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Engineering Support for Adaptations in Information Graphics for Disabled Communities: A Study with Public Space Indoor Maps

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Abstract Most software applications contain graphics such as charts, diagrams and maps. Currently, these graphics are designed with a “one size fits all" approach and do not cater to the needs of people with disabilities. Therefore, when using software with graphics, a colour-impaired user may struggle to interpret graphics with certain colours, and a person with dyslexia may struggle to read the text labels in the graphic. Our research addresses this issue by developing a framework that generates adaptive and accessible infor-

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mation graphics for multiple disabilities. Uniquely, the approach also serves people with multiple simultaneous disabilities. To achieve these, we used a case study of public space floorplans presented via a web tool and worked with four disability groups: people with low vision, colour blindness, dyslexia and mobility impairment. Our research involved gathering requirements from 3 accessibility experts and 80 participants with disabilities, developing a system to generate adaptive graphics that address the identified requirements, and conducting an evaluation with a total of 99 participants with disabilities. The evaluation showed that users found our solution easy to use and suitable for most of their requirements. The study also provides recommendations for front-end developers on engineering accessible graphics for their software and discusses the implications of our work on society from the perspective of public space owners and end users.

Keywords accessible graphics, adaptive graphics, SVG, public space floorplans, disabled communities

1 Introduction

Information graphics such as charts, diagrams, and maps are used in software applications to convey complex information concisely and in an easy-to-understand format [5]. For this reason, they are heavily used in software focusing on fields such as entertainment, education, health, and finance. However, these are currently designed for a “typical" user and do not address the specific needs of minority groups, such as disabled users. Therefore, these groups face difficulties in accessing the information graphics. Disabled communities can be people with sensory and speech impairments (blind, deaf), intellectual impairments (cognitive impaired, dyslexia), physical impairments (wheelchair users, motor impaired) and more.

Researchers have identified this problem and have developed some solutions to attempt to generate more accessible graphics for different disabled groups. Some of the solutions used to date include: graphics presented with audio cues and 3D graphics (for the vision impaired) [6,30]; multi-modal graphic presentation with audio and gestural information (to aid those with dyslexia) [35]; and using shapes and patterns instead of colours on graphics (for the colour vision impaired) [22]. However, most of these solutions have focused only on a single disability, provide limited tailoring of the interface for different disabled user needs and preferences, or provide bespoke solutions with limited ability to apply to diverse application domains. In contrast, we wanted to address multiple disabilities using the concept of *adaptivity*. Adaptivity has traditionally focused on device-driven characteristics like size, format, and screen resolution [39]. Recently, UI research has also started to adapt UI layout, themes, and textual content [16,27]. However, adaptivity for disabilities has limited exploration to date for graphics. We wanted to support colour, vision and dyslexia impaired users of graphics-intensive applications via user controlled adaptations of the graphics, as supported in some of these earlier studies. We also wanted to overcome limitations of some related work by using a standard graphic type, the vector, to adapt. We specifically concentrate on Scalable Vector Graphics (SVG), as this is a standard graphics format.

This research presents an approach to designing accessible graphics for multiple disabilities using adaptive SVG graphics. It involves requirements gathering, development and a preliminary evaluation with disabled users to achieve this. In this study, we specifically focused on four types of disabilities to achieve this. These are ,

1. *Low Vision*: People who have permanent vision loss that cannot be corrected with prescription glasses
2. *Colour Impairment*: People who struggle to perceive colour differences due to complete or partial loss of cone systems
3. *Dyslexia*: People who struggle with tasks associated with language processing: reading, spelling and associating speech patterns to letters
4. *Mobility Impairment*: People who experience a permanent or temporary reduction in their ability to navigate their environment

We chose these categories as they are some of the most common disabilities [11], the authors had pre-established connections with organisations that work with these individuals, and we were able to recruit a number of participants from these communities for our requirements and prototype evaluations. This allowed us to gather some representative samples focusing on these disabilities for our study.

The rest of the paper is structured as follows. In the next section, we present a motivating example of our work, followed by related work. Section 4 discusses our approach for generating accessible graphics, and sections 5 and 6 contain two steps of this approach: requirement elicitation and system design/development/implementation, respectively. Section 7 includes a preliminary evaluation, Sections 8 and 9 have threats to validity and recommendations, respectively, and the last section summarises the paper while presenting suggestions for future work.

2 Motivation

Consider the example of an indoor map from a retail centre website as shown in Figure 1 (a). Currently, this map is designed for an average user by following a “one size fits all" approach and ignores the specific characteristics and capacities of many people with disabilities. For instance, 1) someone with red-green colour blindness won’t be able to separate most colour-coded shop categories in this map (Figure 1 (b), 2) a low vision user will struggle to read the small fonts used for the store names, 3) a person with dyslexia would face difficulties in reading the used font family, 4) for a wheelchair user, the issues will be around the lack of critical information such as the location of lifts, ramps and corridor widths. In addition to the movable obstacles, permanent architectural barriers such as revolving doors, escalators and narrow lift entrances also pose significant problems to users with mobility impairments [33]. These problems limit their access to information, making it challenging to navigate these spaces independently. This is discrimination against disability and a violation of laws in many countries [11]. Due to this importance of public space maps, we decided to use the case study of indoor maps in our study.

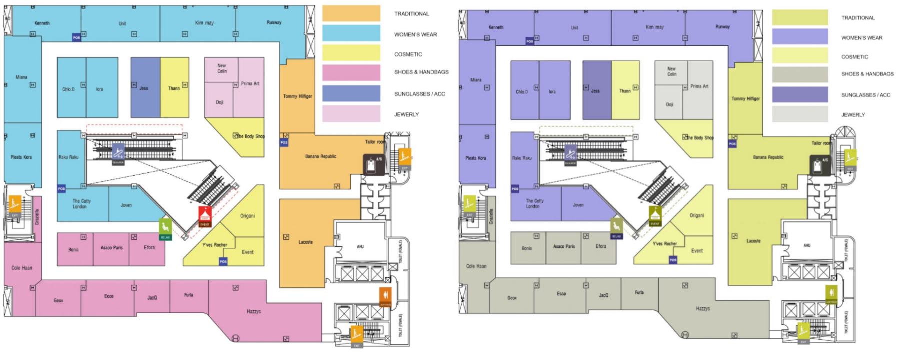


Fig. 1: A floorplan diagram (a) Original graphic (b) View of a person with Deuteranopia (Red-Green colour blindness)

2.1 Key Challenges

Researchers have sought to address this challenge by developing accessible graphics based on each disability. This has led to a collection of standalone solutions with their own device and platform constraints, making it challenging to combine these. Therefore, there is a need for a comprehensive solution that addresses multiple disabilities, ideally in a single graphic. One challenge in this approach is that it may lead to an overly complicated graphic that is cluttered and complex. A second challenge is a need for compromises when requirements between groups clash with each other, e.g. colour preferences change between different types of colour-blinded users; people with ADHD may prefer layered information with less information in each layer, but someone with memory issues such as elderly may choose less layered information. Therefore, while it is imperative to address the various needs of disabled users, this can not be achieved with a single graphic in a conventional sense. Our research seeks to address this problem by developing an approach that supports integrating complex requirements into the SVG's XML back-end and reveals only the necessary information per group adaptively. In doing this, we plan to answer the following research questions:

1. **RQ1**: What are the requirements from an inclusive information graphic?
2. **RQ2**: How to address these requirements adaptively via a single solution?

3. **RQ3**: To what extent does the disabled community accept our adaptive graphics solution?

3 Background

3.1 Graphic Accessibility

Many researchers have explored accessible graphics for users with vision issues. They have devised solutions that involve different combinations of audio cues, tactile displays, 3D models and vibration to make graphics accessible for legally blind users [6, 30, 7]. These technologies help users explore graphics with their hands, allowing them to build a mental graphic model. Colour-impaired users are also addressed under graphic accessibility, and these solutions focus on presenting a selection of colour scheme options for colour-blind users to choose from [17], and using information other than colour to present visual information, such as shapes, sizes, and patterns [22].

Accessible graphics are explored for people with dyslexia, where studies explore using multi-modal graphics presentations, such as audio, gestural information, and written language, on top of traditional visual representations [35]. Another group of users that benefit from accessible graphics are people with mobility impairment, which involves motor impairment, wheelchair users, cane users, crutch users and others whose reduced mobility presents difficulties in performing everyday physical tasks such as interacting with graphics [38]. Independent tools like head-based point trackers and eye-based interaction graphical user interfaces (GUI) have been developed to help motor-impaired users. However, these tools are yet to be explicitly implemented for graphics [21, 9]. Most of these involved developing prototypes and evaluating with end-users via surveys, interviews and focus groups. While there are all these individual solutions, there is still no solution that caters to multiple disabilities.

3.2 Map Accessibility

Maps are essential for navigating unfamiliar spaces [13]. Map-based navigation solutions have focused on various disabilities, such as vision-impaired, cognitive-impaired, and mobility-impaired [46, 36]. In these studies, based on the focused user group, the supported interaction methods changed significantly. For wheelchair users, solutions supported enabling voice commands and avoiding manual interaction to free the hands to push their wheelchairs [4]. Audio and tactile cues were used in interactions with blind users [30]. For the hearing impaired, a combination of visual and tactile feedback was provided [37].

The outdoor maps in these studies used GIS data, such as OpenStreetMap and PostGIS, to directly build accessible maps [41, 23]. Indoor maps use Bluetooth beacons and WiFi to extract user locations in buildings and map them to floorplans provided by buildings [8]. However, the accuracy of indoor map localisation requires significant improvement [46]. Due to these reasons, there is less work on indoor maps than on outdoor maps. Most of this research involved a design guideline generation stage based on existing application reviews or via direct interactions with end-users. Many recruited end-users of the target group and conducted usability evaluations to validate their concepts or applications. The predominant method employed for these assessments was user or field testing, during which end-users were tasked with using the interface to navigate indoor or outdoor settings [46]. The evaluator then assessed their performance and gathered their subjective feedback on the solution, typically through surveys or interviews conducted at the end of the study. This work needs to be extended to cater to multiple disabilities.

3.3 Adaptivity

Adaptivity is used by many researchers when different types of requirements need to be addressed in a single solution. It is used in areas such as User Interface (UI) design to adapt content based on human needs and features. There have been studies on developing adaptive UI for chronic diseases [1, 44], age [28, 15], vision impaired [20, 24] and on multiple vulnerable groups, such as colour impairment, low vision and dyslexia [27]. However, all these different forms of adaptivity focus on web elements such as textual content, layout, and colour in UI, and none has focused on making graphics adaptive.

This can be attributed mainly to the challenges in accessing and editing the currently most used graphic format: raster. Raster (PNG, JPG) uses pixel-based representation, meaning pixel-level changes must be made to implement adaptivity on any graphical elements, such as layout, colour, and fonts [30]. This requires advanced image processing mechanisms, and even after using such methods, the graphic can still be distorted due to the granular, pixel-level changes [31]. A possible solution is to explore adaptivity with vector graphics.

3.4 Scalable Vector Graphics (SVG)

SVG is a type of vector graphic that uses a set of XML-based tags to position lines, shapes and other geometric features on a plane. Compared to raster, vector such as SVG has several advantages, such as faster download speeds due to reduced size, and the ability to scale in high resolution without allowing distortions [31, 12]. In generating adaptive graphics, SVG's XML-based back-end will support direct manipulation of the graphic via its tags and allow modification of colors, and fonts via tag attributes.

Researchers focusing on vision-impaired users have started exploring SVGs to generate accessible graphics. In one solution, using SVG's XML back-end, a colour-filled graphic was converted to a simple line graphic, which was then directly printed as a tactile graphic [25]. Another embedded supplemental information within the SVG tags of a map, which was then interpreted by assistive technology devices such as screen readers [40]. However, SVG is yet to be explored to generate adaptive graphics for multiple disabilities.

4 Methodology

We adopted a double-diamond style exploratory development approach with key phases discovery, design, develop and deliver, outlined in Figure 2. We aim to iteratively create our adaptive graphics tool using this approach and the results were validated by a small-scale evaluation using a mixed method approach.

4.1 Discovery: literature Review, expert interviews and initial user survey to elicit accessibility requirements

The first *discovery* phase consisted of requirements elicitation by gathering information from a detailed literature review, interviewing three experienced accessibility experts, and conducting a survey with 80 disabled users. By obtaining requirements from both experts and disabled users, we sought to conduct a more rigorous requirement elicitation.

We wanted to understand how people with disabilities used floorplans using a survey. By asking questions about their issues and suggestions for improvements, we extracted their key requirements for a floorplan graphic that adapts to their needs. A link to the detailed survey can be found here [`https://github.com/anukmd/DoubleBlindContent/blob/main/Survey%20Plan.pdf`]. Key survey items included:

1. Demographics: Age, gender, country, disabilities, how long were they disabled, methods used for navigation support
2. Experiences in public spaces: Types of public spaces they visited and how they planned these visits
3. Floorplans: How frequently these were used, methods of accessing, issues in using and suggestions for improvements

According to Denscombe's categorisation, we chose the method of an internet survey which was launched as a web questionnaire [10]. We used the Qualtrics platform for this. For the participants from the eye hospital and the disability school in China, we translated the survey into Mandarin. A representative at these locations obtained responses from participants in a face-to-face discussion and shared these responses with us. A research team member translated the answers into English and entered them into the Qualtrics platform.

4.2 Design: thematic analysis of collected requirements

In our *design* phase we then refined these requirements by structured analysis from our collected requirements. This involved thematic analysis of our candidate requirements, selection of a representative case study – interactive map floor plans – and prioritisation of requirements.

We designed several candidate interfaces that proposed to present users with individually activated layers where each layer had highlights for accessibility information related to one specific type of disability. Our mock-up supported multiple layers to overlap in order to support users with multiple conditions. We utilised the IBM accessible colour scheme as the default palette and used graphical icons as an alternative method of conveying information.

4.3 Develop: prototype development

We then developed a prototype implementation using adaptive SVG graphics for an interactive floor plan map application, aiming to support users with a variety of accessibility and navigation challenges.

4.4 Deliver: Evaluation of prototype

Finally we *delivered* this prototype via two evaluations, including a preliminary evaluation interviewing a small number of users, and an evaluation with 92 people with disabilities.

4.5 Integration

We gathered requirements for adaptive graphics for people with disabilities from three sources: literature, three experts working in support positions for large numbers of people with disabilities, and a survey of people with disabilities. This discovery phase aimed to gather a range of requirements reported to date in the domain, detailed interviews with experts with extensive experience in the domain, and target adaptive graphics end users themselves.

We then chose to design a candidate solution to address some of these requirements for an under-researched target adaptive graphics application domain: adaptive floor plans. Public spaces encompass a large variety, including educational: libraries, public transport: train stations, entertainment: museums, and commercial: resorts. Floor plans are used to pre-plan visits to these spaces and navigate once inside the building. As these are designed for average users, most people with disabilities face challenges in accessing them, which leads to issues in navigating these spaces independently. We applied our requirements to try and improve design of these floorplans to generate more accessible versions of these graphics for a variety of people with disabilities. Following the iterative nature of the double-diamond research process, we mocked up examples of our adaptive floorplans design, got feedback from our experts, and use this to further refine requirements and design.

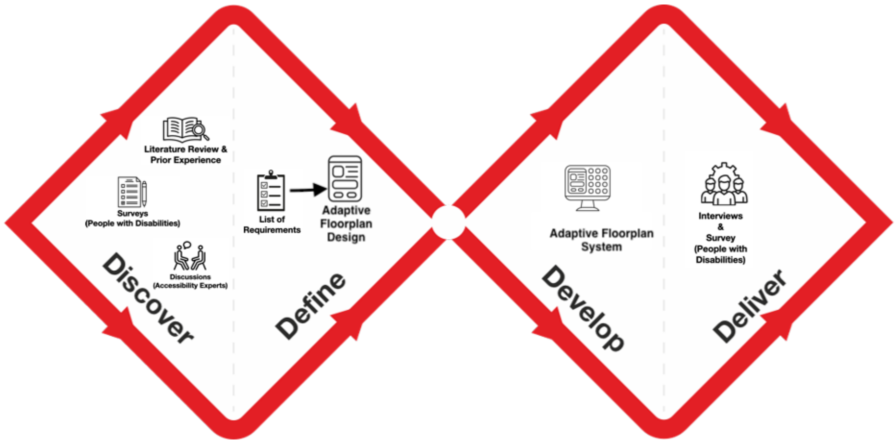


Fig. 2: Research design (adapted from the design council double diamond : www.designcouncil.org.uk)

We then used our adaptive floorplan designs to create a novel SVG-based adaptable graphics generation system. This was motivated by the desire to produce a practical application (web based), using real, high-detail property data information (provided to us as multi-layer SVG models), use the ability to server-side select elements to adapt these SVG models and HTML controls, and to easily make iterative changes to these adaptations from user profile and preference information.

Our prototype adaptive SVG-based floorplan web system was evaluated with a user study involving interviews with seven disabled users and a survey with 92 disabled participants. This provided us with feedback not only on our prototype but also on our adaptive floorplan design, and more generally, on the requirements we collected for adaptive graphics for people with disabilities.

5 Requirements Elicitation

Our requirement elicitation consisted of three steps: 1) reviewing related work, 2) interviewing representatives of key disability support groups, and 3) surveying disabled users. Sections 5.1 to 5.3 represent the "Discover" phase of the double-diamond framework, where we gathered user requirements through literature review, expert interviews, and user surveys.

5.1 Identifying Broad Requirements from Related Work

A limited amount of work has been conducted on designing graphics for the multiple disabled groups. We conducted a targeted literature search for works pertaining to information graphics for people with disabilities. We didn't limit ourselves to particular disabilities or particular applications. We used several search databases with keywords and incrementally refined these as we searched. We used forward and backwards snowballing of references to discover related research papers. This was not intended to be any sort of systematic review, but intended to inform our requirements gathering process and compliment our expert interviews and surveys. We analysed these works, several of which are overviewed in Section 2, by extracting key requirements identified in these prior works relating to people with disabilities, and from their evaluations of their reported prototypes. We thus identified the following summarised key requirements/guidelines, tagged by representative works that report them:

1. Highlight features that are deemed important for accessible design, such as ramps, tactile flooring, accessible toilets, and support desks [26]
2. Support multiple disabilities: Some may have more than one disability [27]
3. Use accessible colour schemes [19]
4. Use icons when possible instead of text [32]
5. Keep unnecessary elements to a minimum [18]
6. Group elements with a similar focus together [18]
7. Keep everything on one page and reduce/avoid scrolling [18]
8. Ensure map controls do not overlap the map: otherwise, it is challenging for visually impaired users to locate these [18]

5.2 Mock-ups and Expert Feedback

Based on the guidelines from related work, we developed a number of adaptive floorplan mock-ups, a few of which are shown in Figure 3.

To obtain feedback on our initial mock-ups, we conducted semi-structured interviews with three executives from disability support groups. These were the manager of Monash University disability support services, an executive officer from AUSPELD, and an executive of Ability First Australia. The interviews involved presenting the mock-ups to the participants and asking for general feedback on our planned colour schemes, floorplan elements, and text labels. When we showed mockups of our proposed adaptive floormap design, we asked them to imagine users with different disabilities trying our different key navigation tasks. We obtained expert feedback of UI approaches and elements they thought could be useful, ideas for improvement, and took on board queries about issues for certain disability groups for refinement of our requirements and design.

For example, when interviewing one of the experts they highlighted key obstacles for several disabled student groups as things that maps should highlight: Glass Panels, Path Highlighting, Staircases, Signage, Obstacles, Handrails,

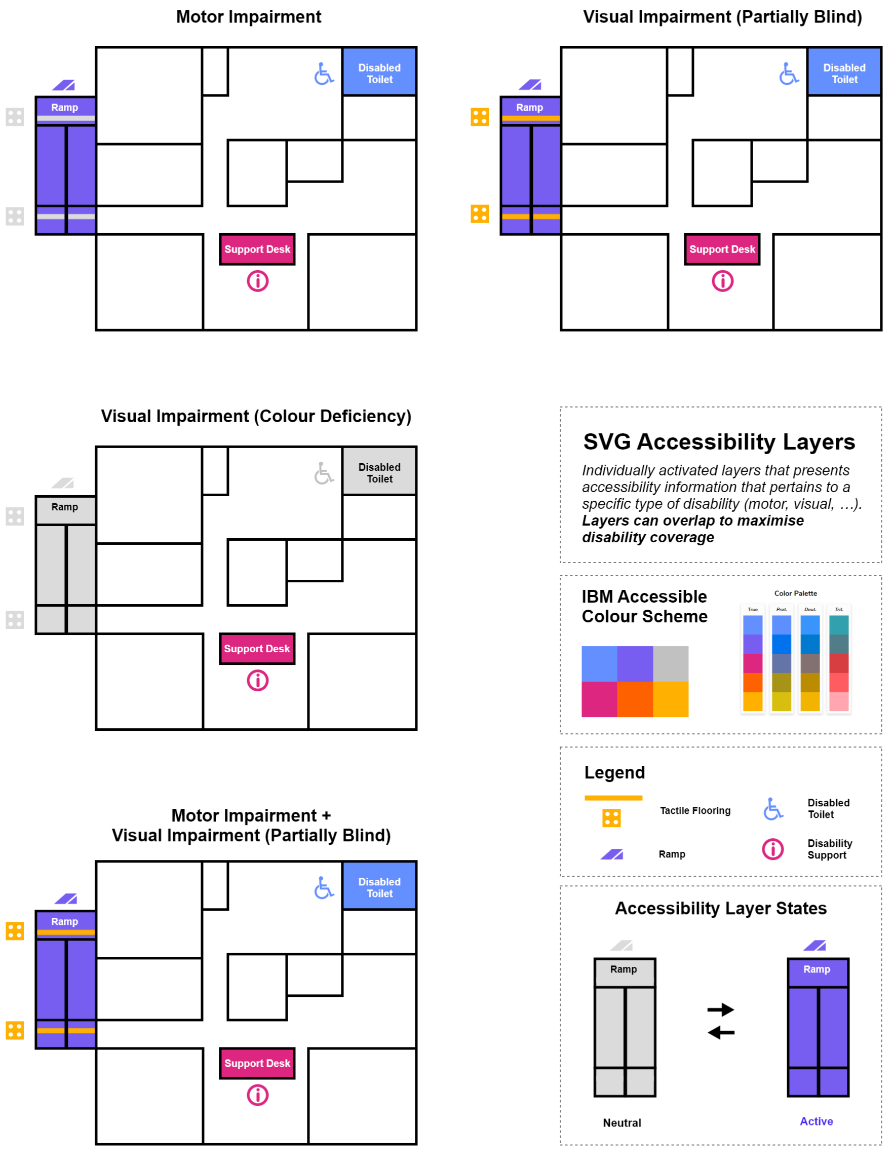


Fig. 3: Mock-ups of Adaptive Floorplans

Tactile Flooring, Accessible Toilets, Disabled Parking Spots, Main Entrance, Lifts, and Easy To Open Doors (Automatic Sliding Doors). They also highlighted that several impediments for particular groups are critical to highlight and why. For example, things to be avoided for visually impaired – Rotating Doors (Hard to calculate depth); impediments that cause inconvenience to Motor-Impaired Users (Heavy Doors); things a map should highlight for Hearing Impaired (Hearing Loops); and supports for Dyslexic Users (Icons Are A Great Alternative To Displaying Text).

Expert feedback was assessed through semi-structured interviews, during which verbal feedback was noted and thematically analyzed to identify design choices and suggestions for improvement. Their feedback indicated that these experts generally approved of our layer-based design and highlights based on disability. They did not perceive an issue in the colour schemes or icons used. However, they had a number of key suggestions on how these can be further improved, and these are listed as additional requirements below:

1. Adding more information about accessibility impediments, such as heavy doors and staircases, as these are essential for mobility and sight-challenged users
2. Using an inclusive language: “accessible" rather than “disabled", when describing toilets
3. Use simplified language in all user interactions

Using the understanding gained from related work and these discussions, we designed and conducted a detailed survey of disabled users, as presented in the next section.

5.3 User Survey

5.3.1 Survey Recruitment

We recruited participants using the probability cluster sampling technique [10]. This is a common technique where we choose several recruitment locales with likely candidates, advertising our study, and aiming to gather a representative diverse group of participants across the groups [2]. Ethics approval for this study was obtained from the Monash University Human Research Ethics Committee. We advertised our study on three main channels. One was via social media platforms, including social media groups of people with disabilities. The second channel was via organisations, namely AUSPELD (the Australian Federation of Specific Educational Learning Difficulties Associations), University disability support units, an eye hospital in China and a disability school in China. The third channel was advertising on Prolific, an online platform that helps researchers recruit participants from a pool of pre-registered participants. These multiple venues helped us obtain 80 responses, which is considered a significantly large data set when working with disabled users [34,30]. Out of these 80 responses, we collected 10 from the first [social media platforms], 40 from the second channel [organisations] and 30 from the third channel of Prolific.

5.3.2 Survey Data Analysis

We analysed our data using a mixed-method approach. We had 6 close-ended questions, mainly focusing on demographics and 11 open-ended questions focusing on experiences with public spaces and floor plans. We used descriptive statistics from the quantitative field for close-ended questions. For the open-ended questions, we used thematic analysis. We first used open coding to assign codes for each response, then categorised these codes and, lastly, grouped them by themes. The results of these analyses are described below.

Demographics The demographic distribution of our participants is shown in Table 1. Under disabilities, we have 1) Single disability: participants with one of our four chosen disabilities, and 2) Multiple disabilities: participants with more than one of these disabilities and possibly other disabilities. As shown in Table 1, there were 34/80 participants with multiple disabilities. If a person had colour impairment along with another disability/ies, we did not count them in the colour vision category; instead, we included them in this category.

Table 1: Demographics of Participants

Gender		**Disability**		**Countries**	
Male	37	Low vision issues	16	China	29
Female	42	Dyslexia	12	USA	12
Others	1	Mobility Impaired	14	UK	12
Age		Color Impaired	4	Sth Korea	9
<30	44	Multi. Disabilities	34	Australia	8
31-50	27	**Mobility**	**Aids**	Poland	3
51+	9	Canes	12	Sth Africa	2
Duration		Scooters	7	Others	5
<2 Yrs.	5	Wheelchairs	5		
3-10 Yrs.	22	Guides	4		
11-20 Yrs.	20	Combined	14		
21+ Yrs.	32				

Public spaces: We found that our participants visited a range of public spaces, including shopping centres, supermarkets, parks, hospitals, etc. Out of these, shopping centres and supermarkets were the most visited. The distribution of visits between these places for 80 participants is shown in Table 2.

34% of our participants pre-planned their visits to these spaces, while 65% did not, as they only visited familiar public spaces or had an accompanying friend/relative when visiting new places. Those who pre-planned searched for floorplans and other information using 1) online technology [websites, mobile apps, search engines and public reviews] and 2) human assistance [friends and relatives]. They used pre-planning to find “shortest routes" and “wheelchair

Table 2: Participants' Visits to Public Spaces

Type of Space	Often	Periodically	Rarely
Shopping Centres	10	27	2
Supermarkets	24	3	2
Parks	7	4	1
Hospitals	5	3	2
Libraries	3	4	1
Museums	1	3	4

access, lifts, exits and disabled access toilets". They considered pre-planning helpful to "avoid and anticipate any challenges" and "because visits [to unknown places] make me anxious".

Usage of maps: We asked our participants if they used floorplans or maps during their visits to these complex public spaces. There was a close split between Yes and No responses, with a few stating they used floorplans very often. The reasons for using these were identified as a travel aid to navigate new places and to locate emergency exits. All our participants with colour blindness, low vision, or mobility impaired (wheelchair users) said they used floorplans often. For dyslexia, it was a split between yes and no.

Methods of accessing maps: Most participants found floorplans onsite at building entrances, elevators, handouts and information desks. Some found them online from websites, via apps created for these spaces, and one mentioned emailing the organisations. Some used a combination of onsite and online methods, and a few did not use floorplans as they were hard to find.

Required information: Most of our participants required information about the layout of the public spaces from the floorplans where they searched for locations of shops and toilets. Additionally, they searched for facilities such as elevators, ramps, entrances and exits, accessible parking areas, accessible seating, information desks, water filling stations, location and count of stairs, and terrain information. Many also searched for navigation information such as shortest paths, accessible paths or a general path to a destination.

Issues in current maps: Most of our participants faced several problems in using the floorplans while some did not have any issues. Some identified 1) Technological issues such as bugs, not being updated, missing functionalities and general unavailability. But most reported 2) Design issues such as *Font issues:* small fonts, hard to follow font styles; *Colour issues:* non-colour blind friendly colour usages, confusing use of colours and personal dislike to adopted colour schemes; *Information overload:* - overwhelming design, "if there are massive legends ... or if there are a lot of semi-randomly coloured lines I kinda just skip over them in my head". Few also reported they found maps hard to understand as graphics are blurred for them, didn't understand graphics in general, and 1 participant mentioned, "I'm too old to understand the map".

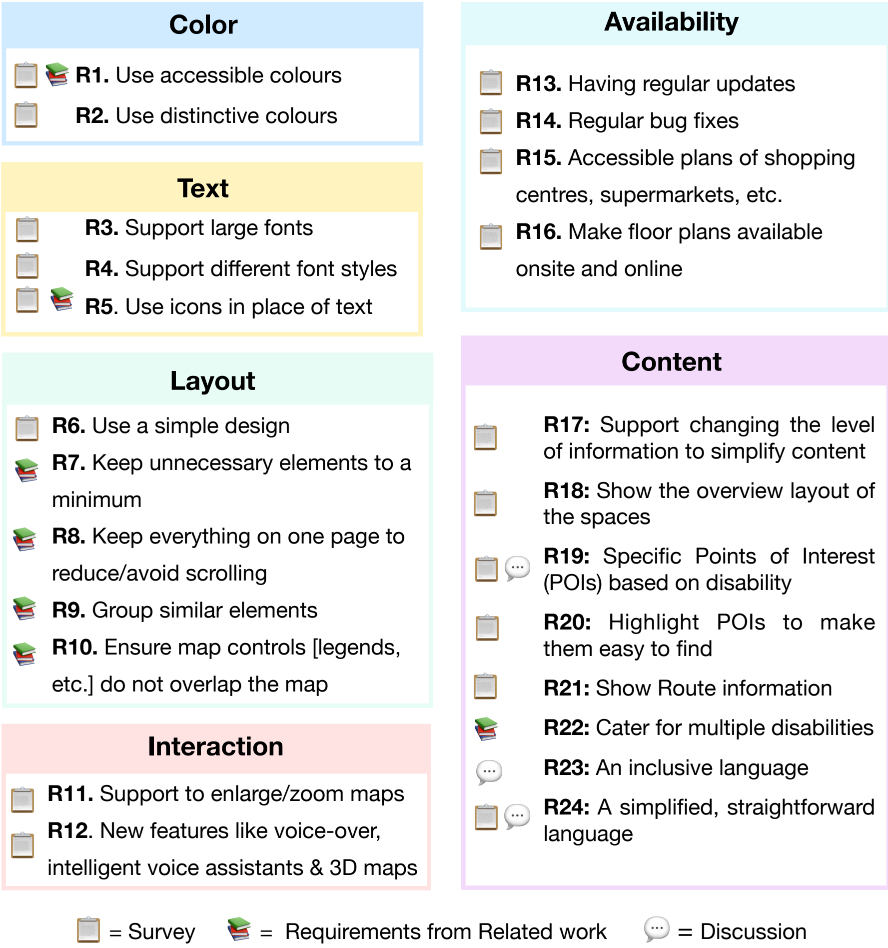


Fig. 4: Visualisation of Identified Requirements

Suggestions for improvements: Key suggestions included three categories. Category 1 was design changes: *colour changes* to use more accessible colours, clearly distinctive colours; *font changes* to use larger fonts and different font styles, and *enlarging* maps to fit user needs. Category 2 was Content changes: such as changing the level of information to simplify content to make it easier to read, replacing text with icons and using more straightforward vocabulary as well as adding more accessibility information and highlighting them, e.g. ramps, accessible toilets, emergency exits, size of doors etc. Category 3 was Technological changes: such as having regular updates and bug fixes Several of our participants with low vision and some participants with dyslexia suggested adding new features such as voice-over, intelligent voice assistants and 3D maps.

5.4 Identified Requirements

The requirements we identified from our three-step process are shown in Figure 4. These were categorised into four categories: Color, Text, Layout, Interaction, Availability and Content. As shown in the figure, each of these requirements are numbered as R1...Rn. We will use these numbers as **[Rx]** to refer to specific requirements when we explain our design decisions. In this section, we transition our research into the "Define" phase, where we analyzed, categorized, and prioritized the requirements to prepare for design.

6 Prototype development

Section 6 aligns with the "Develop" phase of the double-diamond framework, which focuses on translating the defined requirements into a working prototype. We created a workflow, as shown in Figure 5, to generate accessible and adaptive graphics and implemented it with an SVG map of a large retail centre from a university **[R15]**.

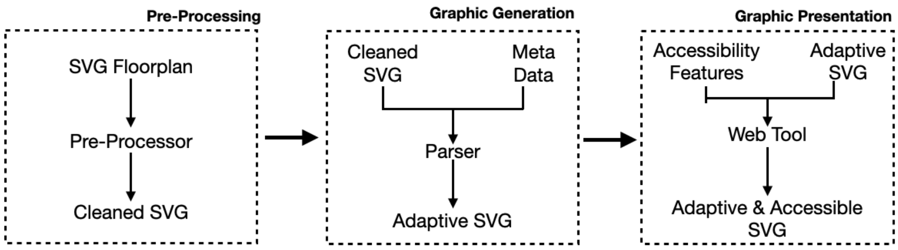


Fig. 5: Adaptive Graphic Generation Framework

We chose SVG as our graphic presentation method due to its XML based backend support, which allows direct manipulation of the graphic without causing any distortions on the visual aspect. Using XML tags we supported adaptivity of fonts, colors and patterns to match the requirements of different disabled communities. Using SVG layers and bit fields we presented building information adaptively based on disabilities e.g switch on layer for mobility impaired to highlight accessible entries.

The design of our adaptive SVG maps considered Web Content Accessibility Guidelines (WCAG) 2.1, specifically ensuring compliance with Criteria 1.4.1 (Use of Color), and 1.4.3 (Contrast Minimum) [43]. However, formal WCAG conformance testing, including evaluation with magnification software and color contrast analysis tools, remains an important direction for future validation.

6.1 Pre-processing

SVG files have an XML-based back-end, which allows direct manipulation of the graphic without causing any distortions on the visual aspect. However, SVG can be created by different tools, e.g. Inkscape, and CAD. Based on the used tool and the creator's design decisions, the XML can be simple or quite complicated [29]. Therefore, this step focuses on cleaning the SVG to remove unnecessary data layers to generate a cleaned SVG as shown in Figure 5.

6.2 Graphic Generation Stage

This step accepts the cleaned SVG and any metadata associated with that file as input. For example, in generating an accessible university map, we received SVGs of building plans for the retail centre and metadata about rooms in them from the Monash Building and Planning department. These metadata included room names, categories, and departments/faculties to which the rooms belong. In this study, the metadata was not incorporated into the original SVG as it would make the SVG's XML too complicated. We only integrated the room names/numbers into the SVG. We coded our parser in the Python programming language, and it performed two main tasks. Task 1 was combining the SVG with metadata (currently in CSV format) and generating a more detailed SVG. Task 2 was adding pre-defined adaptive features to the new SVG. The output of the Parser was an adaptive SVG. The pre-defined adaptive features that we added to the SVGs are listed below.

1. HTML elements that support accessibility: HTML usually acts as the container for SVG, with other web technologies such as JavaScript and CSS providing additional support for SVG presentation. Most HTML and SVG elements support accessibility features such as tooltips and screen readers. However, this is not true for all HTML and SVG elements [14]. Therefore, we conducted a preliminary evaluation across web browsers and screen readers to find the elements that work best and included these in our accessible SVG structure, e.g. *<aria-describedby>* chosen over *<desc>* tag, as it was compatible with all screen readers **[R12]**. More details about our preliminary evaluation of screen reader compatibility can be found in Appendix A.
2. HTML Focus Feature: HTML focus refers to which item on the screen (a button, menu, text) currently receives input from the keyboard. The screen readers and tooltips will present the information in 'HTML Focus' when interacting with HTML pages. We used this feature to help screen readers access Accessibility layer-based information via the keyboard **[R12-support for screenreaders]**.
3. Colours: We used IBM Design's colour blind safe palette [19] as the basis for our solution and generated a half-fill colour mechanism to increase the number of colour options as shown in Figure 6 **[R1,R2]** We also supported

allowing users to change these colours at run time to suit their personal preferences.

4. Patterns: According to WCAG 2.0, Guideline 111, when colour differences are used to convey information, patterns should optionally be available to depict the same information [42]. Therefore, in our adaptive graphic structure, we added support for patterns as shown in Figure 6.

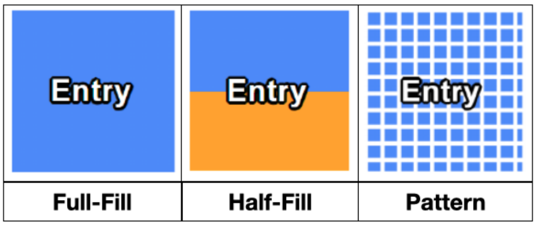


Fig. 6: Full-fill and half-fill colours and Pattern fill

5. SVG Layers and Bit Fields : We use SVG layers to provide adaptive information based on disabilities. Our Accessibility Layers represent each disability, and switching them on or off helps to present building information based on disabilities, e.g. for the mobility impaired, the stairs are hidden, and elevators are highlighted. To support users with multiple disabilities, our layered architecture allows these layers to be overlapped intelligently. We used the Bit field data structure, which is popular in the C Programming language, to switch on and off these layers **[R17,19,20,22]**.

```
<g id="toilet-001" class="toilet" tabindex="1"
   data-layer-type="layer" data-layer-state="1"
   data-layer-bit-field="8" role="img"
   aria-labelledby="toilet-001--title"
   aria-describedby="toilet-001--desc">
            <title id="toilet-001--title">Toilet</title>
            <desc id="toilet-001--desc">Disabled Toilet</desc>
            <path data-layer-type="bg" d="M412 431H0V622H412V431Z"/>
            <text data-layer-type="txt" xml:space="preserve">
                <tspan x="159" y="538.98">Toilet</tspan>
            </text>
</g>
```

Fig. 7: XML structure for an Adaptive SVG for a Toilet in a Floorplan

After integrating these features into SVG, we could generate an adaptive SVG. In Figure 7, we have given an extraction of this adaptive SVG, and it presents the use of “data-layer-bit-field" for disability-based layers, ’data-layer-state' to show activated/de-activated layers, “tab-index" for focus and <title>, <desc> for element details.

6.3 Graphic Presentation

This step involved developing the web tool, which accepted the adaptive SVG created in the Graphic Generation stage.

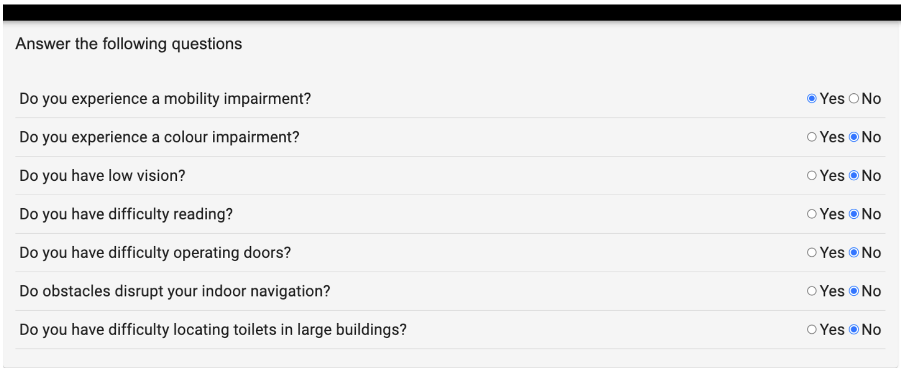
6.3.1 Design and Structure:

To address requirements, we designed our tool with three main pages, as shown in Figures 8 and 9. Page 1 was the main screen with the map (Figure 8), page 2 was the “User profile" page (Figure 9a), and page 3 was for the keyboard shortcuts (Figure 9b). We designed the UI of page 1 in a grid layout, with the different panels grouping similar key features **[R9]**, and we took steps to use a simple and inclusive language [**R23, 24**]. A user profile can be created by clicking 'Open User Profile' and moving to page 2. The shortcuts can be found by clicking the “Open Keyboard Shortcuts' and opening page 3.

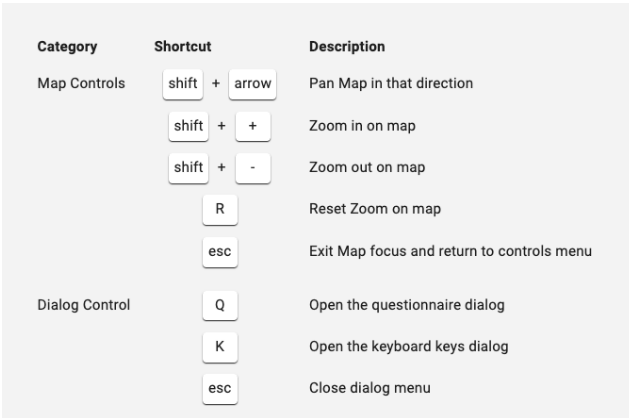
We implemented this tool using the React framework **[R16]**. It was based on a use case of the Monash University building map provided by the Monash University Building and Planning Department. In the tool, to explore the adaptive features, a user must create a profile with disability information as shown in Figure 9a. This will enable/disable certain SVG layers, and it will lead to a version of the floorplan that is adapted to fit the specified disability **[R17, 22]**). The UI of this web tool contained five simple components, and these are listed below and are shown in Figure 8 **[R6, 7, 8, 10]**.

1. SVG Panel: Assigned the largest block on the UI and shows the graphical view of the SVG. Users can interact with this graphic by clicking on elements and using the control panel below **[R18]**.
2. SVG control Panel: Contains features to control the floor plan, like the panning and zooming buttons or the ability to load in a new SVG **[R11]**.
3. Information Panel: Whenever a graphical element is selected with either the keyboard or the mouse, the element's title, description, and any associated icons describing the element are displayed **[R5]**.
4. Menu Panel: Contains the buttons to open the dialogue menus, define user disabilities, and explore keyboard shortcuts. We added these under separate screens to follow guideline 3 of [18] and reduce scrolling.
5. Legend Panel: The legend contains different element types and their assigned colour details. Any changes made to the colour options below are reflected in the legend as well.
6. Options Panel: Groups different options to tweak the colour, font, or apply patterns to the floor plan **[R1,2,3,4]**.

Fig. 8: Main UI of the web tool
Available at: `https://accessible-svg.github.io/floorplan-viewer/`



(a) User Profile Menu



(b) Keyboard Shortcuts

Fig. 9: Pages from the Web tool

6.3.2 Using the Web Tool:

To ensure all UI components were accessible via non-visual access methods, such as the keyboard and screen readers, we integrated the following functions. used an aria-specific react library for elements like drop-down menus, radio buttons, tables, and switch buttons. To make the legend panel accessible for screen readers, we added tab indexes. Similarly, the control buttons were embedded with additional aria-label tags to describe their function, as they are icon-based buttons. The information panel displayed the information related to any element selected via keyboard or mouse.

1. ARIA Tag supported React library: Ensures that keyboard-based navigation is supported for UI elements like drop-down menus, radio buttons, tables, and switch buttons

2. Tab indexes: This HTML attribute specifies the tab order when using the "tab" button for UI navigation. We added this to the legend panel to make the panel accessible for keyboard-based screen reader navigation
3. ARIA-label tags for icon-based buttons: The SVG control panel of the UI, as shown in Figure 8, had icon-based control buttons to move the SVG around. Hence, to support accessibility, we embedded aria-label tags to describe the function of these buttons
4. Keyboard navigation: The information panel on the top right of the UI, as shown in Figure 8, displayed the information related to floorplan elements/rooms when these elements are selected by mouse or via keyboard navigation

In using this tool, a user will first answer the user profile questionnaire, which will lead to activating necessary SVG layers and adapting the map accordingly. A user with multiple disabilities can answer "Yes" to more than one question, and this will lead to activating multiple layers as needed.

7 Evaluation

This section represents the "Deliver" phase of the double-diamond approach, we validated the adaptive SVG prototype through a small-scale evaluation. After the framework was completed, we evaluated the adaptive SVG and the web tool, as these were the components of our framework that involved direct interactions with disabled users. For this, we conducted semi-structured interviews with seven disabled users and an online survey with 92 disabled participants to get feedback from potential users. All interview and survey procedures were conducted under approved ethics protocols from Monash University Human Research Ethics Committee.

7.1 Interviews

7.1.1 Design and Recruitment

In this evaluation, we requested our participants to explore and evaluate our adaptive SVG-based floorplans via our web tool. This involved first playing an introductory video of the web tool and answering any clarification questions participants may have to give them an idea of how to interact with it. All participants found the video helpful in understanding the tool's functionality. Then, we provided a task list, as shown in Table 3, and asked the participants to perform these tasks by interacting with our prototype tool. We then interviewed participants and each interview took approximately 45 minutes.

We advertised our study via social media platforms, the university disability support centre, and personal contacts. We received seven responses and conducted Zoom-based online interviews with them.

Table 3: Tasks to interact with web tool

Task 1: Open “User profile", and select options that suit the participant
Task 2: Open the user profile and answer "yes" to “Do you experience a mobility impairment?”. You’ll see that accessible entries are represented with blue, as seen on the legend and the map. Change the colour of the accessible entries to black.
Task 3: Change the font of the text labels to OpenDyslexic using tool functions
Task 4: Can you download the SVG at this link. Now, can you switch the floor plan to the new SVG?
Task 5: Return to the original floorplan by clicking refresh. Turn on the “pattern mode" in the web tool and identify three elevators
Task 6: Starting at the Support Center (labelled by G163), can you identify a route to the nearest Accessible Toilet?

7.1.2 Data Analysis

We audio-recorded each interview and transcribed these later using Zoom’s transcription feature. We used a mixed-method approach to analyse the data. We had four demographic questions, six tasks, feedback on these tasks and questions on general feedback for UI. We conducted descriptive statistical analysis on demographic questions and task completion. The feedback on tasks and general UI were analysed using thematic analysis.

Demographics: The results of the demographics analysis are shown in Table 4. We had seven participants and at least one representative from our target participant groups.

Table 4: Demographics of Interview Participants

Gender		**Age**		**Disability**		**Duration**	
Male	2	<30	4	Low vision	3	<5 yrs.	1
Female	5	30+	3	Wheelchair	1	5-10 yrs.	1
				Colour Impaired	1	11-20 yrs.	2
				Motor Impaired	2	21+ yrs.	3

Task Completion: The participants were given six tasks, as shown in Table 3, and most of our participants completed these six tasks successfully. The ease of completion of each task is shown in Figure 10 below, with different colours indicating participant disabilities.

In **task 1**, our participants mentioned that the user profile function was easy to find, and the impairment-related selections were easily accessible. However, a participant with low vision suggested making the user profile button

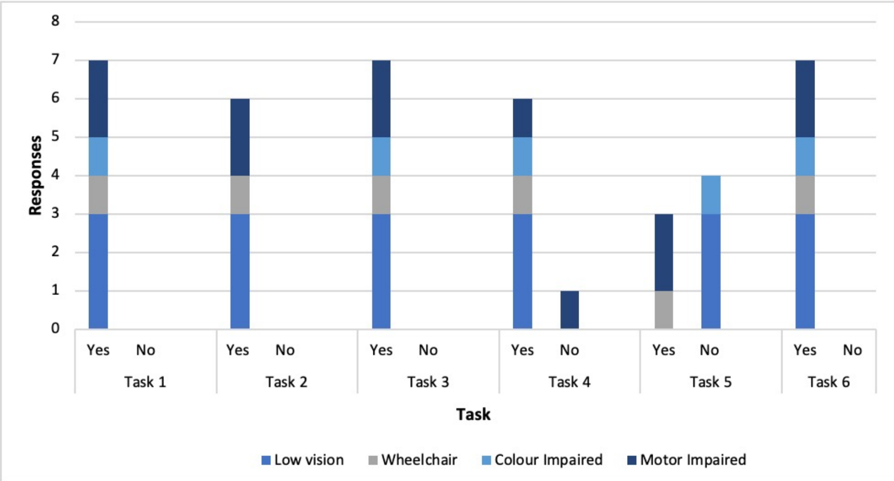


Fig. 10: Ease of task completion for interview participants

more significant and evident. For **task 2**, six participants completed the task quickly, and one participant could not complete the task. Those who completed the task easily mentioned that they had no problem changing colours for different legends. However, the participant who failed to complete the task was colour-impaired; he stated that he "could not identify similar colours (blue/purple) when they are used to represent different elements". For **task 3**, all participants completed the task easily; they stated that the font button was easy to find, and all fonts were recognisable and reader-friendly. For **task 4**, six participants completed the task easily, and one participant found it moderately difficult to complete the task. Those who completed it easily stated that the procedures of the whole task were straightforward, while the motor-impaired participant who found this task difficult felt that there were too many steps and that the process was tiring. For **task 5**, three participants completed the task easily, and four participants found it moderately difficult to complete the task. However, those who completed it easily stated that the locations were easy and obvious to find. Alternatively, the reasons for the moderate difficulty were: 1) the colours representing certain locations were overlapping, 2) the "pattern mode" of the web tool was difficult to use, and 3) Certain locations were too small on the web tool, making them confusing to find. The participants who struggled with this task were three vision-impaired participants and one colour-impaired participant, suggesting that the patterns were hard to use when you had a vision issue. For **task 6**, all participants completed the task easily; they identified multiple routes on the floor plan and chose the shortest route or the first route seen. Apart from the one participant who could not complete task 2, all participants completed the other tasks with ease or moderate difficulty.

Feedback on UI and SVG: We asked our participants about their thoughts on the web tool UI, and all participants said that the UI was "easy to use", "easy to follow", and "tidy and skilful". We also asked them if the web tool provided help to them, and all seven of our participants said yes. The reasons for yes were that 1) the web tool helped them find different locations, 2) the legends with different colours were helpful, and 3) the tool was convenient and easy to use. All our participants with mobility issues liked the tool's features, highlighting accessible toilets and entries using different colours. They mentioned that they would always use the floor plans to look for lifts and accessible toilets when they go out, and this web tool made it easier to find these: "The legends were very helpful with places like lifts, toilets, and stairs, the colours made it easier to distinguish different areas". We can conclude that our participants were generally satisfied with the web tool.

Suggestions for improvements: Regarding suggestions for improvement, some of our colour-blind participants suggested using a brighter colour palette like blue or orange. They recommended refraining from using similar colours like blue and purple as it makes separating elements with similar colours difficult. Six of our participants felt the pattern mode of the web tool was difficult to use and "hard to play with". They thought it made the text labels hard to read at times. One participant suggested making the User Profile button more apparent, and one suggested adding hover text for icon buttons in the SVG control panel. To help with navigation, they suggested displaying the shortest routes with bright colours and highlighting accessible routes with ramps and accessible parking areas.

7.2 Survey

7.2.1 Survey Design

The survey involved participants using the tool and performing the same 6 tasks as in the interviews and providing feedback on the tool. A link to the detailed survey can be found here [`https://github.com/anukmd/StudyMaterial_FP/blob/main/Evaluation_Survey%20Questions.pdf`]. A summary of these questions includes,

1. Demographics: Age, gender, country, disabilities, how long were they disabled, methods used for navigation support
2. Task Completion and Feedback: Perform 6 tasks using the web tool and provide feedback on each
3. System Usability Scale (SUS) Study: Participants completed this after using the tool

7.2.2 Recruitment and Data Collection

We recruited participants using similar approaches as for the requirement gathering survey with a probability cluster sampling technique [10, 2]. We advertised our study on Prolific, an online platform that helps researchers recruit participants from a pool of pre-registered participants. This helped us gather 92 valid responses from the disabled community.

According to Denscombe's categorisation, we chose the method of an internet survey, which was launched as a web questionnaire [10]. We used the Qualtrics platform for this.

7.2.3 Data Analysis

We analysed our data using a mixed-method approach. We had 5 close-ended questions focusing on demographics, 6 tasks with a Likert scale to rank the ease of completion for each task, and 10 SUS scoring questions. We used descriptive statistics from the quantitative field for these close-ended questions. The 6 tasks also contained 6 open-ended questions to understand participants' experience in completing those tasks and a final open-ended question on the potential use of this tool to navigate complex public spaces. For these open-ended questions, we used thematic analysis. We first used open coding to assign codes for each response, then categorised these codes and grouped them by themes. The results of these analyses are described below.

Demographics: The demographic distribution of our participants is shown in Table 5. Similar to the requirement gathering survey, under disabilities, there are two categories: 1) Single disability and Multiple disabilities. As shown in Table 5, there were 34/80 participants with multiple disabilities. If a person had colour impairment along with another disability/ies, we did not count them in the colour vision category; instead, we included them in the multiple disabilities category.

Task Completion: Similar to the interview, during the survey, the participants were given six tasks, as shown in Table 3, and all our 92 participants completed these six tasks successfully. After completing each task, we asked the participants to rank the ease of completion on a Likert scale ranging from "Extremely Easy" to "Extremely Difficult". The results of this ranking are shown in Figure 11.

In Task 1, participants were asked to define a 'User Profile' based on their impairments and the challenges they may encounter while navigating public spaces. As per Figure 11, 75% reported the task to be easy, 11% were neutral and 14% found it difficult. The number of participants who responded 'Yes' to each listed option is presented in Table 6. The results indicated that although some users initially identified with a single disability (e.g., low vision) in demographic questions, they later reported additional challenges when defining their user profile. For example, they answered 'yes' to questions such as 'Do you have difficulty reading?' or 'Do you experience a mobility impairment?'. This suggests that while individuals may self-identify with one primary impairment, they may also have other underlying conditions that affect their ability to use web tools or navigate public spaces.

Task 2 required participants to highlight 'Accessible Entries' by selecting 'Yes' to the question 'Do you experience a mobility impairment?' and then

Table 5: Demographics of Participants

Gender		**Disability**		**Countries**	
Male	51	Low vision issues	19	South Africa	33
Female	38	Dyslexia	13	Poland	13
Others	3	Mobility Impaired	10	Mexico	6
Age		Colour Impaired	16	Portugal	5
<30	54	Multi. Disabilities	34	France	5
31-50	34	**Mobility Aids**		Canada	5
51+	4	Crutches	7	Italy	4
Duration		Wheelchairs	4	Greece	3
<2 Yrs.	9	Mobility Scooters	3	Finland	2
3-10 Yrs.	33	Walking sticks	3	Kenya	2
11-20 Yrs.	17	Walkers	2	Hungary	2
21+ Yrs.	33	Combined	5	Others	12

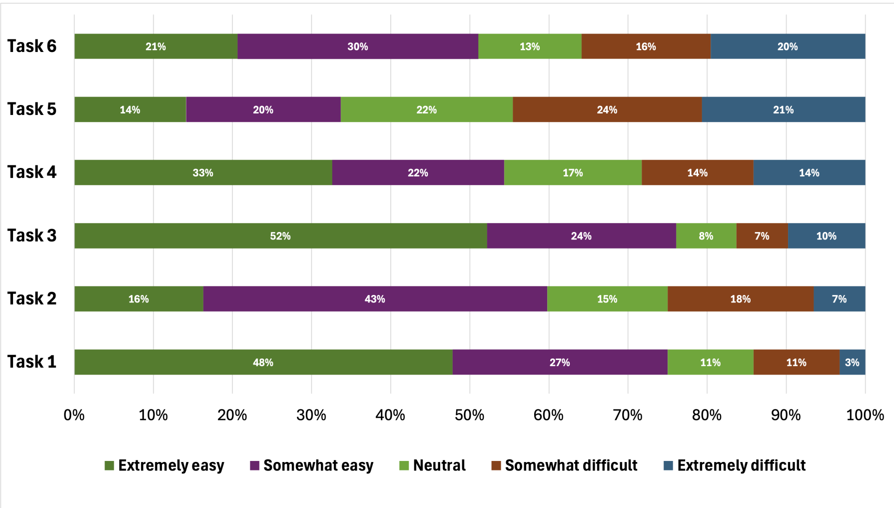


Fig. 11: Ease of tasks for survey participants

changing the colour of these entries from blue to black. All participants completed the task, with 59% reporting the task to be easy, 15% being neutral, and 25% finding it difficult (Figure 11). When asked to explain the challenges, participants cited UI-related issues, such as separating the map and colour legends, overlooking the scrollable map legend, and low-vision users having difficulty distinguishing between black and blue.

Table 6: Preferences in User Profile

User Profile Option	Yes
Do you experience a mobility impairment?	31
Do you experience a colour impairment?	45
Do you have low vision?	47
Do you have difficulty reading?	35
Do you have difficulty operating doors?	16
Do obstacles disrupt your indoor navigation?	20
Do you have difficulty locating toilets in large buildings?	34

Task 3 required participants to change the font of all text labels on the map. According to Figure 11, 76% of participants found the task easy, 8% were neutral, and 17% found it difficult. Participants who found the task easy appreciated the simple UI, with the font change option being easy to locate and a straightforward drop-down menu offering only a few choices. Those who encountered difficulties suggested using simpler terms, such as 'Text Label Type' instead of 'Font Family,' removing the scrolling feature in the right pane, and making the font change option more prominent in the UI.

In Task 4, participants were given a more advanced challenge, which involved changing the floorplan. They were given a link to download a new map and instructed to replace the current map with the newly downloaded version. According to the results, 55% of participants found the task easy, 17% were neutral, and 28% found it challenging. The difficulties were primarily attributed to the technological skills required to download and upload the map, particularly the task of locating the map in the file system. A few participants also struggled to find the map upload button in the UI.

Task 5 involved testing the 'Pattern Mode.' Participants were instructed to restore the original floor plan by clicking 'refresh' in the browser, then activating 'Pattern Mode' and locating three elevators on the map. 34% of participants found the task easy, 22% were neutral, and 45% found it difficult, making this the most challenging task among the six. Many participants found the patterns distracting and suggested that the patterns should be more distinct. Some also reported difficulty reading the text labels once the patterns were enabled. Additionally, several participants were confused by the legend, which mapped only to the pattern color rather than the pattern style. Lastly, some participants noted that the elevators appeared too small on the map, making them difficult to locate.

The final task was a path-finding exercise where participants were asked to navigate from the Support Centre to the nearest accessible toilet. All participants successfully completed the task. Among them, 51% found the task easy, 13% were neutral, and 36% considered it difficult (see Figure 11). In their feedback, participants noted that features such as colour coding, text labels, and zoom functionality contributed to the ease of completing the task. Several participants suggested improvements, including the option for a larger map to reduce the need for zooming and the addition of a search function to help users quickly locate points of interest such as their starting point and destination, instead of manually searching the map.

System Usability Scale (SUS) Study: The System Usability Scale, developed by John Brooke in 1986, was designed as a quick and efficient method for evaluating the usability of virtually any type of system [3]. The scale consists of 10 standardised statements or questions, where participants rate their level of agreement on a 5-point Likert scale, with 5 indicating complete agreement and 1 indicating complete disagreement. The full list of statements is provided as the final question in our survey, which can be accessed here [`https://github.com/anukmd/StudyMaterial_FP/blob/main/Evaluation_Survey%20Questions.pdf`]. After each participant has ranked all 10 statements, a total SUS score is calculated per participant. A histogram of SUS scores of the participants are shown in Figure 12.

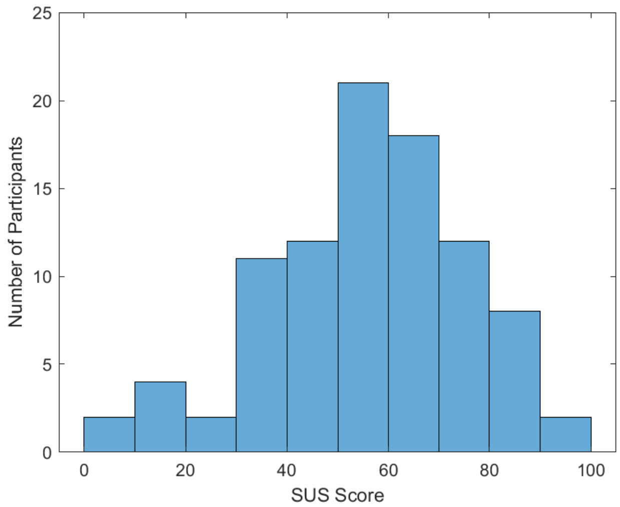


Fig. 12: Histogram of System Usability Scale (SUS) scores for participants

The participants reported an average System Usability Scale (SUS) score of 55%, suggesting that the tool was perceived as user-friendly while leaving room for improvement. A detailed analysis of the average SUS scores for different types of disabilities, as presented in Table 7, revealed that participants with low vision, color impairments, mobility impairments, and combined disabilities provided scores exceeding 50. However, the cohort with dyslexia recorded a low average score of 42, indicating the need for additional features tailored specifically to this group. It shows that enhancements beyond the existing dyslexia-friendly font adaptivity could improve usability for these users.

It is important to emphasise that the primary focus of this study was the development of adaptive graphics, with the web-based user interface serving merely as a presentation medium. As the SUS evaluation primarily measures interface usability, the relatively lower SUS scores for the web tool are considered acceptable within the scope of this research. Nevertheless, for future studies in similar domains, we recommend placing greater emphasis on the design and functionality of the presentation medium, as it significantly influences users' perceptions of the content.

Table 7: SUS Score by Type of Disability

Type of Disability	Count	Average SUS Score
Low Vision	19	61
Colour Impairments	16	58
Mobility Impairments	10	57
Dyslexia	13	42
Combined	34	54

Overall Feedback: Lastly, we asked our 92 participants for their overall feedback on the tool, and their responses were categorised into three themes: Feedback on the tool, Feedback on usage, and Suggestions for improvements.

Feedback on the tool included both positive and negative perspectives. The positive comments highlighted several key features: 1) Map Element: This feature had helped users visualise and understand the building's layout; 2) Route Function: It had aided in the visualisation and memorisation of paths; 3) Zoom Function: This function was noted for making it easier to locate points of interest (POIs) and orient oneself within the space; 4) Change Map Function: Users found this feature valuable for uploading maps of new locations; 5) Fonts, Patterns, and Colours: These were recognised for enhancing text readability, and the use of distinct patterns and colours helped differentiate between various types of rooms and facilities. Additionally, users commended the tool's adaptability, noting its potential to cater to the needs of disabled communities as well as individual users. The colour adaptability, in particular, was highlighted for its role in helping users locate POIs. One respondent commented, *"I believe that it is an excellent idea and I most definitely would use such a tool. There are many indoor spaces that are complex for people with disabilities. If you can address the characteristics of these people then you can develop adaptive floorplans and help a lot of people".*

Negative feedback primarily centered around the user interface (UI), ease of use, and the floorplan structure. Common UI issues included difficulty distinguishing patterns, legend not reflecting the patterns, and mismatches between the map and color legends. Regarding ease of use, several participants found the UI overwhelming and not intuitive, particularly when navigating on mobile devices, where map and legend elements often overlapped. Additionally, some users felt that the tool required more experience or familiarity to be used effectively.

Feedback on Usage showed that 68% were positive about using this for navigation in these spaces and 20% were unsure about it, while 9% had a neutral opinion. The detailed comments focused on how the tool will help the disabled communities with pre-planning when visiting unfamiliar buildings, how it will help to find accessible routes using accessible POIs and how it will help to navigate complex, large and unfamiliar buildings. One participant stated *"This would really help me, especially if I am travelling with my children and it's to a place I am not familiar with. I could plan ahead so that I don't have to keep asking for assistance at the venue which is usually what ends up happening"*. Some participants also commented on how this tool will help to provide equal access to complicated buildings by accommodating everyone and one user stated *"It's a lot easier to use that those map kiosks that are in the mall. It would be nice to be able to plan a route as well so that I can finish my errands without straining my ankle, which is where my mobility issue lies. The quicker I can get everything done with as little wandering as necessary is a valuable asset"*.

Feedback on Usage indicated that 68% of participants had a positive view of using the tool for navigation in these spaces, 20% were uncertain, and 9% expressed a neutral opinion. Detailed comments highlighted the potential benefits of the tool for disabled communities, particularly in pre-planning visits to unfamiliar buildings. Users appreciated the ability to identify accessible routes via accessible points of interest (POIs), which would help them navigate large, complex, or unfamiliar spaces more efficiently. One participant noted, *"This would really help me, especially if I am travelling with my children and it's to a place I am not familiar with. I could plan ahead so that I don't have to keep asking for assistance at the venue which is usually what ends up happening"*. Other participants emphasised the tool's potential to provide equal access to challenging buildings by accommodating everyone's needs. One user remarked, *"It's a lot easier to use that those map kiosks that are in the mall. It would be nice to be able to plan a route as well so that I can finish my errands without straining my ankle, which is where my mobility issue lies. The quicker I can get everything done with as little wandering as necessary is a valuable asset"*.

Suggestions for improvements focused on the map, route planning, and UI. Regarding the map, some participants with dyslexia recommended using more symbols or icons instead of room labels, while others suggested a larger map for better visibility. Additionally, some users preferred room names to appear as pop-ups directly on the map rather than being listed in the legend as they are currently. For route planning, participants expressed interest in marking and saving preferred paths. One participant suggested incorporating a "You are here" label to help users identify their current location, followed by an automatic routing feature to guide them to their desired destination. In terms of the UI, suggestions included making legend items clickable to unlock additional functions. For example, clicking on an accessible toilet icon could highlight all accessible toilets on the map and allow users to customise the colour or pattern of these items. Participants also recommended adding a search function to help users easily find their points of interest (POIs), with one user proposing *"a search bar to write what someone is looking for"*. A few participants also suggested adding a "Help" button to assist users with the tool and a tutorial to help people familiarise themselves with its features before use.

8 Threats and Limitations

In our requirement gathering survey, we translated the survey and the responses to Mandarin and back when gathering responses from the eye hospital and the disability school in China. We ensured that the ethics committee was aware of this, and several team members went through responses after receiving the translated responses. But we acknowledge that even with these measures, minor mistakes may happen in translations.

While all participants submitted complete responses for the survey, the Qualtrics platform enforced mandatory completion of questions before allowing submission. However, we acknowledge that full survey submission does not necessarily guarantee that participants correctly or fully completed each interactive task, as the evaluation was conducted remotely. While Prolific was effective in rapidly recruiting a diverse participant pool, it is noted that the platform may not yet fully meet WCAG 2.1 compliance. Furthermore, no consistency-checking questions were included to check for misunderstanding. We will incorporate validation questions and consider hybrid evaluation designs that combine remote tasks with observational tasks to better ensure data reliability.

Another threat is in the evaluation of the tool. We had only seven participants in this evaluation, and while they have significant distribution between disabilities, a more detailed evaluation would be beneficial. It may also be beneficial to obtain feedback from the experts in this stage, similar to the requirement-gathering stage.

Our work presented a detailed evaluation from the point of view of disabled end users. However, it would also be beneficial to obtain feedback from front-end developers who would be the ones using our adaptive graphic generation framework. Therefore, future studies can focus on getting feedback from font end developers on the structure of the adaptive SVGs and the adaptive graphic generation framework.

Our prototype map visualisation used SVG data from our building services team that included a variety of permanent barriers in the retail building, such as doors, stairs, toilets etc. However it did not include temporary barriers such as tables, chairs etc. This might be due to the fact that we did not ask specifically about barriers instead asked for general list of issues participants faced in accessing public spaces and in using their floor plans. Future work should include temporary barriers and their display and positional update.

Although preliminary screen reader testing was conducted by the development team, evaluation with experienced users of screen readers and magnification tools such as ZoomText was not performed. Future studies should incorporate usability testing with participants using such assistive technologies to assess accessibility support.

While we developed our tool with ARIA based enhancements and conducted preliminary screen reader testing to enhance accessibility for blind users, the usability testing with blind participants was not conducted. We plan to include participatory evaluations with users who rely on screen readers and magnification tools, to validate the accessibility of adaptive graphics for blind communities in future studies.

This study focused on four types of most common disabled groups. While our technical framework will be able to address more types of disabilities, a new requirement-gathering exercise will need to be conducted for these other disabilities. More work is also needed to solve the situation where these disabilities conflict with each other, e.g., one obscures the other, or the overall amount of information becomes excessive. It can also explore integrating the shortest path-finding function into the tool, as this is critical in navigating complex public spaces.

We chose maps for our case study as they had a significant real-world impact on disabled communities. But there are other types of information graphics, such as charts and diagrams, that are used more in software applications. Future work can, therefore, explore using our framework and guidelines to generate accessible and adaptive versions of other types of information graphics.

Lastly, while our graphic generation framework provides an excellent one-stop solution to support multiple disabilities, it is still at the proof of concept stage. Therefore more work is needed to explore the possibility of standardising some of these adaptivity aspects so that they are not vendor or tool-dependent. We would also extent our framework to support more dynamic path based navigation, instead of focusing on static style representations.

9 Discussion

Answers to Our Research Questions

We identified a number of key requirements for an inclusive information graphic, overviewed in Figure 4. Key amoung these include use of accessible, distinct colours; range of text font and font replacement by iconic forms where possible; single page, minimal design with clear, grouped elements; map zoom and voice-assisance; online and offline sites with regular updates; and space overviews, points of interest specific to disabilities, route information, inclusive language and catering for people with multiple disabilities. We addressed many of these requirements in our prototype. Some current limitations or omissions include limited text replacements and limited voice plug-in support, no off-line access, scrolling still necessary on very small screen devices, and limited route information. We carried out two evaluations of our prototype.

Our large scale prototype evaluation with 92 participants suggests that many disabled people make use of floor plans to aid their understanding and navigation of complex spaces, most use a mix of kiosks, web sites and mobile app-based maps, and most want accessible map solutions. When using our prototype to perform a variety of map understanding and navigation tasks, over 60% found identifying accessible entries easy to somewhat easy; nearly 80% found changing fonts easy to somewhat easy; half found changing maps easy somewhat easy; half found using the map for path finding easy to somewhat easy. The SUS evaluation produced a moderate score and found room for improvement in prototype usability. Those with low vision, mobility and multiple disability impairments found it easy to use than those with dyslexia. Overall participant positive feedback included for building map layout understanding, routing function, zoom support and multiple font support. Negative feedback predominantly focused on ease of use issues, pattern indistinctiveness, and issues with legends and colour. Key suggested improvements focus around building and saving preferred paths, you-are-here functionality, room name management, larger maps, and clickable lengend items. Searching for key points of interest based on disability needs was also desired.

Implications for front-end developers: Front-end developers can utilise our findings to aid them in engineering graphics and other online content accessible to people with disabilities. While this paper focuses on developing adaptive public space plans, the approach can be used to make different types of information graphics such as charts (bar, pie), diagrams (Venn, flow, mind maps), other maps (political, thematic, public space) that are used in different domains such as education, health, finance, legal, defence, entertainment more accessible. Some guidelines to be followed in engineering graphics for special groups are shown in Table 8. Additionally, we have made a replication package of the tool, including Python scripts for the conversion of SVG. This can be found at `https://github.com/fit4003-group19/adaptive-svg`.

Implications for public spaces owners: Our requirement gathering survey has detailed information on types of public spaces used by disabled users, frequency of use, methods they use to access information about these spaces, issues and suggestions. Public space owners can use our data to understand how disabled groups consume their spaces and take steps to make these more accessible by trying to solve the issues they have reported and by integrating some of their suggestions. Such initiatives will create satisfied consumers who will visit these spaces more and may recommend them to peers, e.g. a wheelchair user who found it easy to locate lifts and ramps at retail would recommend it to other wheelchair users. This would give a competitive advantage to these public space owners over others.

Implications for end users: The described case study will help make public spaces more accessible for disabled users, helping them to pre-plan their visits to these spaces and navigate independently once inside. Since our approach can be used to make other types of graphics accessible as well, it will contribute to creating more graphics accessible for disabled users.

Table 8: Guidelines in Engineering Graphics for Disabled

Low Vision	Provide sufficient contrast using colours and patterns. In using patterns, ensure they are simple and do not overlap with text
	Always provide the ability to manually zoom in/out without causing any distortion to graphics
	Provide support for screen readers and keyboard accessibility
Color Impaired	Use colour impaired-friendly colours
	Ensure there is high contrast, or use monochrome colours (using multiple shades of a single colour)
	Do not place reliance only on colour to convey information; instead, combine it with text and symbols
Dyslexia	Use icons instead of labels as much as possible
	Keep the graphic simple and, if required, present it in multiple layers
	Use dyslexia-friendly fonts when possible
	Use a simple language
Mobility Impaired	Graphics such as maps require, - Locations of ramps, lifts, accessible toilets - Paths with wider corridors - Sufficient turning cycles - Less crowded areas

10 Summary

In this study, we propose an approach used to generate adaptive and accessible graphics for people with multiple disabilities, specifically for low vision, colour blindness, dyslexia and mobility impairment. Our research consisted of a requirements elicitation stage involving informal interviews with accessibility experts and surveys with disabled users. After analysing these requirements, we developed a framework to generate adaptive SVG-based graphics and applied this using a case study of complex indoor environment floorplans. Finally, we evaluated our approach by using a preliminary evaluation with seven disabled users. The approach shows potential for creating more accessible graphics for various disabled users using adaptive SVG-based graphics.

11 Declarations

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Ethical approval: Empirical studies approved by Monash University Human Subject Ethics Committee approvals #45010 and #30527.

Informed consent: All empirical study subjects provided explicit informed consent.

Data Availability Statement: The data sets generated during and/or analysed during the current study are available from the corresponding author at reasonable request. Our Ethics approval forbids sharing raw data but aggregated data and analysis can be shared.

Author Contributions: Anuradha Madugalla designed and led the study, supervised the students, did major part of writing. Yutan Huang ran the second study, did major part of writing. John Grundy co-led the study, co-supervised the students, and did significant writing. Final Year Project students Min Hee Cho, Lasith Koswatta Gamage, Y.P. Lau, Tristan Leao and Sam Thiele designed and built the prototype, carried out first user study, did significant part of the writing.

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Clinical trial number: not applicable.

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A Preliminary Evaluation of Web Browser and Screen Reader Compatibility

An important factor when considering metadata in SVG was its compatibility with screen readers [14]. We created a testing harness to evaluate the compatibility of a few common SVG tags with popular screen readers. We tested with JAWS, NVDA, VoiceOver, ChromeVox and ORCA, as shown in Table 9. We chose these based on a survey conducted by WebAIM [45]. It showed that these were the most used screen readers, with NVDA and JAWS taking the lead of 40.6% and 40.1%, respectively. We tested these with combinations of commonly used web browsers (Google Chrome, Safari, Firefox, MicrosoftEdge) and common operating systems (MacOS, Windows and Linux). As this was a simple preliminary evaluation, we chose the browsers and OSs that the research team mostly used. Out of various tags we tested with *<title>, <desc>, <text>, <aria-label>, <aria-labelledby>, <aria-describedby>* tags. The *<title>, <desc>, <text>, <aria>* tags are the most commonly used SVG tags and *<aria-label>, <aria-labelledby>, <aria-describedby>* are different versions of the *<aria>* tag.

The title tag was supported by several screen readers across browsers, as shown in Table 9. In contrast, the *<desc>* and *<text>* tags were not supported by several screen readers. In terms of the options with *<aria-label>*, *<aria-labelledby>* and *<aria-describedby>*, these did not have issues with any screen readers. In choosing which tags to use in our work, we gave priority to *<title>* and *<area>* tag options. But when needed, we also used *<desc>* and *<text>* tags in combination with <area> tag options as we found the limitations of *<desc>* and *<text>* tags can be overcome when used in combination with <area> tag options.

Table 9: Support of Elements and Web Attributes by Screen Readers

Screen reader	Web browser	OS	<title>	desc	text	aria-label	aria-labelled-by	aria-described-by
ChromeVox	Google Chrome	MacOS	Yes	No	Yes	Yes	Yes	Yes
ChromeVox	Google Chrome	Windows	No	No	Yes	Yes	Yes	Yes
Jaws	Google Chrome	Windows	Yes	No	No	Yes	Yes	Yes
NVDA	Google Chrome	Windows	Yes	No	No	Yes	Yes	Yes
VoiceOver	Google Chrome	MacOS	Yes	No	No	Yes	Yes	Yes
VoiceOver	Safari	MacOS	Yes	Yes	No	Yes	Yes	Yes
VoiceOver	MicrosoftEdge	MacOS	Yes	No	No	Yes	Yes	Yes
ORCA	Firefox	Linux	Yes	Yes	Yes	Yes	Yes	Yes