Better Understanding Diverse End User Website Usage Challenges with Browser-based Augmented Reality Approaches

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Abstract. Software engineers are usually quite different from their end users, especially those with a variety of accessibility related usage challenges. These include, but are not limited to, sight, hearing, cognitive, mobility, hand control, age, language and many others. A popular approach to assist developers in understanding and designing for these diverse end user accessibility challenges are 'Augmented Reality' (AR) browser-based plug-ins. These attempt to mimic how a user with a particular challenge or set of challenges will perceive viewing and interacting with a target web site. We review work on developing such plug-ins, summarise some of the popular AR brower-based plug-ins designed to support accessibility design and evaluation, and report results of a developer survey we conducted on their requirements and usage of such tools. We then report a detailed heuristic evaluation of a popular example, Funkify, and discuss the performance of several of its simulators on commonly used web site exemplars. Finally we identify and report a range of future research needs in this area.

Keywords: Human computer interaction · Accessibility · Human Aspects · Disability Simulation · Software Engineering

1 Introduction

Many end users of web sites have accessibility-related challenges. An estimated 1 in 6 Australians lives with some form of disability[14]. Increasingly, modern life requires greater online access to education, work, leisure and government services – much more since the COVID-19 pandemic. Therefore it is imperative for websites to accommodate these diverse end users accessibility challenges. Unfortunately, there are still many issues in this front. Almost all of the top 1,000 free Android apps have shown to have severe accessibility issues for many of their target end users [4]. The top 100 banking websites in the US have approximately 6 accessibility violations each on average [35]. Analysis of a large number of app user reviews have shown many accessibility and other human aspects are not catered for. [11]. The US saw 3,500 website accessibility lawsuits filed in 2020, and the rate has risen 64% in the first half of 2021[3,22].

Accessibility research has a high focus on development of design guidelines and tools to aid accessibility. These tools focus on automating issue identification and verifying compliance with accessibility guidelines (eg: Web Content Accessibility Guidelines (WCAG)) [2]. Despite these works, the lack of support on web sites for accessibility related challenges of diverse end users continues to exist as a critical problem [2]. One likely cause for this is the lack of understanding amongst developers about the issues faced by people who are different to them [15,34]. Developers may lack the experience, training and insight to fully grasp how different types of end users interact with web sites, which makes it difficult to design and build suitably accessible websites [6,34].

Several researchers have developed Augmented Reality (AR) browser-based plug-ins which mimic accessibility-related challenges faced by diverse end users when using web sites. In this paper, we survey few of these approaches. These are a commonly used to provide developers with an understanding of how diverse end users interact with their web-based systems. We view key related work in this area, summarise some popular AR browser-based plug-ins designed to support accessibility design and evaluation, and evaluate the performance of a particular example – the Funkify simulator. In contrast to other researches, which focus on design guidelines and suggesting changes or accessibility improvements to these tools by working with real end users, our aim is to understand (i) how such tools may elicit a lasting empathetic response from the developer to their diverse end users' accessibility-related needs, and (ii) if they provide a deeper understanding of their users' needs. We also wanted to compare the Funkify simulator's behaviour to prior studies with real end users and published studies on how users with the simulated challenges actually perceive technology.

In this research, we evaluated Funkify Premium as the free version of Funkify limits simulators features e.g. the colour-blindness simulator to a single type of colour blindness. Funkify Premium is available on a subscription basis and provides access to 4 additional simulators - or 'personas', the ability to manually adjust the sensitivity of each of the personas, and the ability to define new personas using a combination of any of the simulators. For example, Funkify Premium allows the user to select between 7 different types of colour blindness to filter the screen for.

The rest of this paper is organised as follows. Section 2 discusses related work on supporting accessibility for diverse end user challenges. Section 3 summarise the key research questions we wanted to answer, Sections 4, 5 and 6 present our practitioner survey, Funkify evaluation design and Funkify evaluation results respectively. We then discuss key findings and future work directions in Section 7 discusses key findings and recommendations from the work and Section 8 key limitations and needed future research recommendations. Section 9 surveys some key related work and finally Section 10 summarises the paper.

2 Background

2.1 Human Aspects

Humans are different and many have diverse challenges when making use of software solutions [15]. Some of these are related to physical and mental challenges of the users and software not designed taking these into account will suffer accessibility problems [29,16]. Currently software engineers lack tools and techniques for adequately modelling end users with diverse challenges that impact accessibility [15]. A few examples include:

Blurred vision: Blurred vision can have a negative effect on a persons' entire line of sight or partially affect one's vision. It includes peripheral vision issues, and it is also possible to experience blurred vision in one eye only. It is often caused by refractive errors (nearsightedness, farsightedness), abrasions to the cornea, age-related macular degeneration, migraine, trauma or injuries to the eye, infectious retinitis [38]. A person with blurred vision can have their functional status and overall well-being severely impacted [23].

Dyslexia: Dyslexia is considered as a language-based learning difference that affects the organization in the brain which controls the ability to process the way language is heard, read, spelled, or spoken. Dyslexia can also have negative effects on a person's working memory, attention, and organization. Davis's research reported 37 common traits of a dyslexic that spans across vision, speech, hearing, writing, motor, math and time management, cognition, behaviour, and personality. Davis stated that people with dyslexia exhibit several common traits and behaviours and these characteristics vary inconsistently[9]. They include reading or writing repetition, transpositions, omissions, reversals or substitutions of letters, numbers and/or words, distraction, movement of letters/words and various others. Mistakes and symptoms increase dramatically with confusion, time pressure, emotional stress, or poor health.

Tremor: Tremor is characterised by shaking movements in a part of the body caused by involuntary muscle contractions. One of the most common neurological diseases, tremor can occur on its own or in conjunction with another neurological disease such as Parkinson's, MS, or stroke. For Parkinson's alone, 1 in every 100 Australians over the age of 60 lives with the disease [10]. Tremors are classified as either rest or action, with action further subdivided to give 7 types of tremors, each with their own typical frequency and amplitude.[32]. Designing apps to support people with tremor has been shown to be challenging [37].

Tunnel vision: Tunnel vision is a colloquial name for peripheral vision loss, a narrowing of the field of view to the extent that the individual can only see directly ahead.[1] It is most commonly seen in patients with retinitis pigmentosa or glaucoma, with glaucoma alone affecting over 300,000 Australians. Limited work to date has been done on design guidelines and support for users suffering from tunnel vision [21].

Cognition: Some users have ADHD, autism, cognitive decline and other neurological challenges. Most software developers are unfamiliar with the challenges these can bring, and like Dyslexia, these manifest in different ways for different people [12].

Age: Differently aged users may have very different experiences and expectations of their software [25,20]. Most software engineers are male, relatively young and relatively affluent. When designing for children, elderly or those from different education, cultural, language and other backgrounds to themselves they may struggle to understand needed software differences [20].

2.2 Browser Plug-ins for Accessibility Analysis

A great many browser plugins exist providing web and app accessibility support [1]. Only a few seem to use augmented reality-like simulation of end user challenges. Some provide a range of accessibility issue analysis and/or simulation support, whereas others focus on a small range of end user challenges. Table 1 summaries a few examples.

Tool	Description
WAVE	WAVE is a popular Chrome plug-in that highlights potential accessibility issues in a web page
IBM Equal Access Accessibility Checker	Uses IBM's accessibility rule engine to check web site issues and highlight issues
ChromeLens	Provides a range of tools for visual accessibility issue detection
Tenon	Accessibility-as-a-service that scans web site to highlight issues
Chromatic Vision Simulator	Simulator showing impact of various forms of colour blindness
Toptal Colour Blind Web Page Filter	Shows a web page after filtering illustrating different colour blindness impacts
Silktide	Web site accessibility simulator including simulated screenreader
Web Disability Simulator	Plug-in simulating the impact on web site usage of colour blindness, low vision, dyslexia

Table 1: Examples of browser plug-ins to assist with web accessibility

2.3 Funkify

Funkify is a publicly available extension for Google Chrome that offers a range of simulators for vision, motor, and cognition impairment as well as dyslexia[13]. The extension breaks users down into personas, with each representing a class of challenged end users. Some available personas are shown in Figure 1. These include vision personas, cognition personas, dyslexia and motor personas. The premium version has some support for combining multiple persona challenges in a simulation. The tool does not support adding new simulators, additional persona information e.g. user stories, demographics etc, or multiple developers sharing persona configurations if working on the same project. To use Funkify, a Chrome browser is installed. The developer then enables a simulator - tagged as a 'persona' - and makes use of their software. The browser plug-in intercepts keyboard input and browser display to mimic how a user with the selected simulator and its configuration settings might experience using the web site.

[1] A large list is provided by W3.org – https://www.w3.org/WAI/ER/tools/

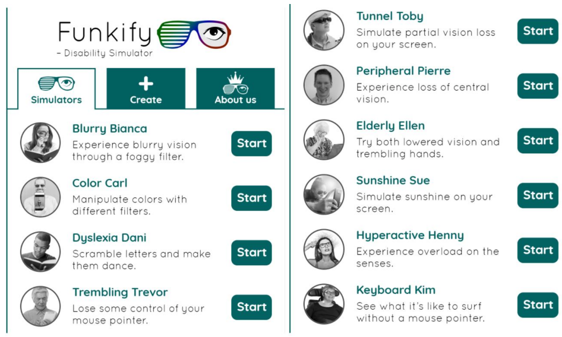


Fig. 1: Examples of Funkify Personas (from [34])

3 Research Questions

The research was divided into answering four major Research Questions:

RQ1: What do developers think about the use of augmented reality browser-based plug-ins for supporting design of web sites for their accessibility challenged end users? To answer this we conducted a survey of developer current usage and opinion on augmented reality browser-based plug-in approaches to help them support diverse user accessibility challenges.

RQ2: Can a browser-based augmented reality simulation tool such as Funkify personas give software engineers a useful experience of diverse end user web accessibility challenges? We identified a range of exemplar websites requiring diverse end user accessibility. We identified a range of Funkify personas representing diverse end users with quite different accessibility challenges.

RQ3: How comparable are Funkify's simulations to documented experiences of web accessibility challenges? We then designed and carried out an evaluation of Funkify Premium personas on these representative websites and tasks. We looked to see how the simulator's mimiced challenged end user experience compared to those documented by earlier studies with real challenged end users and documented medical literature relating to the simulated challenge.

RQ4: What extensions to tools such as Funkify would enhance their usability for more human-centric software engineering? We identified a range of needed improvements to the current state of Funkify and related augmented reality browser-based plug-ins.

4 Developer Survey

4.1 Purpose

We conducted this survey to answer the first research question. We achieve this by trying to understand (i) Developers current usage of augmented reality browser-based plug-ins in websites to support accessibility; and (ii) Developers opinions about using such plugins to support accessibility.

4.2 Procedure

The survey consisted of two main sections: demographics and open ended questions. Demographic questions focused on user characteristics, qualifications, job role, domain, expertise and experience in software development. The open ended questions focused on developer's current practices to support accessibility, their understanding and usage of augmented reality browser-based plug-ins to support accessibility and general feedback on software accessibility.

We created the survey in Qualtrics platform and launched it via social media and Prolific platforms. We obtained 30+ responses in a duration of 2 months.

4.3 Results

Participants: We had 30 usable responses whose results we report here, 24 male and 6 female. Ages ranged from 20-29 (16), 30-39 (9), 40-49 (1), 50-59 (2) and 2 not specified. Locations were Europe (19), Africa (9), North America (4), Oceania (4) and South America (3). Most (25) has a Bachelors degree, and most areas were Computer Science (12) or Information Technology (12). Years of experience were 0-3 (20), 4-6 (4), 7-9 (4) and 10+ (2). We asked about job roles (past and present) and domains of work. These are summarised in table 2.

Role and Domain (past and present)	Number of Participants
Project Manager	9
Requirements Engineer	7
Software Architect	4
User Interface Designer	12
Programmer	40
Tester	15
Operations	6
Other	3
Finance	12
Social Media	5
Transport & Logistics	5
Education	4
Insurance	2
Other	7

Table 2: Survey Participant Role and Domains

Processes and Tools Used: We asked what development processes participants used to help address diverse end user challenges, and any tools they use to aid them. 11 focused on accessibility in the design stage with 5 adopting User-Focused Design and 6 designing based on Guidelines. 7 considered accessibility after development with 5 focusing on gaining user feedback and 2 using different testing methods such as user acceptance testing. 6 claimed did not use any specific approaches to address diverse end user challenges while 7 explained general software development approaches such as MVC patterns which showed lack of awareness on accessibility.

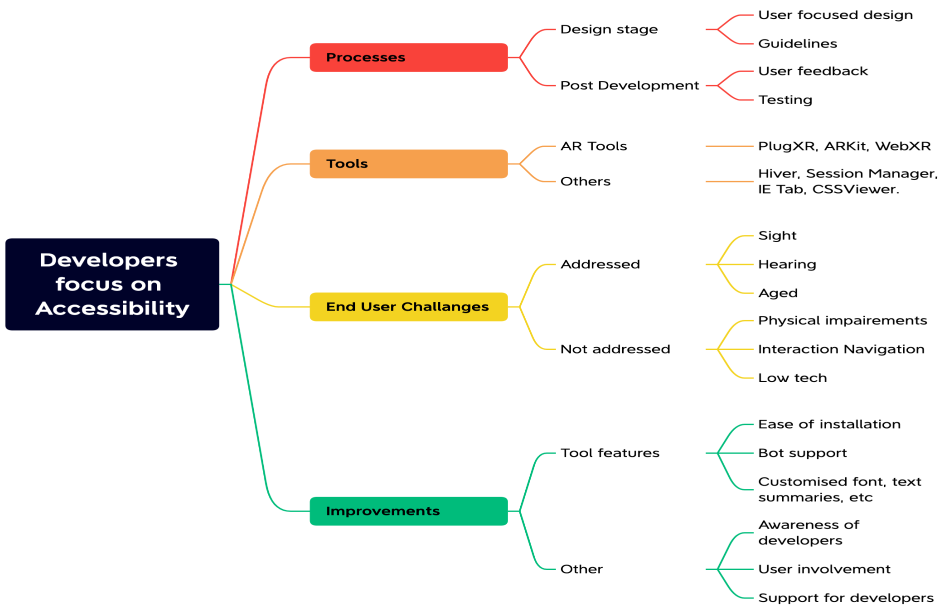


Fig. 2: Summary of survey findings

"We do research and monitor accessibility by building products that can adapt and change when we have feedback from our users" [P23]

"Follow accessibility guidelines by the Web Content Accessibility Guidelines (WCAG)" [P16] and *"Reading WCAG guidelines to understand accessibility needs"* [P25]

"for every stage ... I make sure that I test with the user, ... enable[s] me to know exactly what the user expects" [P6]

"Using screen readers during QA process" [P25] and *"Screen reader functionality"* [P4]

In terms of tools, very few participants used augmented-reality based browser plug-ins to aid them in these tasks, with only 5 naming specific support tools. These included AR tools such as PlugXR, ARKit, WebXR and other browser based plugins such as Cisco Web Assist,Web Developer, Google translate, Hiver, Session Manager, IE Tab and CSSViewer.

Focused End-user Challenges: Only a small number of diverse end user challenges were named by our participants who had used AR-based web browser plug-ins.

"Free tester tools for screen readers are key for us" [P25]

"better UI designs for the visually impaired, the option for audio-description for those who may have trouble reading, and various language translation to limit language barrier" [P27]

"Enlarged texts and textures mostly, maybe we should give better try by image contrast [P23]

Most named sight challenges as those addressed e.g. *"especially people that have accessibility issues, such as sight problems"* [P10], *"varying font sizes options to help sight-challenged users"* [P12], *"Maybe the bigger fonts could help users who couldn't see very well"* [P21] and *"Sight impairments"* [P28]. A few named other challenges e.g. "The aurally impaired" [P4], age based issues *"content for users of all ages"* [P24].

Some noted they followed design practices without needing to use AR-based tools to help them e.g. *"We didn't use any plugin to address color blindness, we simply follow guidelines and do user experience tests to validate the correctness of the implementation"* [P19] and *"Our aim was always to make the UI as intuitive and easy-to-read as possible (bigger fonts, colors, etc), we didn't consider that maybe some of our users could be sight-challenged"* [P21]

Participants felt some issues are not commonly addressed and those are, physical impairments and technical skills *"non-technology inclined individuals"* [P27]. It was noted that navigation was also a challenge for many users. *"Interaction navigating and finding People navigate and find content using different strategies and approaches depending on their preferences, skills, and abilities."* [P16], and that tools could help most/all users have an improved interaction experience, *"I believe it is beneficial to all"* [P10].

Support for some issues was claimed not to be helped by current AR-based plug-ins, *"It does not support anything outside of hearing, speech and vision"* [P20]

Suggested improvements: The improvements can be categorised to two: *tool feature improvements* and *general improvements* to help developers better support diverse end user needs.

Several suggested improvements to AR-based browser plug-in tool features. These included *"I think there could be some sort of bot which guide us through website"* [P11], better support in installation and support for graphic accessibility. One participant gave many interesting suggestions for improved web site design/AR-plugin support: *"[supporting] customized fonts and colours:changing the font types, sizes, colors, and spacing to make text easier to read"*, *"Document outline:representation of the content that only shows the headings and relevant structures"*, *"simplified summaries for passages of text ... Progressive disclosure:design technique that involves showing only the least amount of information or functions necessary for a given task or purpose"*, *"Reduced interface: representation of the content that only shows most relevant information or more frequently used functions"* [P16]. They also suggested supporting use of symbols instead of text in some situations, and use of sign language to indicate both content and emotions/intensity. Other improvements suggested included *"Live transcriptions for deaf people or clear speech relays"* [P23], and *"Understanding graphs for sight challenge users"* [P3].

The general suggestions to help developers better address accessibility challenged end user issues can be categorised in to three, Awareness, Involvement and Support. Under *Awareness*, more knowledge and training with such tools was suggested, e.g. *"more advertising to make developers aware of the presence of such tools"* and *"Make it easier to access them and have them taught in varsity"* [P17]. It was noted there are sometimes clashes between accessibility needs and e.g. security e.g. *"As a bank we thought of using voice prompts but it's not practical as some sensitive data can be intercepted"* [P9].

Under *Involvement*, the need to engage with diverse end users throughout the design process was emphasised by a four respondents, whatever development support tools are used e.g. *"Constant engagement with individuals with the accessibility challenged end user"* [P2], *"...conduct a study about end users with accessibility issues. Short-sighted people, hearing impaired, etc"* [P21], and getting feedback from diverse end users.

For *Support*, participants believed that developers need to be better supported to adapt these plugins. They suggested providing open source code of the plugins to allow developers to make changes as needed [P6] and providing public APIs for accessibility services [P20].

5 Funkify Evaluation Study Design

We carried out an evaluation of the Funkify augmented reality browser-based plug in to see how well it supports developers understanding end user web based interface usage challenges. The range and number of personas and websites that we evaluated were chosen with regards to a diverse, representative set of digital services needed by many in the community and relatively common end user accessibility challenges.

5.1 Funkify Persona Selection

Personas are fictional profiles of characters, created to represent different types of users with the aim to provide a perspective, or observations about different challenges or experiences diverse users face, ultimately building empathy from developers and designers towards their end users [27]. In our research, these personas represent users with a disability or multiple disabilities that affects the users' experience while interacting with software, whether they be visual, motor and/or cognitive impairments. Our set of target personas were selected on the basis of (i) covering a wide range of user's challenges, and (ii) relatively common disabilities that would have the most effect on users' experience and would be difficult to simulate effectively and thoroughly with an augmented reality tool such as Funkify. From the 10 personas Funkify provides, 4 personas were selected for our evaluation – tremor, tunnel vision, blurred vision and dyslexia.

5.2 Target websites

To perform the evaluation on the selected personas, a set of target websites were chosen. Our approach to choosing these websites were to cover a wide range of topics, layouts, content of the sites (content-heavy news sites, websites with a lot of interactions, pictures...) The websites were chosen to also differ in user needs when using them, spanning from recreational purposes to daily fundamental needs. In the end, a set of 3 such target websites were selected:

Commonwealth NetBank: Commonwealth Bank of Australia (CBA) is one of the most popular banks in the country and has an online system to support all the fundamental banking tasks like checking your balance, making a transaction, finding an ATM or branch, and so on. These are tasks that most people do almost every day, and can have direct detrimental effects on a person who is unable to do them effectively and accurately.

Reddit: Reddit is a social news platform with a large user community, covering a wide range of topics and subjects. Its website is very content-heavy consisting of mainly text and pictures with a lot of interactions between interactions. Reddit was selected to assess the experiences of diverse end users on a content-heavy site where most of the interactions and content are casual using a lot of colloquial language.

Amazon: Amazon is the world's largest e-commerce website with more than 1.5 million transactions every day. Amazon was selected to evaluate how one of the largest and most visited websites in the world design their platform in regard to accessibility for diverse end users.

5.3 Evaluation Method

We conducted a heuristics evaluation of our selected personas using Funkify Premium applying a set of evaluation criteria, including:

- What range of diverse end user challenges does Funkify support? How do such challenges manifest in the browser?
- How well does the tool work with our selected websites when performing tasks?
- How is the AR environment produced by the tool for developers comparable to the documented experiences of end users with these challenges?
- Does the modification of website interaction appear to be based on actual evidence or literature?
- Do Funkify personas provide a software developer a good idea of how someone using the website with this challenge would find the experience? Can the software developer "empathise" with this target end user's accessibility-related challenges?
- Can users with multiple accessibility-related challenges be addressed, and how feasible and efficient does the tool address users with such multiple challenges?
- What new challenges (combination of challenges) are we able to add to the tool? What challenges are not possible to add?

To support the evaluation of this set of criteria, we conducted cognitive walk-throughs with each persona on all the target websites. From the results of the cognitive walk-throughs, we assessed how effective the persona's challenges manifest in the browser with Funkify, what the notable limitations of the tool for a persona/target website are, and how the personas challenges relate to real users' experience based on existing accessibility studies and literature on the disabilities. From these we identified opportunities for improvement in Funkify's augmented reality approach for better supporting software engineers in designing and building interfaces for diverse end users.

5.4 Cognitive walk-through

Cognitive walk-through is a method primarily used in usability evaluation to look for usability issues in interactive systems, with a focus on task completion for novice users [8]. Its emphasis is on studying how easy it is for new or infrequent users to learn a system. It was first used as a tool to evaluate systems such as ATMs or interactive exhibits in museums where users will generally have little to no prior experience or training. Due to its ease of use and feasibility, the method's usage has been extended to complex software systems including CAD and software development tools.[28]

Cognitive walk-throughs were conducted, one for each selected persona and website combination. We chose a set of tasks for each website and conducted the walk-throughs. Our approach to selecting these tasks for each target website was to select those that were the most basic and relevant for all the websites (e.g., logging on, registering) and the most major tasks for each site (e.g., make a transaction). A series of 4-6 major tasks were chosen for each of the target websites. The next step was to define a goal or success criteria for each of the tasks to determine how effective can the task be done in the augmented environment created using Funkify for each of the personas. After finalising the tasks and their respective definition of success, we would then conduct the walk-throughs for each of the personas on all the target websites and tasks.

Each persona was be assessed as to how it affects the tasks' feasibility, whether the task could still be done with the Funkify filter active at different intensity settings or if it proved to be impossible to complete the task when Funkify is active, based on the defined success criteria. The results of each task and target website from the walk-throughs could then be generalised into the feasibility and effectiveness of the Funkify persona in terms of how well it achieves the simulation of the persona's challenges and what the major limitations of the tool are or in general the limitations of augmented reality tools in simulating diverse end users' experience.

The evaluators of the websites and Funkify personas were software engineering students with real-world software practitioner experience. Each has expertise in software engineering processes and tools, UX/UI design, web and app development, but no particular training in designing for accessibility.

5.5 Website Tasks

All of the target websites have similar tasks for logging on and registering a new user where the definition of success is straightforward and consistent among all websites. Key tasks which differ across the websites are as follows:

Commonwealth NetBank tasks:

Make a transaction: this is the most common and fundamental task to be completed on a banking website. The definition of success was to be able make a transaction for the correct amount of money from a specific account to the correct recipient. The user needs to navigate to the transaction page, choose the correct 'To' and 'From' accounts and input the correct amount to complete the task.

Find a branch or ATM: Commonwealth NetBank provides a feature to show a map of ATM or branches nearby or to selected set of filter options. How this task is considered as done can vary between use cases, so we chose to define success for this task to be able to navigate around the map effectively and be able to find a specific CBA branch on the map.

Reddit tasks:

Join and navigate subreddits: Reddit is a social news platform where each subreddit represents a community that focuses on a specific category or topic. It was difficult to define a tangible success criterion for navigating through the subreddits, so we focused on joining a subreddit while assessing how the Funkify filters affect the experience of navigating through subreddits.

Read comments on posts: comments are a large proportion of all content and interactions on Reddit posts. Users need to successfully read comments, navigate through all comments and replies, and be able to follow and understand comment threads.

Post on subreddit: A Reddit post can be simple as a sentence or it can consist of pictures, links, various font options... We decided to assess the task's completion on the user's accessibility and effectiveness in using these additional options when posting.

Post comments: this task involves composing a comment relating to a post and is relatively simple, so a definition of success is not required.

Amazon tasks:

Find a product (example - an HDMI cable): Being an e-commerce site, Amazon's most fundamental task would be to find a product. The definition of success was to be able to search for a product (an HDMI cable was selected for this task) and effectively compare all the search results (in terms of descriptions, prices, quantities...).

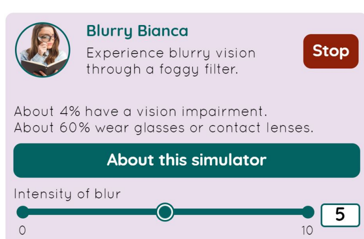
Buy a product: conventionally buying a product on Amazon involves selecting the product, comparing and choosing the products' options if any, adding it to the user's cart, and checking out with the required user billing details. For this research, we define this task as completed when user has selected the right product, read its descriptions effectively, compared between product's options, and add it to their cart.

6 FUNKIFY EVALUATION RESULTS

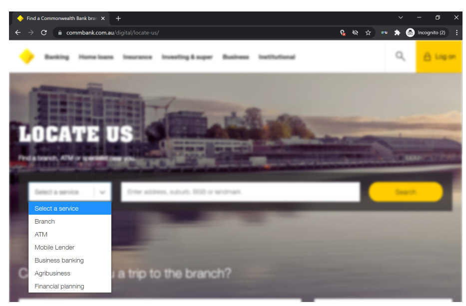
For each persona we describe how Funkify attempts to simulate the underlying accessibility issue, report key findings from the cognitive walk-throughs [RQ1], and discuss the extent to which the experience provided by Funkify mirrors the documented experiences of diverse end users with these challenges [RQ2]. Notably, Funkify only augments the browser window underneath the title bar, so any changes to the url or open tabs are not concealed. A limitation of the tool is that it only applies to the view within the page so all the other components in the browser UI are not affected such as tabs' names, browser menu, settings. This is of course not consistent with the real-world experience of a person with blurred vision.

6.1 Blurred Vision Augmentation

Blurred vision is the most common sight challenge, but varies in level. Funkify applies a blur filter to the entire window, with intensity being able to be varyied on a 0-10 scale. Figure 3a shows the persona and Figure 3b how this manifests for the CommBank website ATM locator page.



(a) Blurry Bianca Persona

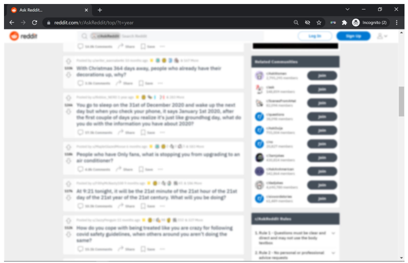


(b) NetBank ATM search dropdown

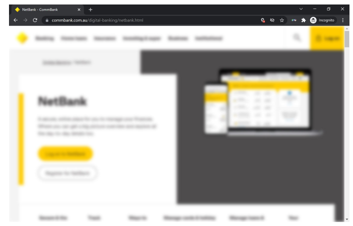
Fig. 3: (a) Blurry Bianca simulator and (b) example of applying to NetBank web site (from [34])

While there were isolated instances like Figure 3b of components such as drop-down selections appearing as normal on top of the filter, overall the simulator performed consistently well. It immersed the user in the persona and allowed them to identify areas where the site design led to user frustration.

For content-heavy websites like Amazon and Reddit (Figure 4a), the visual strain made browsing particularly difficult and tiring. However, fatigue was also experienced when navigating NetBank, with lower information density. Amazon, with many busy pages, description blocks and copious amounts of small, clickable, text was very taxing to navigate. Product titles and costs, as the top elements of Amazon's typographic hierarchy, are the only readable parts of the



(a) Reddit with Blurry Bianca filter, 2.5 intensity



(b) NetBank login colour highlights the most important interactions

Fig. 4: Examples of Blurry Bianca simulations (from [34])

page at 1.5 intensity. Even Amazon's captcha posed a difficulty. Although the registration process allows the user to select an audio challenge, the explanation of what is required is shown in unreadably small font.

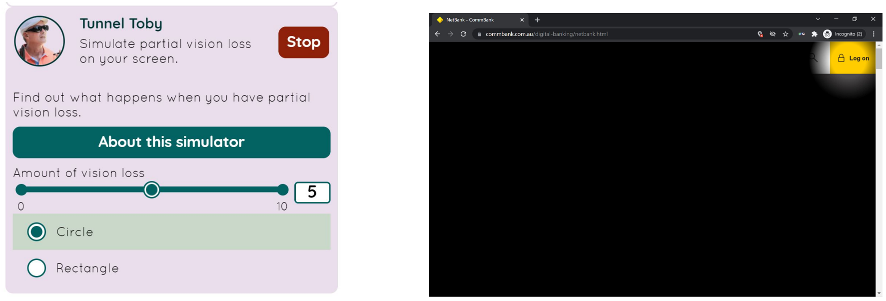
As navigation was tiring, accessible and bold design choices stood out for their ease of use. The use of contrasting and vibrant colours drew the user's focus more easily, and was used to good effect by NetBank's yellow log in button as shown in Figure 4b. It also highlighted the benefit of iconography and logos as opposed to reliance on text. Reddit's login modal has the Google and Apple logos alongside their login options. The text became unreadable at 1.8 intensity, whereas the logos remained recognisable until 3.0, reducing the cognitive strain.

The experience produced by the tool was very comparable to that of a short-sighted person when not using prescription glasses. A noticeable takeaway is that for most of the evaluated websites and tasks, it is almost impossible to read any content or text on the screen when the intensity reaches 3.0, so a large portion of the intensity spectrum will yield the same results when using this augmentation. And the characteristic of the blur filter is the same for all the websites and all the intensity levels (a blur effect to the entire screen) which might not be the experience for all users with blurred vision (partial blurred vision, left or right blurred vision, short-sightedness compared to age-related causes...).

6.2 Tunnel Vision Augmentation

The Tunnel Toby Funkify persona, shown in figure 5a, shrinks the visible area in the browser window to either a circle or rectangle centered at the current position of the user's mouse. The remainder of the window is covered by an opaque black filter. A sensitivity slider from 0-10 is provided to change the amount of vision loss desired. We evaluated the circular option intended to simulate peripheral vision loss.

Evaluating this simulator was found to be a very confronting and intensely uncomfortable experience. Although solely isolated to the browser window, and with the user able to stop at any time, prolonged exposure to this persona repeatedly led the evaluators to spikes of anxiety and claustrophobia. On unfamiliar



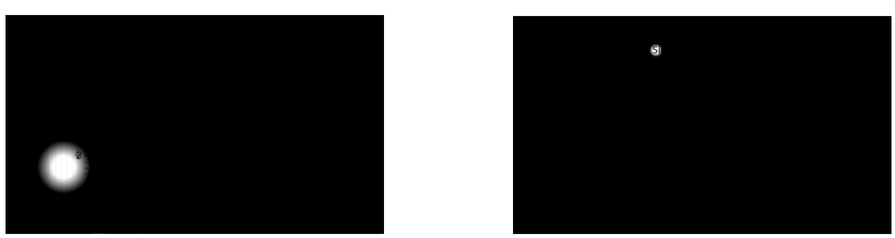
(a) Tunnel Toby Persona (b) NetBank login button placement

Fig. 5: (a) Tunnel Toby simulator and (b) example of its impact (from [34])

sites navigation times were dramatically slowed due to the need to systematically scan each page, building a mental picture of the structure and ensuring key details were not overlooked.

To compensate, there was a noted reliance on established UI norms. For example, assuming a button to login would be in the top right corner of the window (shown in Figure 5b). Similarly, visual identifiers of page structure helped with maintaining an understanding of position. As shown in Figure 6a, Reddit displays its nested comment hierarchy with parallel vertical lines signifying the level of indentation, where clicking on a line navigates the user to the parent comment of that level. Without such a visual aid it would be extremely difficult to follow conversations.

This confusion manifested when evaluating Amazon's product search. Products were arranged inconsistently, alternating between a single product per row and three separate products side-by-side. Advertisements and sponsored products were interlaced at unpredictable intervals. Product images were larger than the visible circle, and product names were long and technical in nature. All of these factors combined to make comparisons between products difficult.



(a) Reddit hierarchy lines (b) Tunnel Toby sensitivity 10

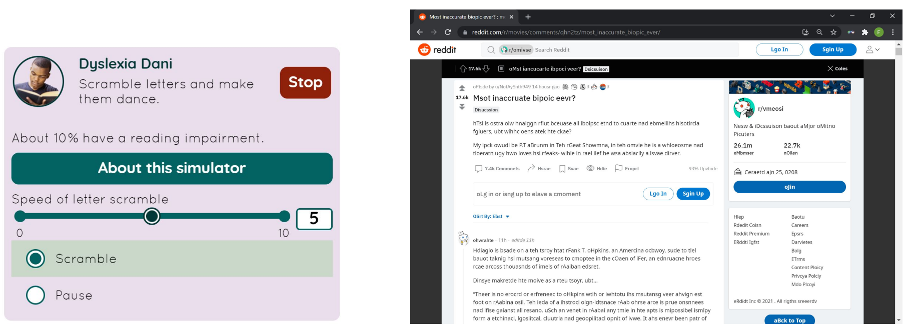
Fig. 6: Examples of Tunnel Toby simulations (from [34])

A number of bugs were identified with Funkify's tunnel vision augmentation. When using the persona, the mouse could not enter the Reddit login modal and lagged significantly when Reddit posts were opened. Scrolling on a page moved the visible area in tandem, as opposed to it sticking to the mouse position. This resulted in most scrolling occurring with an entirely black screen, only refreshing on mouse move.

Funkify provides a 0-10 slider for amount of vision loss, however this scale is quite a narrow range. 0 is no vision loss at all, but 0.1 is already significant impairment. 10, demonstrated in Figure 6b is almost complete vision loss. To better reflect reality this range should be much wider, with lower numbers just showing some darkening around the edges of the screen and gradually decreasing the vision.

6.3 Dyslexia Augmentation

Funkify attempts a simulation of dyslexia by scrambling text on the web page. Scrambling is localised to a word with the exact characters swapping at random. Figure 7a illustrates this persona.



(a) Dyslexia Dani Persona (b) Browsing Reddit with Dyslexia Dani

Fig. 7: (a) Dyslexia Dani and (b) an example of its impact (from [34])

It was found that content-heavy sites such as Amazon are difficult to read, and small site elements escalate the challenge. It became difficult to ascertain and remember product names when trying to find a product that had been seen previously. Evaluating Reddit (Figure 7b) exposed a set of challenges around comprehending slang and internet colloquialisms, which proved to be barriers to entering the conversation.

The simulator only changes page text, and therefore it does not scramble any text in images, branding, tooltips, and certain buttons. It fails to work on Reddit's login modal and seems to not scramble two-digit numbers, even when they appear as text. Additionally text typed into websites remains unaltered. Figure 9 shows the ATM search stage of a NetBank evaluation, where neither the input text or dropdown list are scrambled. These limitations cumulatively limit the immersive experience of the simulator, as in Figure 8 where the focal point of the screen is text embedded in an image.

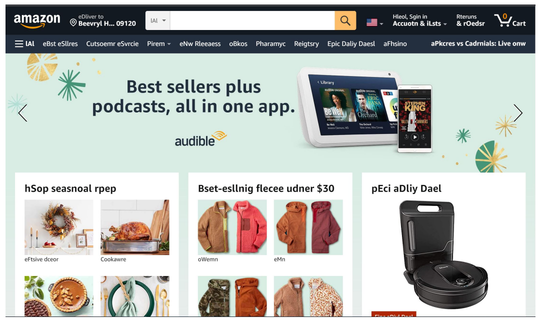


Fig. 8: Amazon home page - banner unaffected by dyslexia filter (from [34])

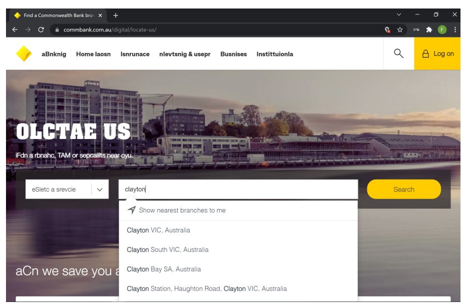
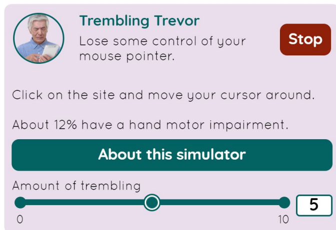


Fig. 9: Dropdown item and form inputs do not scramble (from [34])

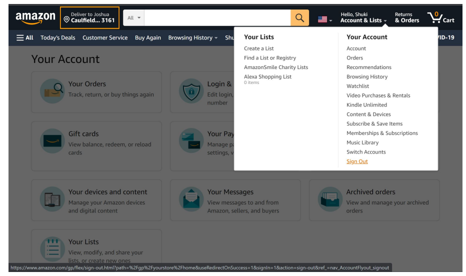
With each letter generally not moving far relative to their correct position; words with 2 or less characters stay the same during the simulation. The tool's capability is only limited to the visual aspects of dyslexia, so it is not comprehensible enough to generalize the whole set of challenges a dyslexic person experiences. The tool is not able to cover other aspects related to the persona including hearing, writing, motor, especially behavioral traits. It is not clear that all people with dyslexia experience reading in this manner, and some have simulated dyslexia by removing lines from normal lettering [5].

6.4 Tremor Augmentation

The Trembling Trevor Funkify persona simulates tremor by moving the mouse involuntarily and unpredictably in all directions. As the mouse continues to move without user input it would be classified as a resting tremor, as is commonly seen in Parkinson's disease. The amount of tremor is adjustable on a 0-10 scale. Figure 10a shows the persona from Funkify.



(a) Trembling Trevor UI

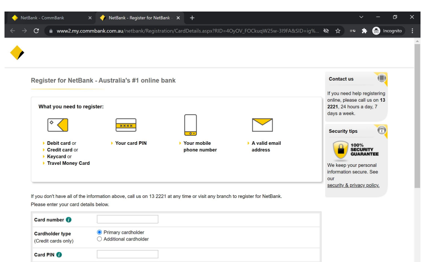


(b) Amazon sign out button

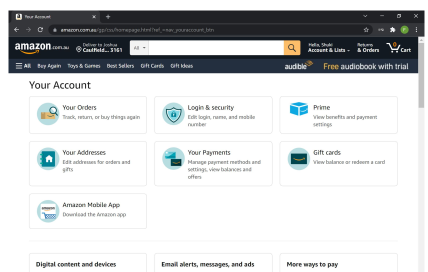
Fig. 10: (a) Trembling Trevor simulator and (b) challenges when activated (from [34])

While using the persona, accurately selecting small targets posed a significant challenge. This was most prevalent in the Amazon walk-through, due to the abundance of clickable text. When searching for products the filter options are inaccessibly small, as is the breadcrumb navigation in the user profile section.

Critically, signing out of an account necessitates clicking on a small piece of text at the bottom of a dropdown menu, as shown in Fig. 10b. It requires fine motor control to accurately click the correct button, with the additional frustration that unintended movements that cause the cursor to move outside of the box results in the dropdown menu collapsing.



(a) NetBank registration form radio buttons



(b) Amazon profile page

Fig. 11: Examples of impact of Trembling Trevor simulator (from [34])

Similarly, when applying to register for NetBank (Figure 11a), the user is prompted to select between radio button options, which were basically unclickable with this Funkify persona enabled. The most accessible pages had large, separated buttons, like on Amazon's user profile page shown in Figure 11b.

The sensitivity adjustment is a 10-point sliding scale of an ill-defined "amount of trembling". Although probably sufficient to emulate the experience of navigating with a tremor, this could be broken down into frequency and amplitude to better align with the medical literature. An advanced feature set could also break it down by tremor type.

7 Discussion

Cognitive walk-throughs with Funkify provided both valuable insights into accessibility issues on the evaluated sites and also a lasting impression on the evaluators of the constraints experienced by end-users who live with the examined disabilities. The lessons learned were applicable beyond the local scope of one website, and the tool elicited the desired empathetic response above and beyond accessibility issue identification. We recommend its use in further research that can explore this relationship further and to identify whether it can lead to improved long-term improved accessibility outcomes.

Funkify as it currently exists is a straightforward and easy to use extension that offers flexibility and customisation across a wide range of disabilities. Personas are toggled with a single button click and any combination of existing simulators can be combined into a new persona. Having all of the functionality neatly packaged in a single plugin allows Funkify to add value if included in future projects that use personas to model diverse end users. However, a number of potential limitations were found, and a number of extensions to Funkify identified that would enhance its suitability as a basis for future research [RQ3].

7.1 Expanded personas

Prior research on the use of personas to understand end users includes more biographical and emotional context than Funkify currently allows. Other work has proposed personas that are tailored to the needs of the development team and express the background, goals, and frustrations of the modelled end user to specific problem domains [24]. We propose that another button be created underneath "About this simulator" for each Funkify persona, where the user will be able to read and edit more of the human aspects of the persona. This ability to enrich Funkify personas by defining more contextual data would improve the quality and utility of the personas for testing purposes, and simultaneously provide a mechanism by which to instantly simulate the perspective of the previously text-based persona.

7.2 Sharing capability

As a Chrome extension, any custom personas or changes to sensitivity settings are localised to a single account. To facilitate repeatable testing and consistency amongst team members, support is needed for sharing personas with other Funkify users. This could be combined with extending persona human aspects to provide richer, more contextual personas.

7.3 Predefined intensities

At present, Funkify Premium always allows the user to adjust the simulator intensity. However as we move to richer personas we may, for consistency, want to specify the exact desired values and disable the ability of users to deviate from it. Therefore we suggest that the screen to make or edit a new persona should contain a field for whether the intensity values are locked. It will always be possible to return to the edit screen to unlock them, but this feature would prevent accidental miscalibration. If this is not possible, we would suggest a button in the persona window that would return all values to a preset default.

7.4 Broader range of intensities

A finding of our cognitive walk-throughs was that the range of intensity options provided for each persona was too narrow, often resulting in the user solely utilising the lower end of the spectrum. For example the minimum amount of vision loss (0.1) for the Tunnel Toby persona shown in Figure 6b is already quite advanced peripheral vision loss whereas the circle size in upper half of the range (> 5) is too small to be useful. The sensitivity range should be re-calibrated to allow the minimums to represent a far more gentle form of the disability.

7.5 Combining personas

Funkify provides a limited ability to define new personas and some target end users have multiple challenges that would be good to be able simulate concurrently. As Funkify uses different approaches to its augmented reality-based simulations, this may be difficult if not impossible for some multiple challenge personas. This may require a more sophisticated augmented reality-based approach.

7.6 New simulators

Finally, we would add new simulators to Funkify targeting aspects of dyscalculia, hearing impairment, and developmental disabilities including autism. While these conditions may not be able to be replicated precisely, we would implement targeted parts of their documented end user experience from other studies and medical literature. As above, we would aim to leverage Funkify's ability to combine simulators in order to scaffold a more holistic persona from constituent symptom personas.

8 Limitations and Future Work

One major limitation in this research was limiting our evaluation to Funkify. This opens further potential research paths and questions as to whether all of the personas provided by Funkify yield the same evaluation results as other comparable tools, or if there are better performing tools compared to Funkify to simulate diverse end users' experience for some challenges. Although our selection approach was to cover the widest range of personas and websites possible, there are of course many other widely used websites and tasks that could be evaluated with Funkify's augmentation approaches. The small number of people doing the cognitive walk-through-based evaluations is also a limitation. This can result in the lack of integrity between each cognitive walk-throughs as members would have had some prior experience with the target websites and tasks. With the evaluation only done internally by research team members with experience in software engineering, UI/UX and web development, this may not reflect actual experience of target end users. However a major aim of our work was to see how software engineers perceived the augmented browser-based interfaces, and whether they could help identify key usability challenges for such target end users. We also wanted to see if software engineers could gain a more empathetic understanding of these target end users by using Funkify's persona and augmented browser-based interface approach.

Another limitation in our study was the lack of real end user involvement. This can be overcome in the future by conducting user studies with actual visual-impaired users. It would also help to overcome the limitation of possible bias in current participants since they were from a software engineering background. A comparison of task completion between real versus simulated user groups may reveal further interesting insights. However, we did compare Funkify's augmented interfaces to the impacts of different user challenges reported in prior studies and medical literature. Further studies into evaluating a wide range of users at different levels/manifestations of the disabilities are also necessary to assess the impact on their web usage and study different UI solutions required to cater to different range of users with the same disabilities (e.g., different levels of tunnel vision, different manifestations of dyslexia).

The effect on software developers and designers after using tools such as Funkify on their design process is an important area to study. Some studies have shown having able-bodied people experience disability simulators can reinforce negative stereotypes and attitudes to these challenged people.[26]. It would be interesting to see how developers assess their existing UI designs using the Funkify personas, and how this might influence their designs to better accommodate more diverse challenged end users and empathise better with them after experience with these tools. A notable perspective raised by Huynh et al. was the use of personas of developers with their own challenges[17], and how they would diagnose and fix UI problems differently to other developers. Future research could use such different software engineer personas to evaluate Funkify.

9 RELATED WORK

Alshayban et al. [4] developed an automated accessibility evaluation tool that they used to evaluate 1135 free Android applications and conducted a follow-up survey of Android developers. They found that accessibility issues are prevalent and pervasive throughout all categories of apps, and that these issues are not limited to affecting a single type of user disability. Although they surveyed a relatively small sample of 66 developers, it was found that the respondents lacked awareness of accessibility issues or training to address them. It's noteworthy that the minimum amount of development experience among respondents was 0.25 years, a very short amount of time that may raise questions about the ability to generalise this result. An interesting observation was that no existing accessibility analysis tools are prioritising issues by severity or importance, leading developers to either overlook critical flaws or be overwhelmed with the quantity and variety. They identified accessibility issues within half of the templates provided directly by Android Studio. Developers view these templates as a trustworthy foundation and build their apps around them, thereby propagating the issues. This raises the question of whether a similar phenomenon may be occurring in the website space, for example with front-end component libraries or popular website templates. However, they only evaluated free Android apps, and it would be interesting to investigate whether the same reliance on templates is present in popular paid apps that presumably have higher development budgets.

Bai et al. [5] investigated and compared six accessibility testing methods for software development teams. They evaluated these methods in terms of their usefulness, satisfaction, ease of use and ease of learning to determine the methods that would yield the best engagement for the participants, investigated how different software roles and development phases would affect the choice of appropriate testing methods. The sample size of participants was relatively small (53 participants) with 74% were male, and it would be interesting to see how this fact relates to the empathy of developers towards end-users. A notable observation was that there are no set rules to determine the types of issues a testing method best identifies, which made it difficult to choose a method and resulted in developers neglecting testing entirely. The de facto method for the participants was WCAG walk-through. However, the assessment of this method yielded the lowest result in terms of satisfaction and ease of use with a hostile attitude in many responses. This poses a question of whether enforcing use of a specific testing method is appropriate to engage the developers. Their work highlights how different software roles prefer different methods. They identfied that the methods assessed were valuable and easy to use, except for the WCAG walk-through.

Schulz and Fuglerud [30] introduced methods to create personas more comprehensively. They presented the potential barriers, proposed multiple techniques, and discussed the application in their studies. A notable observation made was that if personas are simply recycled or imitated, then the empathy and engagement from developers is lost. Also, personas are not complete replacements of true end users, and misconceptions are possible when personas are developed without prior real interactions. Schulz and Fuglerud provided in-depth details to some commonly known methods and conducted research on real-world use cases. They made suggestions for persona creators to be mindful when using different Assistive Technology versions, and aim at creating personas with the same learning attitudes as focus groups.

Several design approaches have been developed specifically for visually impaired and blind users, encompassing a range of sight related accessibility challenges [31,18]. Dyslexia is another accessibility challenge faced by a range of users but with limited research on solutions to date [36]. A number of recent works have looked to to help software engineers take better account of diverse end users during development. This includes use of enhanced personas capturing user differences that allow software engineers to more easily examine accessibility considerations at all stages of development without requiring the overhead of finding many varied live users [24]. It also includes work extending modelling languages documenting different end user accessibility-related and other human-centric related challenges [20]. Recent work has investigated how to support users with mild cognitive impairments [19].

Some work has investigated use of augmented reality-based interfaces to aid improved accessibility in software development. Biswas et al. [7] discussed different user modelling approaches in regard to designing inclusive interfaces for elderly and disabled people. They proposed a simulator to address the limitations of existing modelling techniques in predicting likely interaction patterns and estimating the time needed to complete an action for users with disabilities. Stearns at al. [33] design and evaluate an AR-based magnification aid for sight challenged end users to improve accessibility. Such approaches aim to fill the gaps in limited existing user modelling techniques by breaking interactions up into smaller components and combining different approaches in each component, while considering the needs of challenged people with visual or mobility impairments. In Biswas et al., roughly 30% of situations had more than 50% relative error. This raises the question of whether these case studies are sufficient to determine the validity of such simulators. Their research showed that developing models for simulators of people with disabilities is valuable. However, it needs further research and development to be sufficient on its own and replace other qualitative techniques for assessing diverse target end user experience.

10 Summary

Augmented reality browser-based plug-ins have the potential to assist software engineers in identifying accessibility challenges in web-based applications for their diverse end users. We identified a number of challenges that developers have in addressing these issues from a practitioner survey. We then evaluated a representative tool, Funkify, to see how well several of its simulators work when using banking, e-commerce and social media web applications. We identified a number of promising further research and development enhancements that may better assist software engineers in understanding and empathising with their diverse end user accessibility challenges.

Acknowledgements Grundy and Madugalla are supported by ARC Laureate Fellowship FL190100035.

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