal, inclusive design is the only one that considers the flexibility and ability of the designer to loosen design efforts aimed at universal access, social inclusion and design resonance if those are deemed prohibitively costly and/or hard to implement [100]. However, Heylighen, Van der Linden, and Van Steenwinkel remain skeptical in regards to how applicable inclusive design is in practice [32], whilst Persson *et al.* speculate that such concerns more closely relate to the lack of a clear definition of the concept of accessibility rather than pitfalls within design approaches [37]. Despite such discrepancies, research efforts continue to advocate the necessity to include a diverse selection of people, especially people with previous hands-on experience of having been confronted with accessibility barriers in the design decision-making process of such environments [18],[21],[29],[32],[37],[55],[82],[83],[101]. Consequently, there is a need to shift from adjusting a design to accommodate specialized needs to shaping the environment in a way that it is independent of accessibility and disability.

2.3.7. User-centered design (UCD)

Accordingly, user-centered design approaches which are concerned with the variety of ways a user, regardless of ability or preferred modes of functioning, may possibly interact with the environment have been considered [102]. A UCD approach is different from a human-or-people-centered design approach, as the latter is typically more closely related with stakeholder requirements [32]. In effect, Persson *et al.* argue that *User-Sensitive Inclusive Design* (USID) is a more prominent approach, as it is rooted in both user-centered and inclusive design. In USID, the term 'centered' is substituted with the term 'sensitive' to support population diversity [37], and the term 'inclusive' is added to encompass the afore-mentioned designer flexibility and ability inherent in an inclusive design approach [103]. Whereas an abundance of attitudes to designing for accessibility, usability, inclusivity and utility have been suggested, Stratton *et al.* propose the need to reimagine, and possibly also repurpose, accessibility design approaches to suit more modern digital settings, such as the Web, video games, etc. [66].

2.4. Accessibility standards and guidelines

Whilst a variety of accessibility standards and guidelines have been developed over the years, the *Web Content Accessibility Guidelines* (WCAG), which were devised within the W3C's Web Accessibility Initiative (WAI), are the most acclaimed [65]. Since their development back in 1999 (WCAG 1.0), there have been three more iterations (WCAG 2.0, 2.1 and 2.2) with their latest one (WCAG 2.3) pushed out in October 2023 [104]. WCAG ranks Web content on accessibility per a hierarchically arranged scale of three levels - Level A, AA and AAA - with level A being the minimum and level AAA being the maximum level of conformance with WCAG [27],[105]. The emergence and wide acceptance of WCAG has helped provide a common blueprint for content creators of varying abilities [19],[27],[54],[106]. As can be observed in Table 1, focus on accessibility varies, as each set of standards and guidelines is concerned with a specific part of the interaction with digital media, *e.g.* content, technology, or software.

Table 1: Synthesis of official global accessibility standards and guidelines

Name	Description	Focus	Level(s)	Year
ISO 9241	Ergonomic standards to improve the accessibility and usability of hardware, software and user interfaces	Technology	N/A	1992
WCAG	Developed by W3C, a set of guidelines for making Web content more accessible to people with disabilities	Content	A, A, AAA	1999
ISO/TS 16071	Complementary guidelines to ISO 9241 for improving software accessibility and usability without assistive technology and hardware design recommendations	Software	N/A	2003
ATIA [a]	Guidelines developed to improve the accessibility of technology for people with disabilities	Technology	N/A	2005
WCAG - OG [b]	A set of guidelines developed by AARP [d] to make Web content more accessible for older adults	Content	N/A	2009
ISO/IEC 40500:2012 (former ISO/IEC 20071)	International standard providing guidance on making software and Web-based applications more accessible	Software	A, A, AAA	2012
ARIA [c]	A set of attributes to enhance the accessibility of dynamic content and user interface controls	Technology	N/A	2014

Name	Description	Focus	Level(s)	Year
ISO/IEC 25010: 2023	A software quality standard consisting of characteristics and sub-characteristics for both software product quality, and software quality in use together with practical guidance on the use of the quality models, incl. usability and accessibility	Software	N/A	2023

[a]Assistive Technology Industry Association

[b]Web Content Accessibility Guidelines for Older Adults

[c]Accessible Rich Internet Applications

[d]American Association of Retired Persons

There are four main guiding principles based on which WCAG have been built - Perceivable, Operable, Understandable and Robust (POUR) [108]. Vollenwyder *et al.* claim that the development of the POUR principles for WCAG 2.0 mitigates the risk of standard and guideline conformance growing obsolete with the passage of time [31]. However, past work indicates that the 'Understandable' principle disregards hearing-related and cognitive-related impairments [40],[41]. In fact, there is evidence to suggest that WCAG, and accessibility studies more generally, have focused more closely on blindness-related impairments [19],[35],[41],[107]. Moreover, Ruth-Janneck discusses that there is a lack of interdependency between the POUR principles and in response proposes four Web accessibility aspects to categorize accessibility issues [29]: Technical (Inefficiencies in hardware and/or software), Editorial (Inefficiencies in content and metadata), Design (Inefficiencies in aesthetics and perceptibility), and Organizational (Inefficiencies in accessibility affordances). Utmost, the complexity of Web accessibility standards and guidelines has also been noted by [108],[109],[110], who explored the potential to use games to acquaint Web content creators in a more engaging manner.

There is now sufficient evidence to suggest that conformance to standards and guidelines alone is by no means a complete picture of Web accessibility [31],[33],[54],[56],[111]. As identified in the previous section, relying solely on conformance fails to encompass population diversity and content consumers' expectations, activities and/or needs, which is particularly important for people with disabilities [35]. Evidently and despite the above, most Web accessibility evaluation efforts still typically start and end with compliance with Web accessibility standards and guidelines [48],[49],[50]. Relatedly, there is a dearth of empirical evidence on users' hands-on experiences interacting with accessible content or Web 2.0 applications [31],[89], which indicates the persistence of a functional gap between the multitude of ways users would like to interact with the Web and how many, if any, of those ways are offered and/or denied to them in practice. Aizpurua, Harper and Vigo suggest that there is a conceptual distinction between accessibility, as defined via conformance with Web accessibility standards and guidelines, and accessibility as characterized by actual users' perceptions and experiences [33], which points to the need to bridge the gap between them. Despite this, past work suggests that conformance is an ironclad first step in the Web accessibility life cycle [14],[27],[31],[54],[58],[59]; however, a notable number of Websites have yet to adequately comply with such standards and guidelines [60],[112]. Whilst Web accessibility standards and guidelines are fundamental within the Web design and development life cycle, they are inadequate as a standalone solution to Web accessibility. An in-depth understanding of accessibility through diverse user perspectives is thus imperative to inclusively embed accessibility.

2.5. Summary

The plurality of design approaches towards accessibility discussed in the previous section invite approaching accessibility in relation to other relevant concepts, such as usability, universal design, design for all, inclusive design and UCD. These various streams of perspectives and their interplay have been summarized and classified in Figure 1 below, which maps the relationships between design approaches discussed in the above sections on a matrix demonstrating how closely or distantly-related such approaches are; therefore, highlighting the nuanced and dynamic nature of designing for and delivering accessibility. For clarity, UCD and design for all approaches are not included in Figure 1, as the former is not an accessibility-specific approach and the distinctive qualities of design for all are identical to those of universal design, respectively.

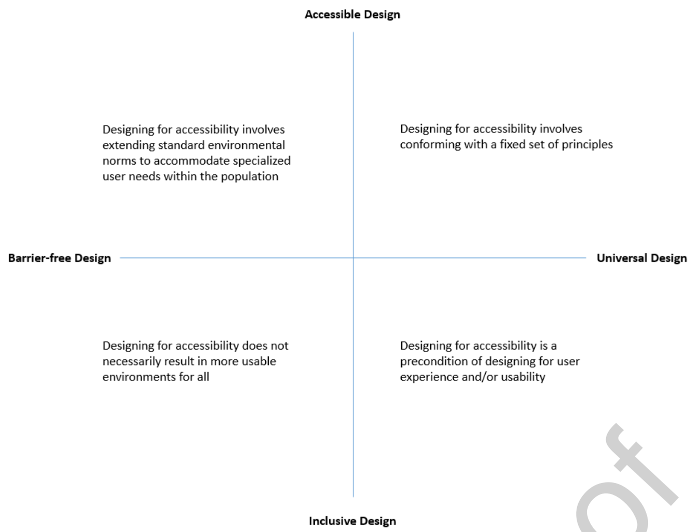

Figure 1: Classification matrix of accessibility design approaches inspired by Avgerou [113]

The above figure is revealing in two main ways. First, it identifies a *mentality gap* in design efforts towards accessibility which is aligning with the two prevailing models of disability, i.e. the medical and the social model described in Section 2.1. Second, it highlights a further gap between accessible design and inclusive design approaches, as the former adopt a mentality towards accessibility that involves accommodating specialized user needs, whilst the latter place accessibility within the responsibility spectrum of the designer. It can be reasonably surmised that this mentality gap in design efforts and attitudes towards accessibility further feeds into a *functional gap* that also exists between the multitude of ways users would like to interact with the Web and the actual number of such ways that are offered and/or denied to them in practice, as informed by the discussion in Section 2.4. Accordingly, the multitude and diversity of approaches, expectations, and practices, not least in relation to the identified mental and functional gaps, points to the need for a much-needed review of Web accessibility barriers across diverse disabilities, and state-of-the-art practices and tools for tackling such barriers.

3. LITERATURE SURVEY METHODOLOGY

A scoping review of the literature was performed to assess the state of the art in accessibility studies and synthesize the available evidence on the various components and barriers involved within the Web accessibility life cycle. A scoping review approach was chosen for this purpose as the landscape of accessibility literature is heterogeneous and complex [13],[37], so a scoping approach will allow for the incorporation of non-research sources of evidence [114], such as annual Web accessibility reports [45] and inclusion statistics [22], which are highly-acclaimed in Web accessibility studies. The methodological guide proposed by Peters *et al.* [114], which extends the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [115] is adopted in this study. Accordingly, three PCC (population, concept, context) research questions have been formulated and are investigated in this work:

- RQ1. What are the main components within the typical Web accessibility life cycle for Web professionals and their respective roles?
- RQ2. What are the main Web accessibility barriers for different user groups of people with disabilities across relevant eSystems and the opportunities for future research for Web accessibility?
- RQ3. What is the impact of Web accessibility barriers in relevant eSystems across different user groups of people with disabilities?

3.1. Search strategy

To select the appropriate search string, we defined the below set of terms according to our research questions concerning the accessibility (components, tools and guidelines/standards), barriers, and future research directions domains. The search strategy consisted of queries formed by combining three classes of terms linked by 'AND' and 'OR' operators, where the OR operators were between the terms and the AND operators were between the classes of terms. These terms were:

1. *Accessibility terms*: 'Web Accessibility', 'Disability', 'Impairment', 'Usability', 'User Experience', 'Accessible Design', 'Design for all', 'Universal Design', 'Inclusive Design', 'Human Components', 'Technical Components', 'Web Content', 'Disability Divide'
2. *Guidelines, standards and tools terms*: 'Norms', 'Standards', 'Guidelines', 'WCAG', 'Accessibility Tools', 'Authoring Tools', 'Evaluation Tools', 'User Agents', 'Assistive Technologies', 'Assistive Software'
3. *Scoping literature review terms*: 'User Study', 'Evaluation', 'Assessment', 'Systematic Review', 'Narrative Review', 'Scoping Review'

The following search strings were then formulated based on the above organization of terms (Table 2), which were applied in six digital databases: *ACM Digital Library, ScienceDirect, SpringerLink, Scopus, Web of Science, and IEEE Xplore*, due to their size, comprehensive coverage, and relevance to the Web accessibility topic area.

Table 2: Search Strings

Search Strings
("Web Accessibility" OR "Accessible Design" OR "Design for all" OR "Universal Design" OR "Inclusive Design") AND ("Evaluation Tools" OR "Authoring Tools" OR "Accessibility Tools")
("Disability" OR "Impairment" OR "Disability Divide") AND ("User Agents" OR "Assistive Technologies" OR "Assistive Software") AND ("User Study" OR "Evaluation" OR "Assessment")
("Human Components" OR "Technical Components" OR "Web Content") AND ("Norms" OR "Standards" OR "Guidelines" OR "WCAG") AND ("Systematic Review" OR "Narrative Review" OR "Scoping Review")
("Usability" OR "User Experience") AND ("Accessibility Tools" OR "Assistive Technologies" OR "Assistive Software") AND ("User Study" OR "Evaluation" OR "Assessment")

Similar search syntax was applied across the selected databases for consistency. We used strings that seek to locate articles, but each database has its specific syntax. In total, 3059 results relevant to the research questions were retrieved.

3.2. Inclusion and exclusion criteria

The application of inclusion and exclusion criteria is essential to filter the results. Accordingly, the extracted literature has been evaluated to include the most relevant studies in this research, whilst the literature that did not meet the inclusion criteria was excluded. The inclusion criteria were: peer-reviewed articles that explicitly discussed the process of delivering Web accessibility to users, its inherent components and their roles in relation to this process, as well as Web accessibility barriers and what is their impact per disabled user group, written in English, and publication period between 2000 and 2023, which is inevitably broad due to the afore-mentioned sparsity of reported inclusive Web design efforts [31] and disability-specific Web accessibility studies [58] throughout the years. The criteria for papers reporting on Web accessibility barriers were more restrictive to more closely capture the current state of the art. Specifically, such papers were included if they were: published in the last five years (between 2018 and 2023), while only the latest (between 2022 and 2023) official statistics were used for the calculation of the measures discussed in Section 5. The exclusion criteria were the following: duplicate articles, not written in English, irrelevant articles to the research focus, and articles that are not freely accessible. We aimed to adopt minimal exclusion criteria to enable a significant and representative corpus. Importantly however, the only study reporting on the impact of Web accessibility barriers across the wider range of disabilities, to the best of the authors' knowledge, is Berger *et al.*'s study in 2010 [35], which we deemed crucial to read closely and translate, as it is written in German.

3.3. Screening and selection process

The initial search returned total of 3059 research results, as well as in 35 non-research results such as the previously mentioned highly-acclaimed annual Web accessibility reports and inclusion statistics. These 35 non-research results were found on specific websites of organizations known for publishing Web accessibility work, such as W3C and WebAIM based on digital accessibility expert colleagues' recommendations. These works were not available in the databases that we have searched in this work, but we considered them to have important input and offer significant insights in this work. After applying the above inclusion and exclusion criteria, a total of 1927 results were considered upon removal of duplicates. These were then screened for relevance to the topic by two researchers independently based on their title and the abstract and against the predetermined criteria resulting in the exclusion of another 1540 sources. The following step included the full-text retrieval of the remaining 387 articles for further independent review by two researchers against the eligibility criteria, resulting in 275 of these being excluded. One hundred and eighteen of these were excluded as they did not provide any insight into the interplay between the components involved in the design of accessible Web products to understand how, when and why barriers emerge. Accordingly, a further 94 and 56 studies were excluded for not providing recent or disability-specific insight on Web accessibility barriers, respectively, and seven studies were unable to be retrieved. Any discrepancies were discussed between the authors either via consensus or via requesting the help of a third team member until consensus was reached. As such, 112 studies were finally included in this review. The results of the screening and selection process are depicted in detail in Figure 2 below.

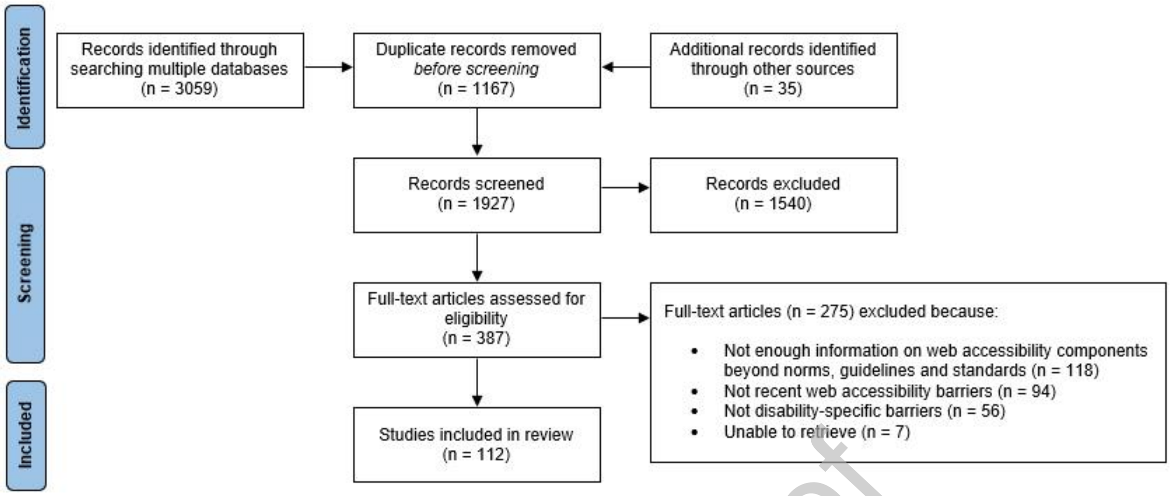

Figure 2: Flow diagram showing the study selection process using the PRISMA template [116], adapted for scoping reviews [115],[117]

3.4. Data extraction and validation

Two researchers independently extracted the data items, pertaining to reference, author names, and results/findings relevant to the RQs, and then recorded them in a charting table as per the adopted PRISMA-ScR [114]. Information was initially extracted into a draft charting table adapted from [118] to this research's focus and RQs, which was then iteratively refined and updated throughout the data extraction process to its final format in Table 3. Prior to the scoping review, the draft charting table was trialed on three different sources to ensure that all relevant data items were effectively extracted. A third researcher was requested to independently verify the data extraction for ten percent of the included studies, as well as to resolve any disagreements.

As the focus of this work was to conduct a scoping review to survey the body of research relevant to the RQs, a critical appraisal of the overall quality of the identified works was deemed as not necessary based on available guidance [118]. However, the quality of the extracted research in this work was assessed for their scope and relevance to the RQs against the defined inclusion and exclusion criteria, as well as by applying PRISMA-ScR [115], which is considered as a tool to enhance quality and clarity in systematic reviews whilst avoiding bias. In fact, the choice of involving multiple team members in the charting process was motivated by the need to mitigate error- and bias-related risks and to ensure adequate record keeping for developing a shared understanding of extracted items in relation to their relevance to the RQs.

Finally, the extracted data were used to answer the RQs and are overviewed alongside their relevance in answering them in Table 3. Deferring to RQ1, findings relating to the components involved within the Web accessibility life cycle are discussed in Sections 4.2, 4.3 and 4.4. Deferring to RQ2, the review of the interplay between the components identified after answering RQ1 allowed for the specification of barriers. In respect of RQ3, the impact of barriers per disability and/or impairment is then surveyed (see Section 5) in accordance with the aim of this review to draw on such disability-specific data to contribute with much-needed measures of the impact of Web accessibility barriers across disabilities (see Table 5).

4. RESULTS

In this section, an overview of the 112 studies that complied with the eligibility criteria are first presented. When reporting the findings, the view of Chisholm and Henry on the importance of involving various components, their distinct roles, and their interplay in improving Web accessibility [38] was adopted. Specifically, three main components emerged during the review of the literature: *Human*, *Technical* and *Web Content* components, which are discussed in more detail in the following sections. Past efforts recognize the necessity to extend existent attitudes to Web accessibility in eSystems to show awareness of the complementary and interdependent roles of the human and technical components within the Web accessibility life cycle [10],[12],[49],[65]. Their interdependencies are also explored in other past similar work [22],[36],[55].

4.1. Overview

The characteristics of the 112 sources of evidence included in the following sections of this review are presented in Table 3, including the relevant reference, author names, and the information relevant to the RQs and the scope of the review, as per PRISMA-ScR [114].

Table 3: Overview of included studies, semantic grouping, and their relevance to the RQs

Author(s)/reference	Results/findings and relevance to RQs
Web Accessibility Life Cycle Components (RQ1)	
Petrie *et al.* [15]	Web content creators rely on technology to address accessibility for them
Brewer [17]	Content consumers affording a passive role in Web content creation causes concern
Zong *et al.* [18]	Visually impaired users primarily use screen magnifiers and secondarily screen readers

Author(s)/reference	Results/findings and relevance to RQs
Miranda and Araujo [19]	Accessibility experts teach content creators and commissioners in Web accessibility
Abuaddous, Jali and Basir [23]	Accessibility experts are hard to find and crucial to recruit, but their 'expertise' varies
Ruth-Janneck [29]	Upgrades WCAG's POUR principles into technical, editorial, design and organizational aspects, to capture the interdependencies between them
Chisholm and Henry [38]	Provides insights into the components involved in the Web accessibility life cycle
Kaur and Kumar [49]	Provides a framework covering the strengths and weaknesses of accessibility tools
Kaur and Kumar [50]	Comparatively analyses accessibility tools, not least in how far they comply with norms, guidelines and standards
Cooper and Rejmer [51]	Early documentation on the performance of Bobby, the first automated evaluation tool
Mayol and Nadal [53]	An evaluation tool that detects barriers and proposes indicative solutions to handle them
Iniesto *et al.* [56]	Documents content creators' accessibility perspectives in an online education context
Nedelkina [57]	Highlights the interoperability between user agents and assistive technologies
Power, Cairns and Barlet [59]	Advocates customizability of accessibility solutions to encompass population diversity
Crespo, Espada and Burgos[60]	Approximates tailoring accessibility solutions per disability via an expert system
Lange and Becerra [80]	Maps accessibility human and technical component aspects to universal design principles
Keates *et al.* [83]	Provides insight into the effect of accessibility design decisions varying per disability
Bi *et al.* [89]	Essentializes the role of accessibility experts in the design of accessible Web products
Power and Petrie [101]	Recommends basic Web accessibility knowledge to use authoring tools more effectively
Vollenwyder *et al.* [119]	Heeds the risks in accessibility knowledge inconsistencies between human components
Vollenwyder *et al.* [120]	Stresses the crucial role of the POUR principles in the robustness of WCAG

Author(s)/reference	Results/findings and relevance to RQs
Abou-Zahra, Brewer and Henry [121]	Highlights the interplay between human, technical and Web content components, not least in relation to the rapidly evolving nature of Web environments
Petrie and Bevan [122]	Outlines approaches for evaluating Web accessibility, usability and user experience
Moreno *et al.* [123]	Contrasts manual and automated Web accessibility evaluation approaches
Amado-Salvatierra *et al.* [124]	Provides a compilation of assistive technologies and their potency in relation to learning
Ismailova and Inal [125]	Compares six evaluation tools on accessibility barrier detection, highlighting disparity in their results which can be reduced by the use of multiple tools for the same evaluation, but the fact that such tools are limited to WCAG conformance necessitates manual testing as well.
Hadadi, Sarsenbayeva and Kay [126]	Highlights deficiencies in 163 accessibility evaluation tools to support Web content creators during the design phase of the life cycle.
Abu Doush *et al.* [127]	Investigates how successful automatic testing via evaluation tools is across levels of WCAG conformance: Level A (58%), AA (50%) and AAA (32%).
Kenigsberg *et al.* [128]	Explores how assistive technologies have helped reduce everyday hazards that people with specific cognitive impairments are exposed to, due to changes in the discourse around disability models since the early 2000s.
Macakoğlu and Peker [129]	Systematic review of 72 papers on Web accessibility evaluation practices over the last two decades reveals that evaluation is largely automated and limited to contexts of education and government.
Freire, Goularte and de Mattos Fortes [130]	Systematic review of 53 papers with the aim to classify Web accessibility practices per ISO / IEC 12207 processes.

Author(s)/reference	Results/findings and relevance to RQs
Kumar, Shree and Biswas [131]	Proposes a Common User Profile to extend WCAG success criteria across diverse disabilities upon comparison of ten WCAG tools.
Web Accessibility Future Research Opportunities (RQ2)	
Iwarsson and Ståhl [14]	Involving diverse-ability users in the design of accessible Web products is essential
Lengua, Rubano and Vitali [27]	There is mismatch between consumer and creator perspectives in solving accessibility, and acquiring knowledge in accessibility is cognitively demanding
Hackett, Parmanto and Zeng [28]	Converging inclusive design with assistive technology improves Web navigation
Vollenwyder *et al.* [31]	Experimental evidence from 66 visually impaired users compared with 65 users without visual impairments intimates actively involving users with diverse abilities in accessible Web product design, as standards, guidelines and norms are no complete picture of accessibility
Heylighen, Van der Linden and Van Steenwinkel [32]	Active involvement of hitherto passive content consumers in the accessible Web product design-decision-making process can foster inclusive design practices
Moreno *et al.* [48]	Proposes EASIER, a tool for substituting complex Web text with simpler synonyms
Cooper [54]	Approximates future, more user-centered, iterations of norms, guidelines and standards
Green [55]	Notes a knowledge gap as regards the impact of user experience in authoring tool design
Waller *et al.* [82]	Notes benefits in educating Web content creators in accessibility beyond disabled users
Spyridonis, Daylamani-Zad and Paraskevopoulos [108]	Approaches acquaintance with Web accessibility via gamification after acknowledging the high cognitive effort required in acquiring such knowledge via other means
Spyridonis and Daylamani-Zad [109]	Draws on Web content creators' low engagement with norms, guidelines and standards to explore the use of games in acquainting them with WCAG

Author(s)/reference	Results/findings and relevance to RQs
Spyridonis and Daylamani-Zad [110]	Explores the use of Web accessibility norms, guidelines and standards during the design phase, presenting GATE, a serious game for raising designer awareness of WCAG
Boldyreff *et al.* [132]	Intimates making Web text dyslexia-friendly improves access for all user groups
Clark [133]	Associates improved cost and usability with adopting an inclusive design approach
Aizpurua *et al.* [134]	EvalAccess 2.0, an evaluation tool inspired by WCAG 2.0 is developed and measured for its effectiveness in relation to Web accessibility barrier detection
Centeno *et al.* [135]	WAEX, an evaluation tool using a custom set of Web accessibility rules
Von Ahn *et al.* [136]	Phetch, a game for increasing Web image accessibility by generating better captions
Yeratziotis and Zaphiris [137]	Develops HE4DWUX, 12 heuristics for evaluating deaf users' Web browsing experience
Nganji, Brayshaw and Tompsett [138]	Uses IDAT, a tool for suitable alt text authorship and evaluation based on heuristics
Campoverde-Molina, Luján-Mora and Valverde [139]	Proposes a model for Websites to retain high levels of WCAG compliance that is adaptable to future WCAG iterations.
Zitkus *et al.* [140]	Inclusive Design Advisor, an evaluation tool that addresses the lack of inclusive decisions towards accessibility in the design phase of the life cycle by simulating actions taken by Web designers to evaluate inclusive design decisions aimed at users with visual and cognitive impairments.
Manca *et al.* [141]	Analysis of user perceptions on the transparency of the results of 11 popular evaluation tools highlights the need for specifying the disabilities that are affected by the detected barriers and WCAG conformance level when success criteria are unmet.
Campoverde-Molina, Lujan-Mora and Garcia [142]	Systematic review of 25 papers on Website accessibility evaluation shows 80% of evaluation is automated, while mixed evaluation is suggested.

Author(s)/reference	Results/findings and relevance to RQs
de Godoi, Guerino and Valentim [143]	Systematic mapping study of 112 papers stresses the need for assistive technologies to be evaluated for accessibility, usability, and user experience.
Holanda, Virginia and Monteiro [144]	Develops AppTalk, an interface for users with deafness to become active contributors within the life cycle by communicating with a 3D avatar.
Web Accessibility Barriers across relevant eSystems (RQ2 and RQ3)	
Gartland *et al.* [21]	Cognitively impaired users' nuance in relation to accessibility barriers is underreported
Open Inclusion [22]	There are barriers in addition to accessibility, such as low awareness of the benefits associated with incorporating Web accessibility practices, and low resource allocation for accessibility
Hanley *et al.* [26]	Alt text suitability varies per context for blind and visually impaired users, and there is a mismatch between their perspectives on such suitability and content creators'
Aizpurua, Harper and Vigo[33]	Eleven blind screen reader users' insights show how individual user Web accessibility expectations extend beyond what is covered by norms, guidelines and standards
Abou-Zahra, Brewer and Cooper [34]	Artificial Intelligence (AI) alone lacks accuracy and reliability to address accessibility
WebAIM [5],[45]	Annual report on the general prevalence of Web accessibility barriers for homepages in 2023 [45], and the latest such report for both home and interior pages in 2020 [5]
Dobransky and Hargittai [58]	Reports on the online activities of disabled user groups, and the involved barriers
McCarthy and Swierenga [112]	Proffers the low availability of assistive technology support for people with dyslexia
Brewer [145]	Explores Web accessibility barriers from the perspectives of each involved component
WebAIM [146]	WebAIM's introduction to alt text
Lee and Ashok [147]	Indicates a mismatch between blind users' and Web content creators' perspectives on what makes Web content accessible, and outlines state-of-the-art screen readers

Author(s)/reference	Results/findings and relevance to RQs
Govindarajan [148]	Compares screen reader software per blind and visually impaired users' requirements
Salisbury, Kamar and Morris [149]	Explain how unsuitable alt text can cause concerns on par with missing alt text
Mack *et al.* [150]	Corroborate previous research on the importance of alt text suitability for people with dyslexia, motor and/or cognitive impairments beyond blind and visually impaired users
Takagi *et al.* [151]	Early research on the disturbance of 124 out of 323 users by alt text unavailability
McEwan and Weerts [152]	Intimates alt text unavailability as the most pivotal Web accessibility barrier
Sayago and Blat [153]	Investigates Web accessibility barriers in relation to cognitive declines due to aging
Sala *et al.* [154]	Uses norms, guidelines and standards, and complexity measuring metrics to approximate disturbance rates for visually impaired users in relation to electronic service complexity
Tang and Carter [155]	Intimates a mismatch between Web content creators and consumers' judgments related to the suitability of alt text for images
Nierling and Maia [156]	Interviews with assistive technology experts and users of such technology with low visual, cognitive, and hearing acuity stress a lack of expertise in the use of such technology and, thus, the need for incentives, such as recognized qualifications, to receive training towards inclusive interfacing.
Sannomia, Ferreira and da Costa Ferreira [157]	Interviews with Web developers and users with low hearing, and visual acuity highlight the need to adapt assistive technologies for a plurality of disabilities, developers had low to no knowledge of how to use and implement such technologies.
Salvador-Ullauri, Acosta-Vargas and Luján-Mora [158]	Systematic review of the convergence of serious games and accessibility reveals that accessibility efforts beyond one disability are largely limited to WCAG conformance, and motor impairments are least addressed by scholarly work.

Author(s)/reference	Results/findings and relevance to RQs
Gutiérrez,Cáceres and Muñoz-Arteaga [159]	Addresses underreported deficiencies in accessibility guidelines, *e.g.* WCAG, and solutions aimed at users with no hearing acuity.
Sala *et al.* [160]	Highlights accessibility barriers specific to users with visual impairments via an evaluation of five government Websites.
Larco *et al.* [161]	Systematic approach to gaining insight on Web accessibility barriers faced by users with motor impairments, resulting in the development of a digital catalog evaluated in the contexts of accessibility, usability and user experience.
Lin [162]	Assesses national and public library Websites via an automated tool complemented by observing and interviewing visually and hearing impaired users on the user experience as regards such Websites' support for assistive technologies.
Disability-Specific Insights on the Impact of Barriers (RQ3)	
Lundgard and Satyanararyan [12]	Tackling alt text unsuitability barriers varies per individual blind user preferences
Berger *et al.* [35]	Reports Web activity and disturbance rates by barriers per disabled user group, and usage percentages per disability for a plethora of assistive technologies
Pascual, Ribera and Granollers [40]	Reports on the browsing preferences and access barriers faced by hearing impaired users
Friedman and Bryen [41]	Advocates the lack of accessibility studies aimed at users with cognitive impairments, showcasing similarities and differences between such users, and visually impaired users
Muehlbradt and Kane [43]	Explores blind users' alt text preferences via collaboration with sighted users
Morris *et al.* [44]	Fourteen blind users' insights stress how evolution of alt text as regards suitability has been, for the most part, impervious to technological advancements aimed at accessibility
Rodriguez Vazquez and Torres del Rey [95]	Shows how technological advancements in Web design can frustrate users with dyslexia

Author(s)/reference	Results/findings and relevance to RQs
Bianchi [163]	Recent statistics on the Web activity of the general population in Colombia
Laverde [164]	Recent statistics on the Web activity of people with disabilities in Colombia
Taylor [165]	Recent statistics on the digital competitiveness rates per country
Office of Disability Employment Policy (ODEP) [166]	Recent statistics on the Web activity of people with disabilities in the US
Petrosyan [167]	Recent statistics on internet penetration in the US
Tunberg [168]	Web activity rates for the Swedish population with disabilities, treating disabilities as a homogeneous group
WebAIM [169],[170],[171],[172],[173]	WebAIM's survey results with low vision and screen-reader users
Moreno *et al.* [174]	Evaluates cognitively impaired users' Web navigation experience focusing on barriers
Griffith, Wentz and Lazar [175]	Quantifies the interaction burden experienced by blind users in relation to time lost due to the prevalence of Web accessibility barriers
Rivero-Contreras, Engelhardt and Saldaña [176]	Examines the impact of visual support and lexical simplification on the Web navigation experience of users with dyslexia
Bernard [177]	Relates barriers for users with cognitive impairments users with WCAG's 'Perceivable' principle and poor Web design decisions
Noble [178]	Documents how disturbed users with motor impairments are, in relation to time lost, due to the prevalence of Web accessibility barriers
Johansson, Gulliksen and Gustavsson [179]	Web activity rates for the Swedish population with disabilities, treating disabilities as a non-homogeneous group
Potluri *et al.* [180]	Explores perspectives of blind and visually impaired users on alt text and screen readers
Ramírez-Saltos [181]	Scoping review of 29 papers on Web accessibility in a healthcare context reveals minimal (level A) WCAG compliance and imbalanced consideration of diverse disabilities, suggesting user testing with the

Author(s)/reference	Results/findings and relevance to RQs
	aim of at least addressing non-text content alternatives, and formatting and language barriers.
Giroux *et al.* [182]	Highlights the impact of accessibility barriers on users with motor impairments via a simulation of how such users use assistive technologies.
Ferdous *et al.* [183]	Usability evaluation of InSupport, a browser extension for addressing interaction barriers due to screen reader and magnifier deficiencies, with 16 blind and 14 visually impaired users, respectively.

4.2. Web accessibility components and barriers

This section presents the findings of the scoping review focusing on the identified components (RQ1) and their associated reported barriers (RQ2).

4.2.1. Human components

First, an overview of the human components involved in Web accessibility is presented, namely the individuals who occupy one or more roles in the design, development or consumption of accessible Web content [38], and their associated barriers. Specifically, four human components are discussed: Web commissioners, accessibility experts, content creators and content consumers.

4.2.1.1. Web commissioners

Throughout this work, the term Web commissioners is used to refer to "the individuals who commission, own and manage Websites and Web 2.0 applications" [15]. Content creators (see section 4.2.3) such as Web designers and/or developers, report their design, implementation, and accessibility efforts to Web commissioners. Similarly, accessibility experts (see section 4.2.2) may also be required to report the results of accessibility evaluations back to Web commissioners in order for the latter to be able to monitor the number and type of evaluations performed on Websites and/or Web 2.0 applications [15]. Although it is not fundamental for Web commissioners to possess expert knowledge of accessibility, Vollenwyder *et al.* discuss that lack of such knowledge may indeed pose significant problems [119]. Specifically, it is often challenging for content creators to explain to Web commissioners any design decisions relevant to accessibility, which has implications to the subsequent implementation of such decisions. It is, therefore, necessary to educate and train Web commissioners in Web accessibility, and accessibility experts are typically hired to provide such training [15].

4.2.1.2. Accessibility experts

Whilst expertise in Web accessibility can vary per individual accessibility expert, past work highlights the pivotal role that such experts play in equipping Web content creators and Web commissioners with the necessary expertise in concerns related to Web accessibility [19],[22],[27]. Accessibility experts are therefore those individuals who are expected to, at the very least, have a thorough understanding of Web accessibility technicalities (see section 4.3) and they are expected to leverage such knowledge to provide training and feedback to Web commissioners and content creators at the various stages of the Web accessibility life cycle described by [10] and [34]. While training is most essential during the earlier stages of the life cycle, expert feedback on the other hand is dynamically provided throughout the Web development cycle to surmount any arising issues amid the design, development or dissemination stages [22]. The dynamic aspect of accessibility expert involvement within the life cycle is essential for quality assurance [89]. However, Abuaddous, Jali and Basir note that Web accessibility experts are seldom easy to find [23], albeit crucial to recruit, as nearly half of the respondents (45%) in a recent survey by AbilityNet reported how detrimental the lack of proper accessibility expert involvement, alongside improper resource allocation, may be to the success of Websites and/or Web 2.0 applications [22].

4.2.1.3. Content creators

Content creators is a term that is typically reserved for Web designers and/or developers, which are the individuals responsible for designing, developing and disseminating content on the Web [15],[38]. Ideally, these content creators receive support in the form of training and/or feedback either by accessibility experts and/or via accessibility evaluation tools (see section 4.3). Despite the availability of expert human and/or evaluation tool support to content creators, insufficient Web accessibility knowledge is still a major reason for the prevalence of accessibility barriers on the Web [22],[23],[27],[49],[57],[60]. In effect, the most common reason for this lack of knowledge of Web accessibility practices is the limited time available to content creators to invest in engaging in accessibility-related training and/or in performing accessibility evaluation [22],[27],[49],[55],[60]. Another common cause for this is that content creators often lack the motivation to commit to gaining insight into Web accessibility [23],[27],[89]. This is in good agreement with Hanson and Richards who argue that any progress in Web accessibility is primarily due to technological advancements, rather than content creators actually turning their attention to accessibility [16]. This is further supported by Petrie *et al.* who documented that 88.5% of content creators overly rely on Content Management Systems (CMS) to address accessibility issues for them [15]. The above views reinforce one of the most persistent misconceptions in accessibility studies; namely, the myth of the 'silver bullet' that "all that is needed is for all people with disabilities to acquire special assistive technology that will replace missing accessibility information on Web sites" [17].

Minimizing cognitive efforts required by content creators to address accessibility early in the design stage is a key consideration. Nevertheless, the acquisition of knowledge on Web accessibility is very demanding when it comes to the cognitive effort required [27],[43],[55],[60],[108],[109],[110]. Although expert human and/or evaluation tool support options exist to aid with this, as discussed earlier, there is no guarantee that companies can necessarily afford such solutions [27]. Similarly, when considering the lack of time and motivation that content creators are often faced with to acquire Web accessibility knowledge, Vollenwyder *et al.* discuss that content creators are primarily motivated by the benefits associated with designing for the whole population [31]; however, such benefits are poorly communicated to them by companies [22]. Past work has identified a number of such benefits from adopting an inclusive attitude to designing products and services, including improved access for all users when Websites are dyslexia-friendly [132], 35% improved usability and more cost-effective implementation and maintenance [133], improved navigation for all users when it accommodates assistive technology use [28], reduced need to readjust Web content to deal with barriers along the way [184], an increased chance to reach a wider market, improved consumer satisfaction and reduced risks for business failure [82], an increased chance to reach, growing, aging and/or disadvantaged consumer markets [48], improved consistency between consumer and creator satisfaction, persistent product innovation and cost maintenance [22], and, finally, improved Web product quality [31].

4.2.1.4. Content consumers

On the other end of Web content dissemination are the content consumers who are all those users who employ user agents (see section 4.3) to interact with the Web (and/or a broader range of media). Past work acknowledges that content consumers are in fact the only true experts in Web accessibility owing to their hands-on experience and to being constantly challenged by Web access barriers. Paradoxically, they are typically unable to be involved in the decision-making process of accessible Web content development [14],[32],[43],[120], as content creators are often the only individuals responsible with designing and/or developing accessible Web content. As such and drawing on earlier discussion on eSystem-imposed barriers, content consumers are often compelled to resort to assistive technology to interact with digital content. It is therefore imperative that the roles within the Web accessibility life cycle are repurposed, which has also been shown to benefit all individuals who are flexible in assuming various such roles within this cycle [38].

4.2.1.5. Summary

This section discussed the four main human components involved in Web accessibility and further highlighted their interdependent nature, which encourages the need for approaches that allow them to extend their role within the Web accessibility life cycle. As it stands, Web commissioners, accessibility experts, content creators and content consumers seldom assume more than one role within the Web accessibility life cycle. The current interplay and roles of human components within the Web accessibility life cycle is visually depicted in Figure 3 below following a Business Process Model and Notation (BPMN) approach, as it allows to depict potential bottlenecks within the Web accessibility life cycle. For reference, the blue objects in the notation below represent **tasks** that may be performed by a human component, while the yellow diamonds are used to depict **decision-making events** involved within the process. The objects in the notation that are connected to tasks or events through arrowless connectors, namely policy, assistive technologies and user agents, are **artifacts** that are associated with these tasks or events, namely Website policy creation, accessibility evaluation, use of assistive technology, compatibility check with assistive software and user agents, and Websites becoming available via user agents.

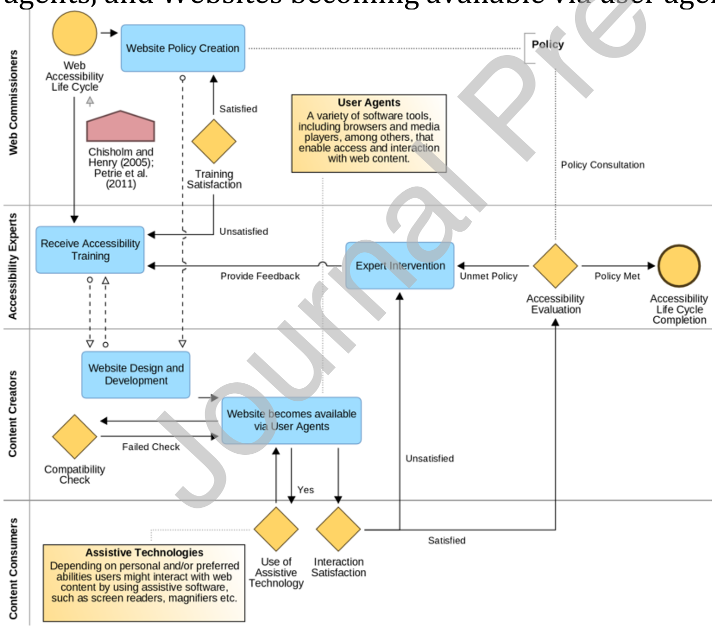

Figure 3: Interplay of human components within the Web Accessibility Life Cycle [15],[38]

As can be observed in the above figure, accessibility issues can be addressed early in the design stage. In doing so, however, Web commissioners require specialized knowledge on Web accessibility to start off the cycle with the creation of relevant policies. Such knowledge can be acquired in the form of training by employing accessibility experts. Similarly, content creators will also need to undergo such training to ensure that Web content conforms to the policies set by the Web commissioners. Figure 3 also pinpoints exactly where bottlenecks may emerge in the cycle, specifically, when insufficient knowledge of accessibility for Web commissioners to create policies and for content creators to develop accessible content can delay the delivery of accessible Web products and can negatively impact overall productivity. Although accessibility experts can be consulted in such cases, Abuaddous, Jali and Basir note that such experts are few and far between [23], and their understanding of accessibility tends to vary [15]. Therefore, this presents another major bottleneck in the form of spending considerable time and effort in finding and recruiting accessibility experts. Accordingly, the following barriers associated with human components and their different roles in the Web accessibility life cycle have emerged from this section and from Figure 3:

- Web commissioners currently lack in knowledge of Web accessibility practices and benefits;
- Web accessibility experts are not easy to find, so there is a reported lack of expert involvement;
- Content creators currently lack in knowledge of accessibility and there is a lack of time and motivation to learn;
- Content creators are faced with an increased/demanding cognitive effort to learn about Web accessibility;
- Companies cannot afford automated solutions to support content creators;
- The benefits of inclusive attitude adoption are not properly communicated to content creators;
- Content consumers are not typically involved in Web accessibility decisions and processes.

The above barriers call for the renegotiation of the roles assumed by the different human components in the Web accessibility life cycle. Specifically, past work highlights a pressing need to turn content consumers into active contributors in the design decision-making process [31],[32],[38]. Petrie *et al.* further discuss that there is a lack of realism in recognizing users with disabilities as true accessibility experts [15]. This lack of recognition results in a lack of appreciation of their preferred activities, habits and needs when interacting with eSystems, which in turn prevents them from providing nuanced accessibility perspectives or from substituting for accessibility experts and/or content creators in their absence [22],[39]. A mismatch of perspectives about what makes digital content accessible between people with disabilities and content creators was also reported [25],[26],[27]. The above strengthen the need to consider renegotiating the role of content consumers to increase productivity and foster overall sustainability of the Web accessibility life cycle.

4.2.2. Technical components

The previous section highlighted a reported gap in the active involvement of content consumers in the Web accessibility life cycle. Similarly, in this section, an overview of the technical components involved in Web accessibility is presented, namely technologies that can occupy one or more roles in the support of the design, development and delivery of accessible Web content [38] and their associated barriers. Accordingly, four technical components are discussed: authoring tools, evaluation tools, user agents, and assistive technologies.

4.2.2.1. Authoring tools

Automated accessibility tools, such as authoring and evaluation tools, are typically employed to support the process of producing accessible products and services [49]. Authoring tools include a range of software, such as HTML editors or Content Management Systems (CMS), that are used to support Web content creators in authoring, managing and/or editing content for accessibility [27],[50],[121]. The potential of authoring tools to enrich the accessibility toolkit of Web content creators has been noted in past work [17],[54],[55],[145], which is in line with Petrie *et al.* finding that about 88.5% of content creators rely on CMS to solve Web accessibility [15]. However, claims about the potential of authoring tools to solve Web accessibility at scale seem to be somewhat exaggerated. Past work, in fact, demonstrated that automated Web content authoring via tools is typically limited to Web accessibility guideline and standard conformance [17],[43],[50]. Despite the automation of the task at hand when it comes to time constraints, Web accessibility guideline and standard conformance alone fails to encompass population diversity, not to mention that state-of-the-art authoring tools have yet to address Web accessibility beyond said conformance [50]. Therefore, relinquishing Web accessibility to content creators alone poses appreciable risks, yet there is sufficient evidence to suggest that content consumers continue to assume an unnegotiable passive role in Web content authorship [17],[38],[43],[54],[55],[56],[57]. Accordingly, the WAI has released the Authoring Tool Accessibility Guidelines (ATAG) [185], specifically about the use and usability of authoring tools, which specify two necessary considerations for Web authoring tools: the need for such tools to be able to solve accessibility as per WCAG and the need for the tools themselves to be accessible to everyone by design.

4.2.2.2. Evaluation tools

Automated evaluation tools help in the recognition of accessibility issues in Web content, so that content creators can then iterate on the design of the content to address such issues [27],[38],[50],[122]. The first and most popular, albeit unavailable since February 2008, tool for automated evaluation was Bobby which was developed in 1995 by the Centre for Applied Special Technology (CAST) [15],[28],[122]. Nevertheless, Web accessibility evaluation via similar tools is also traditionally limited to conformance with Web accessibility standards and guidelines. In effect, early evidence by Cooper and Rejmer showed that automatic evaluation via Bobby failed to address 77% of the WCAG checkpoints [51]. Only a handful of evaluation tools (*e.g.* see [47] and [48]) are capable of proposing indicative solutions to handle automatically detected Web accessibility issues [27],[60]. So, in contrast to manual evaluation by accessibility experts, evaluation tools' utility revolves around such tools' ability to render evaluation more time- and cost-effective [123].

In response, the literature suggests that human involvement is necessary to complement the automatic accessibility issue detection offered by evaluation tools due to the inherently difficult computational nature of evaluating and handling Web accessibility issues, i.e. it is easier for humans, but harder for machines to evaluate and appreciate Web accessibility issues [27],[49],[50],[60],[89]. For instance, alternative text (alt text), which is "a textual substitute for non-text content in Web pages" [146], is only required for non-decorative images. However, unlike a human evaluator, an evaluation tool may find it difficult to distinguish between a decorative and a non-decorative image. Consequently, automatic evaluation via state-of-the-art tools is not yet on a par with manual expert evaluation as regards quality assurance [27],[89]. For completeness, WAI provides a nearly exhaustive list of known evaluation tools to date [186]. EvalAccess 2.0 [134] and WAEX [135] are to the best of the authors' knowledge currently the only two evaluation tools that are not included in WAI's list.

4.2.2.3. User agents

The first point of contact between content consumers and Web content are user agents, which are typically software tools such as Web browsers, media players, mobile applications, plug ins and document readers [38],[121]. User agents facilitate the retrieving, rendering and interacting with Web content (i.e., rendered content) to content consumers and can also communicate with other software such as assistive technologies (see section 4.3.4). Iniesto *et al.* suggest that user agents who conform to Web accessibility standards enable flawless interactive experiences [57]; nevertheless, this assumption can have negative consequences on deepening the functional gap in users' expectations and hands-on interactive experiences. The WAI has developed the User Agent Accessibility Guidelines (UAAG) [187], which are concerned with the specification of essential features that need to be present in user agents so that such tools are accessible via their own interface and interoperable with assistive technologies [54],[57]. These features specify that for Web content to be recognizable by user agents, it needs to be programmatically available, that is, encoded in a way that allows it to be evaluated via officially recognized accessibility evaluation methods. However, it is evident that the target audience of user agents has not yet been extended beyond content creators, as shown in UAAG, which again highlights the earlier point about the need for more content consumer involvement.

4.2.2.4. Assistive technologies

Assistive technologies include hardware or software tools typically used by users with disabilities to overcome access barriers while browsing digital contexts [124]. Assistive technologies are considered user agents that rely on another user agent to provide services beyond those offered by the "host user agent" to meet the requirements of a target audience [188]. Although such technologies can be used to complement some services offered by another host user agent when its support is deemed insufficient, there are now specialized Web browsers that, effectively, blur understandings about the roles of user agents and assistive technologies in addressing Web accessibility issues [41]. In Table 4 below an overview of key assistive technologies and their typical usage rate per disability is provided [35].

Table 4: Synthesis of assistive technologies per eSystem-imposed disability

Assistive Technology	**Description**	**Primary Usage Rate per disability [35]**
Screen Readers	Software that reads out loud the content displayed on computer screens (*e.g.* [58],[147])	Blindness (91%), Low Visual Acuity (21%)
Screen Magnifiers	Software that enlarges text and/or images on screen [18]	Low Visual Acuity (56%)
Voice Recognition Software	Software that allows users to control computer and input text via own voice [121],[145]	Low Motor Capacity (16%)
Alternative Input Devices	Includes alternative, as in non-traditional, keyboards, mice and/or switch devices [189]	Low Motor Capacity (Alternative Mouse: 20%, Alternative Keyboard: 17%)
Braille Displays	Software that displays text in characters that support tactile reading [28],[148]	Blindness (85%)

Assistive Technology	Description	Primary Usage Rate per disability [35]
Closed Captioning	Software that provides subtitles for audio and/or video digital content [49]	Low or No Hearing Acuity (N/A)

As can be observed in Table 4, there is early evidence of a significant difference in blind users' reliance upon assistive technologies (91% for screen readers; 85% for braille displays) compared to the highest reported usage rates for other users with disabilities [35]. More recently, studies have reported similar rates when it comes to the preferences of users with low visual acuity and screen-reader use [169],[170]. It is important to note that these studies took place in different settings and time periods and involved different population samples, however, the noticeably low rates of assistive technology use from other users with disabilities may be attributed to assistive technologies not being adequately in place for content consumers with other types of disabilities [35],[112]. Past work has in fact shown that the only key variable for assistive technology adequacy is the type of disability, rather than, for example, age and gender variables, which instead relate to aging barriers and browsing preferences, respectively [58],[190]. Nevertheless, the above suggest that there is a pronounced need for assistance in browsing Web content for users with blindness and low visual acuity compared to other users with disabilities, who seem to rely less on assistive technology. Specifically, the former rely mostly on screen readers to interact with Web content and users with low visual acuity benefit from screen readers offering features such as screen enlargement, content narration, contrast customizability and alt text descriptions [41]. Host user agent compatibility with screen readers is thus crucial as can be conjectured from the shift in users' preferred browsers [169],[170],[171],[172], which begs the question of whether adequate screen reader support is in place. Along these lines, state-of-the-art screen readers include *JAWS*, *NVDA* and *VoiceOver* [147],[173]. JAWS' latest usage rate by users with low visual acuity is 41.1% which is more than the rate of the other two screen readers combined (32.4%) [169]. The notable increase in the use of JAWS over other screen readers is due to selection criteria, such as cost-effectiveness and availability being reported as more important compared to the need for comfortable use, which had previously been flagged as the most prominent screen reader feature [170]. Additionally, Govindarajan identifies JAWS' potential to increase language proficiency skills as another possible reason for JAWS' popularity [148].

4.2.2.5. Summary

This section discussed the four main technical components involved in Web accessibility and highlighted that the utility of software and hardware tools is restricted to partial conformance with internationally recognized Web accessibility standards and guidelines (see section 4.5). Whilst these are invaluable as a common blueprint to facilitate Web accessibility decision-making, in practice, they are mainly targeted at content creators and appear to disregard the diverse user needs and the high variability in user requirements which are typically present on the Web. The paucity of such proper representation unavoidably feeds into the technical components which in turn fail to support the process of accessible Web design. This is particularly relevant for users with disabilities whose needs and expectations relating to Web accessibility issues tend to vary per eSystem-imposed barrier [17],[19],[31],[33],[34]. For instance, assistive technology software such as screen readers are primarily intended for blind consumers, yet further evidence suggests that users with low visual and/or cognitive acuity, as well as with dyslexia may also use screen readers [35],[41],[112],[170]. However, Friedman and Bryen explain that the expectations of users with low cognitive acuity differ from those of blind users with the former often finding such software too complex to interact with [41]. Accordingly, the following barriers associated with technical components within the Web accessibility life cycle have emerged from this section:

- Content authoring tools are limited to Web accessibility guideline and standard conformance and fail to consider population diversity;
- Evaluation tools are similarly limited to Web accessibility guideline and standard conformance and fail to propose useful indicative solutions to accessibility issues;
- User agents are only targeted at content creators and there is minimal content consumer involvement in the specification of their essential features;
- There is a lack of assistive technology availability for all types of disabilities apart from visual impairments which seem to overly rely on assistive technologies.

It is finally important to emphasize that the complementary nature of human and technical components within the Web accessibility life cycle is hence imperative and should be adopted in practice to ensure sustainable delivery of accessible Web content [17],[31],[54],[121].

4.2.3. Web Content component

The previous section identified Web accessibility barriers within technical components of the Web accessibility life cycle which are concerned with overreliance to Web accessibility guidelines and standards. These mostly concern content creators and fail to involve the diverse population of content consumers in their specifications. In this section, Web accessibility barriers identified from within Web content are also discussed, which is the third essential component of Web development, but it is currently not included in the typical Web Accessibility Life Cycle [38]. Web content is defined as the information in a Web page or Web application, such as text, images, sounds, as well as code or markup that defines their structure and presentation [191].

4.2.3.1. State of Web content inaccessibility

Despite the Web's potential in offering a multifaceted possibility space for inclusion to users with a diverse range of required or preferred modes of functioning, Web content has been growing increasingly more complex with the incorporation of novel technologies and multimedia into Web design [28],[58]. This increase in Web content complexity has inevitably resulted in the emergence of Web content accessibility barriers that are rendering, as a result, certain modes of functioning burdensome or even impossible with regards to interaction with Web content. WebAIM's most recent evaluation of the prevalence of Web accessibility barriers reports that 96.3% of the top 1 million Website homepages fail to comply with WCAG, and identifies that nearly all (96.1%) of the detected barriers can be categorized into six types: low contrast text, missing alternative text for images, empty links, missing form input labels, empty buttons, and missing document language [45].

More specifically, in the case of low contrast text, Friedman and Bryen documented that text clarity and the use of color for contrast have been frequently cited in Web accessibility standards and guidelines for cognitively impaired users [41]. Similarly, Brewer discussed how users with dyslexia are primarily affected by low contrast text, as it renders Web content comprehensibility more difficult [145]. This is also appreciated by McCarthy and Swierenga who advised to implement text configurability to make Websites more accessible to these users [112]. Along these lines, people with visually impairments, who are the primary users of screen magnifiers [18], are also affected by barriers related to low contrast text, and as such, they can be impacted by poor or no text contrast between the background and foreground [28],[29]. Missing alt text for images has also been shown to hamper the Web navigation experience of users with blindness and severe visual impairments who are otherwise unable to discern non-textual Web content [12],[39],[49],[50],[54],[95],[101],[136],[149],[150],[192]; secondarily, missing alt text can also hamper the experience of users with dyslexia and/or cognitive or motor impairments who have also been shown to opt for using screen readers to smoothen their Web interactive experiences [31],[35]. Earlier research by Takagi *et al.* reported that 124 out of 323 users were disturbed by the unavailability of alt text for images [151], agreeing well with McEwan *et al.*'s findings that missing alt text is the most pivotal Web accessibility barrier upon compilation of a diverse range of accessibility studies [152].

Interaction issues during Web browsing such as empty links, missing form input labels, and empty buttons are directly linked to experiential aspects such as prejudices, evoked memories, and expectations, and as such, they have been shown to cause frustration to cognitively impaired [21],[153],[174], visually impaired [50] and blind users [33],[49]. Frustration due to the use of such seemingly operable interaction options in Websites can also be experienced by users with dyslexia, owing to content creators now having access to and having been shown to implement a broader range of more technologically-advanced options [95]. This frustration has, in effect, been shown to increase proportionately with the amount of Website content that users with dyslexia and/or cognitively impaired users need to process [48], not to mention the fact that users with motor impairments can also have frustrating interaction experiences in cases of low or no alternative input device operability [29]. In line with WebAIM's recent findings [45], Hackett *et al.* advocated that there are now increased Web interaction burdens being experienced by users with visual impairments and blindness, as well as by users with cognitive or motor impairments when the language of the text is missing [28].

4.2.3.2. Summary

This section discussed Web content, which is the third and final component that we incorporate in the Web accessibility life cycle. It highlighted the state of accessibility issues that are typically found within Web content, not least in relation to relevant eSystems. The review identified that Web accessibility for individuals with disabilities remains largely unaddressed. Accordingly, the following barriers associated with the Web content component have emerged from this discussion:

- Web content has been growing increasingly more complex with the incorporation of novel technologies and multimedia, which poses considerable challenges for content creators and consumers alike;
- Low contrast text, missing alt text from images and interaction inconsistencies are amongst the most reported accessibility barriers. Missing alt text is the most pivotal Web accessibility barrier reported in a diverse range of accessibility studies;
- Individuals with a visual impairment, cognitive impairment, dyslexia, or a motor impairment are found to be mostly affected by the afore-mentioned barriers.

The identified barriers from the literature are in good agreement with the recent findings from WebAIM's survey [45], which ultimately show that these barriers are persisting and point to the need to increase efforts to make Web content accessible to everyone.

5. WEB ACCESSIBILITY BARRIERS AND IMPACT ASSESSMENT FRAMEWORK

The previous sections identified and highlighted several barriers that derived from human (content creators and consumers, accessibility experts, and Web commissioners), technical (assistive technologies, user agents, and authoring and evaluation tools) and Web content components of the Web accessibility life cycle. Importantly, it was also highlighted that past research on Web accessibility barriers is well-corroborated by more recent findings from WebAIM's annual accessibility analysis, demonstrating that there are certain persistent barriers dominating the past and current state of Web content inaccessibility. Specifically, barriers such as content creators' lack of knowledge in accessibility and accessibility tools' overreliance on guidelines and standards have contributed to the emergence and persistence of Web content accessibility barriers. Therefore, it is Web content that ultimately directly impacts accessibility, usability and user experience and can thus be distinct per disability, so its impact must be measured by taking population diversity into consideration to advance inclusive Web design efforts. More colloquially, barriers associated with human and technical components contribute to the emergent Web content accessibility barriers, and it is through them that end users experience lack of accessibility, usability and user experience. Additionally, whilst these barriers have been highlighted in this work, their impact can be challenging to determine [31], as they can often be disability-specific [21],[54],[112]. To the best of the authors' knowledge, the impact of Web content accessibility barriers per disability has not yet been investigated and reported, despite past research in accessibility [31],[33],[41],[58] having signaled the increased need for such an investigation, not least in relation to the dearth of academic scrutiny as regards the impact of Web content accessibility barriers per disability.

Thus, this section reports on the authors' attempt to gather and amalgamate disability-specific insights to approximate the impact of Web content accessibility barriers in relevant eSystems across disabilities. First, the measures that were used to calculate said impact (see section 5.1) are described; then, these measures are leveraged to explain how the proposed assessment framework for the impact of barriers across disabilities (see section 5.2) was arrived to; and, finally, recommended use cases of the framework are discussed (see section 5.3).

5.1. Web activity (WA) and disturbance rate (DR)

The Web activity (WA) and disturbance rate (DR) measures per disability are inspired by Berger *et al.*'s early report on users' disturbance and Web presence rates [35]. Specifically, the DR per disability based on a range of recent Web accessibility studies [137],[154],[175],[176],[177],[178] is calculated in Table 5. Similarly, the term WA in Table 5 is used to refer to Web Activity rates, namely how actively people use the Web.

Global WA rates per disability are estimated by making use of available rates for the general population in the US [167], Sweden [168], and Colombia [163], as well as disability-specific WA rates in Sweden [179], which is to the best of the authors' knowledge the only study that treats disabilities heterogeneously. This synthesis of sources is motivated by the need to arrive at worldwide estimates of WA per disability, as WA reports are typically country-specific and treat disability as a homogeneous group. Also, to the best of the authors' knowledge, there are currently no such available data, so estimating the above measures will allow for measuring the impact of Web content accessibility barriers per disability, which is not only a significant contribution to scholarly knowledge on Web accessibility, but also a practical tool for informing future Web accessibility studies.

Therefore, the proposed impact assessment framework for arriving at an estimate of worldwide WA per disability begins by using these measures. Specifically, according to the most recent digital competitiveness rates per country [165], Sweden which is ranked 3rd from among 63 countries, the US which is ranked 2nd, and Colombia which is ranked 60th are chosen to extrapolate the disability-specific rates worldwide. For clarity, these countries were chosen for being the highest and lowest ranked countries, respectively, in the previously mentioned digital competitiveness ranking, for which there were available data on WA for people with disabilities. Indicatively, *Formula (1)* shows how WA rates for people with disabilities in the US (63.8%) [166], Sweden (80%) [168], and Colombia (34.6%) [164], are applied to the disability level, and then averaged to arrive at worldwide estimates per disability, where Worldwide Web Activity (WWA) estimate, Web Activity (WA), Users with Disabilities (UD) and Users with Disabilities' Web Activity (UDWA). The results are presented in Table 5.

$$\text{For each Country } i \text{ and Disability } d$$
$$WWA_d = \sum_i^n \frac{UD_i \times WA_d}{UDWA} \qquad (1)$$

5.2. Cross-disability accessibility impact (CxDAI)

The WA measures are then used alongside the *DR* rates calculated from [137],[154],[175],[176],[177],[178] and the general prevalence of each identified barrier for Web content found in the latest report from [5], as well as from accumulated information about whether these barriers primarily, secondarily or not at all affect each group of users with disabilities found in several studies [28],[29],[34],[35],[40],[41],[48],[82],[83],[112],[145], in order to calculate the *cross-disability accessibility impact (CxDAI)* of each Web content accessibility barrier. Therefore, the CxDAI is calculated by averaging the DR and WA, as shown in *Formula (2),* where Website Homepages (HomP) and Interior Pages (IntP) and Affect Weight

(AW). In this calculation, AW is proposed to represent the weight of affect for when a user is primarily (100%), secondarily (50%), or not at all (0), affected by a barrier.

It has to be noted that the terminology used in the literature for each identified Web content barrier differs (*e.g.,* motor impairment and physical disability). In this work, terminology that is consistent with WebAIM's barrier types [45] is used, as their annual accessibility reports are highly-acclaimed within accessibility studies.

For each Barrier i and Disability d

$$HomP_{i,j} = \{h \mid h = HomePage\ of\ Website_j \land h \xrightarrow{includes} Barrier_i\}$$

$$IntP_{i,j} = \{p \mid p \in Interior\ Pages\ of\ Website_j \land p \xrightarrow{includes} Barrier_i\}$$

$$Prevalence_i = \overline{\sum_j^n \left(HomP_{i,j} + IntP_{i,j}\right)} \tag{2}$$

$$AW_d = \begin{cases} primary \overset{is}{\rightarrow} 1 \\ secondary \overset{is}{\rightarrow} 0.5 \\ not\ at\ all \overset{is}{\rightarrow} 0 \end{cases}$$

$$CxDAI_i = \sum_i^n Prevalence_i \times (DR_d \times AW_d) \times WWA_d$$

For example, the CxDAI of missing alt text for images is calculated using (2) as follows:

General Prevalence of Missing Alt Text for Images: (66% homepages + 61.9% interior pages) / 2 = 63.95% Webpages

Blindness: 63.95% * (80.7% * 1) * 56.3% = 29.1%

Low Visual Acuity: 63.95% * (42.6% * 1) * 61.3% = 16.7%

Low or No Hearing Acuity: 63.95% * (35% * 0) * 58.1% = 0

Low Cognitive Acuity: 63.95% * (40% * 0.5) * 48.2% = 6.2%

Dyslexia: 63.95% * (25% * 0.5) * 64.2% = 5.1%

Low Motor Capacity: 63.95% * (43.5% * 0.5) * 53% = 7.4%

CxDAI of Missing Alt Text for Images: 29.1% + 16.7% + 0 + 6.2% + 5.1% + 7.4% = 64.5%

The remaining CxDAI calculations for each Web content accessibility barrier in Table 5 are cumulatively calculated in the exact same fashion.

Table 5: Amalgam of primary (Blue) and secondary (Orange) Web content accessibility barriers and their impact on accessibility per disability

Barrier	General Prevalence %	Blindness		Low Visual Acuity		Low/No Hearing Acuity		Low Cognitive Acuity		Dyslexia		Low Motor Capacity		Cross-Disability Accessibility Impact %
		DR %	WA %	DR %	WA %	DR %	WA %	DR %	WA %	DR %	WA %	DR %	WA %	
		80.7 [175]	56.3	42.6 [154]	61.3	35 [137]	58.1	40 [177]	48.2	25 [176]	64.2	43.5 [178]	53	
Low Contrast Text	85.85													64
Missing Alt Text for Images	63.95													64.5
Empty Links	61.65													69.1
Missing Form Input Labels	54.95													71.4
Empty	32.7													42.4

Barrier	General Prevalence %	Blindness		Low Visual Acuity		Low/No Hearing Acuity		Low Cognitive Acuity		Dyslexia		Low Motor Capacity		Cross-Disability Accessibility Impact %
		DR %	WA %	DR %	WA %	DR %	WA %	DR %	WA %	DR %	WA %	DR %	WA %	
		80.7 [175]	56.3	42.6 [154]	61.3	35 [137]	58.1	40 [177]	48.2	25 [176]	64.2	43.5 [178]	53	
Buttons														
Missing Document Language	27.15													25.1

WebAIM discuss that these barriers actually account for 96.3% of Web content accessibility barriers [45], while the absence of barriers encountered by users with low or no hearing acuity, as well as the absence of organizational barriers [29] can be directly observed in Table 5. Previous studies, however, have examined the browsing preferences and access barriers faced by users with low or no hearing acuity [29],[35],[40],[82],[145],[151],[193],[194],[195], which include strong expectations about the presence of non-complex accompanying metadata, such as captions, subtitles and/or sign language in Web audio and video content; their WA and DR rates are shown in Table 5 as 58.1% and 35%, respectively.

Additionally, it can be appreciated that WebAIM's categorization of barriers appears to not report organization-related barriers, such as insufficient budget and inefficient allocation of resources towards accessibility resulting in the emergence of further barriers in addition to accessibility [27],[56]. Indicatively, more than half of the respondents in a recent survey by AbilityNet noted unawareness, incompetence, and deprioritization of accessibility as the most prevalent barriers [22]. Therefore, an additional finding in Table 5 is that there is a gap in Web accessibility literature regarding the exploration of organizational barriers, as defined in [29], and their impact on accessibility, usability and user experience per user group with disabilities.

Past research, however, has indicated the presence of organization-related factors that impact Web accessibility prioritization, namely organization culture and values, project leadership, and budget and time constraints [49],[89]. Conversely, it has been suggested that large companies, such as Microsoft and Amazon, are less strained by such constraints, as their popularity allows them to more easily attract and recruit Web content creators with more experience in Web accessibility [196]. Overall, the results presented in Table 5 are, to the best of the authors' knowledge, the first scholarly attempt at approximating the CxDAI of Web content accessibility barriers using a compilation of existing knowledge on the general prevalence of such barriers and user-reported disability-specific considerations, such as DR and WA.

5.3. Impact assessment framework in practice

Going forward, two main implications for practice are discussed in the form of potential use cases. It is proposed that the impact assessment framework discussed in this section could advance evaluation tools in their ability to also prioritize Web content barrier detection and resource allocation towards handling such barriers by taking into account population diversity, which has been shown earlier to be problematic to address solely via standard and guideline conformance [14],[27],[31],[50],[54],[58],[59]. In effect, the transparency of the calculations resulting in the CxDAI allows for such measures to be adjusted for each diverse target audience.

5.3.1. Use Case 1: CxDAI and evaluation tools

Indicatively, a practical use case empowered by our proposed impact assessment framework can allow for the CxDAI measure to be employed by evaluation tools to help detect Web content accessibility barriers encountered by a diverse user base, which can be then addressed in a prioritized manner based on their calculated CxDAI. For example, ensuring the suitability of alt text descriptions for non-textual content across a diverse pool of users is often an important challenge for content creators, as there is a substantial reported mismatch between user expectations and needs across disabilities as regards to Web content accessibility barriers, including alt text unsuitability [12],[18],[28],[31],[41],[43],[44],[112],[138],[147],[155],[180]. Utilizing the CxDAI measure within an evaluation tool can allow for addressing Web content barriers according to the needs of a particular user group, which is deemed as an important step to extend accessible Web design beyond standard and guideline conformance and towards inclusivity and usability [60].

5.3.2. Use Case 2: CxDAI and Web accessibility standards and guidelines

The previous discussion highlighted that disabilities are treated as a homogeneous group in accessibility studies [179]. In this framework, it has been demonstrated that each disability can be considered independently and non-homogeneously. It is argued that this characteristic can foster changes in future iterations of Web accessibility standards and guidelines so that they better reflect each disability, which can be achieved through the quantification of the impact of Web content accessibility barriers across disabilities (CxDAI), a notion that was previously suggested based on the reported time lost during Web navigation due to the presence of barriers per disability [175]. This work could thus strengthen evaluation tools via enabling future iterations of Web accessibility standards and guidelines to adopt a USID approach (see section 2.3.7). Specifically, the insights derived from Table 5 can be used as a tool to bridge the afore-identified functional gap between user-expected and Web-offered interaction experience through an increase in the relevance of Web accessibility standard and guideline compliance.

5.3.3. CxDAI practical implementation

Relatedly, the CxDAI measure can be used within automated accessibility evaluation tools as part of Web accessibility training to help shape Web content creators' understanding of Web content accessibility barriers in a more inclusive and quantifiable manner. Specifically, and in more practical terms, we foresee the CxDAI framework being used as part of a typical web accessibility evaluation process. Indicatively, a standard web accessibility evaluation tool, such as WAVE, could be used to identify a number of accessibility and WCAG conformance errors (e.g., indicatively, 5 alt text and 10 contrast errors). The CxDAI framework could be used at the same time to quantify the impact of these errors and their severity, i.e., alt text errors may be less than contrast errors, but designers/developers may prioritize the former due to their larger assessed impact for users of screen readers. Yet, the contrast errors have a much higher impact, compared to alt text errors, on users with reduced vision who do not use screen readers. As such, the CxDAI framework provides the first attempt to quantify impact alongside identified number and types of accessibility errors.

6. CONCLUDING DISCUSSION AND FUTURE WORK

This section discusses the overall findings and presents the identified implications and contributions of this work. It also highlights avenues for future research work.

6.1. Overall findings and contributions

In this work, a scoping review of the literature was conducted to explore recent efforts in Web accessibility across relevant eSystems which included a diversity of disabilities.

The findings present a much-needed review and overview of barriers and state-of-the-art tools (Section 4), but also further propose an impact assessment framework to support relevant parties (human and technical components) in better understanding and measuring the impact of common Web content barriers on disability user groups (Section 5). Specifically, the findings suggest the pressing need to explore alternative solutions to alt text unavailability and unsuitability that would need to consider contributions from content consumers, for instance in the form of authoring and/or evaluating alt text. Section 4.2 highlighted a *functional gap* between content consumers' requirements and expectations and their hands-on interactive experiences with Web content, as well as a *mentality gap* in content creators' and accessibility experts' Web accessibility knowledge and motivation. Both gaps are underpinned by a documented lack of a much-needed inclusive involvement of all affected components in the Web Accessibility Life Cycle. This is in line with previous findings that call for the need to turn content consumers into active contributors in the design decision-making process [15],[31],[32],[38]. It is therefore imperative that content consumers, accessibility experts, and content authors are all engaged in an inclusive and constructive iterative dialogue in an effort to reduce both the functional and mentality gaps identified.

The findings also revealed important inadequacies of the technical components traditionally involved in the Web Accessibility Life Cycle. Whilst content authoring and evaluation tools constitute an essential line of safeguarding against Web content inaccessibility, they do not come without their shortcomings. In Section 4.3, the overreliance of such tools on available Web accessibility guidelines and standards was discussed, and it was demonstrated that the previously mentioned functional gap cannot be supported by the abundance of automated tools, especially as they fail to consider population diversity. The latter is particularly evident for most disabled populations who experience a lack of availability in assistive technologies with the exception of visual impairments where we see an abundance of relevant assistive technologies. In other words, there seems to be an imbalance in the availability of assistive technologies for all types of disabilities. In a similar vein, the findings discussed that content consumers are infrequently, if at all, involved in design decisions relevant to user agents that they are the end users of. Therefore, there are both internal (intrinsic to human components) and external (extrinsic to human components) processes which merely coexist. It is argued that the nature of human and technical components is actually complementary within the Web Accessibility Life Cycle and this should be followed in practice to ensure sustainable delivery of accessible Web content [17],[31],[54],[121].

Web content, which is the third component around which the other two – human and technical – operate has also been found through this review to pose considerable challenges for both content creators and consumers (Section 4.4). On the one hand, the proliferation of new technologies (*e.g.* Virtual Reality and Mixed Reality, Artificial Intelligence, etc.) is allowing content consumers to interact with Web content in new, more engaging, and fun ways, but on the other hand the widely reported issues with missing alt text and low contrast text even within the most fundamental Web content (see [45]) demonstrate that a solution for these pivotal accessibility barriers has yet to be found. Consequently, this inevitably puts additional pressure to content creators to increase their efforts to also make Web content accessible to consumers through the afore-mentioned additional means, which is a significant challenge considering that they are faced with an increased cognitive effort to learn about Web accessibility when there is a reported lack of time and motivation to learn how to do so (section 4.2.3). This becomes even more imperative and challenging if we consider the wide range of individuals with disabilities who are found to be mostly affected by the afore-mentioned barriers.

Finally, this work further identified that despite the breadth of Web content accessibility barriers and their reported persistence, which is now likely to span a wider range of technologies, there are currently no efforts to the best of the authors' knowledge to determine the impact of each barrier across disability groups. Accordingly and in line with past research (*e.g.* [31],[33],[41],[58]), it is argued that there should be a much-needed quantifiable measure of each barrier's impact across the diversity of disabilities, which is proposed and presented in the form of CxDAI (Section 5). It is further discussed that having such a measure will help human and technical components move away from the overreliance on Web accessibility standards and guidelines alone towards a more inclusive understanding of each barrier's implications in practice across disability populations. Accordingly, the main contributions of this work are:

A. A *much-needed review* and overview of commonly reported Web accessibility barriers in eSystems and their impact across disabled groups, as well as a review of relevant state-of-the-art tools and practices across the Web Accessibility Life Cycle.
B. Expanding on previous work on the Web Accessibility Life Cycle by *integrating a Web content* component which is associated with barriers that directly impact accessibility, usability and user experience.
C. The identification of a *mental* and a *functional* gap in current Web accessibility design efforts and attitudes towards accessibility, as well as between users' requirements and expectations and their hands-on interactive experiences with Web content, respectively.

D. An *Impact Assessment Framework*, which is the first, to the best of the authors' knowledge, attempt to measure the impact of Web accessibility barriers by taking into account disability-specific considerations.

The foundation set by surveying the relevant landscape of Web accessibility therefore urges the need for alternative approaches to address the identified barriers whilst also incorporating effective means to further address the demand for *non-expert user involvement* and *trainability.* Furthermore, the findings of this work are relevant beyond the Web, as similar accessibility barriers (*e.g.* alt text) can be found in mobile apps, Virtual Reality (VR), and other emerging technologies. However, their applicability beyond the Web is an avenue for further investigation, as the CxDAI framework specifically was devised and demonstrated based on Web-related studies and data. Studies and data sources that are more relevant to other domains and technologies can be utilized to explore the framework's applicability, which is something that the framework itself supports due to its flexibility and transparency.

6.2. Limitations and future work

This work and findings present some limitations that need to be considered. First, it is acknowledged that the review was limited to the results of the search. Whilst the search protocol was designed to accommodate the most extensive search possible, it should be considered that there may be work which was not included in the final corpus as it may not have been captured through the choice of keywords. It is also likely that there is work that has been published in databases (*e.g.* medical) which was not explored as this was outside the scope of the survey. It is therefore necessary to carry out similar surveys that are inclusive of a broader range of venues and application areas to identify additional work in Web accessibility research.

Second, although every effort to capture Web accessibility preferences, activity and barriers across the diversity of disabilities was made, it is disclosed that the findings may represent an unbalanced documentation of research work per disability, as it is prone to the afore-mentioned extensive available work on blind users compared to limited available similar work on, for example, hearing- and cognitively impaired users. As a result, the reported barriers are naturally more relevant to and more prevalent in users with visual impairments; it is thus imperative to understand that cross-disability data are prone to unbalanced documentation of data from disabled populations per disability. Accordingly, more studies reporting on the preferences, perceived barriers, Web activity and barrier disturbance rates of disabled users other than users with blindness and visual impairments are necessary future steps to achieve more accurate measurability of the impact of Web accessibility barriers across disabilities. More colloquially, if more data were available on users with, for example, hearing and cognitive disabilities, such data would also need to be considered in the proposed CxDAI, and the estimated weighted impact would then increase or decrease for each barrier accordingly. This highlights the possibility of variations in the calculations as per content, context and suitability, which demonstrates the flexibility of the proposed framework.

Third, it is acknowledged that the proposed CxDAI measures derive from different studies and that the taxonomy is disability-specific. The scarcity of research work on the user-perceived impact of Web content accessibility barriers for a range of disabilities rather than an extensive focus on blindness-related barriers [19],[35],[41],[107], and the absence of disability-specific WA statistics per country or region contribute to the inherent high variability of the CxDAI measures. Specifically, for the former, barriers such as missing alt text for images are lacking in consideration of missing alt text for non-textual elements beyond images (*e.g.* infographics), which Muehlbradt and Kane contend are more challenging to author suitable alt text for [43]. Admittedly, Table 5 is only concerned with the availability of alt text descriptions, but it is disregarding the suitability of such descriptions, which has been previously framed as equally or even more problematic than alt text unavailability [149],[150]. If users with cognitive impairments or dyslexia were to be also considered as primarily affected by missing alt text for images, then this barrier's CxDAI would increase to 75.8% (see Formula 2), agreeing well with earlier studies [151],[152] highlighting unavailable and/or unsuitable alt text as the most prevalent barrier. This also highlights the possibility of variations in the CxDAI measures as the discourse around Web content accessibility barriers is deepened. Nevertheless, the proposed impact assessment framework and the associated CxDAI measures are to the best of the authors' knowledge the first such much-needed scholarly attempt to provide a quantifiable and measurable impact assessment per barrier and across disabilities.

Finally, and beyond variability in calculations, the CxDAI framework is currently sensitive to data source changes, however, the strength of the framework lies in its flexibility and adaptability which can allow for adjusting to any such changes. It is therefore independent of data and the transparency of the formulas demonstrates this. It is also acknowledged that there is some subjectivity in assigning AWs in Formula (2) of the framework. However, there is no similar work to the best of the authors' knowledge that estimates any such weighting, and this work constitutes the first step towards a much-needed approach to quantify impact. As such, for the purposes of this work, the use of "1, 0.5 and 0" weights were proposed as a guideline; the formula making use of these weights is transparent (see Formula 2) and weights can therefore be adjusted or changed per use case, domain, or goal. Accordingly, it is recommended that further research can be conducted based on individual scenarios, goals, or domains to investigate the applicability and usefulness of weights, as appropriate. Importantly, it is also acknowledged that the findings relevant to the data used in this work cannot currently be generalized, as specific data sources were incorporated into the framework and there is no balance in terms of the reportability of different disabilities and associated accessibility barriers. However, it is proposed that the CxDAI conceptual framework itself can be generalized, as it can be adapted and adopted, as discussed above.

Accordingly, the findings present three main avenues for future work. The survey shows that there is a pressing need to bring together content consumers, content authors and Web accessibility experts to ensure an all-inclusive discussion, specification and delivery of accessible Web content. It is thus recommended that appropriate organizational processes and skills are developed that encompass all Web components and associated barriers. Kelly *et al.* put forward the concept of 'Web adaptability' that seeks to identify challenges at both community and organizational levels to improve accessibility, which is an approach that appears to suit well this prerequisite to an enhanced and more holistic view of accessibility [197]. In doing so, this survey highlighted the need to also explore **organizational barriers** (*e.g.* insufficient budget and inefficient allocation of resources) [27],[56]. Future work must therefore entail extensive qualitative research into organizational change, which could lead to positive outcomes such as a more effective implementation of process and skill development changes through a set of well-established change process steps [198].

Furthermore, it was previously discussed that the absence of disability-specific WA statistics per country or region contribute to an inherent high variability of the CxDAI measures. A further multinational study is needed to enhance the framework by providing a more comprehensive understanding of global barriers and facilitating cross-country comparisons. Along these lines, there is also room to extend the scoping review with a further systematic review. In this work, it was demonstrated that the CxDAI is an adjustable measure that can be tailored to country-specific nuances and requirements, so an effectiveness study is also needed to explore the usefulness of CxDAI in practice – a valuable endeavor for future research exploits. Finally, another future avenue is to investigate the applicability of the framework beyond the Web, including mobile apps, virtual environments, and other emerging technologies.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.