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Accessibility Study of interactive maps and design recommendation to enhance screen reader accessibility

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Preface

I was given a world atlas poster as a gift for my 11th birthday. I hanged that poster above my desk and spent numerous hours staring at it wondering how huge the world is. I have always been passionate about maps. As a student of Universal Design, working on the accessibility of interactive maps was the perfect topic for me to work on when it was proposed by my supervisor, Terje Gjøsæter. I hope my work on the investigation of interactive maps accessibility and proposal of a few design improvements benefit screen reader users and guide future interactive map developers toward universal design. This research taught me about the systematic literature review process, how to collaborate with other experts and evaluate systems, and how to conduct interviews effectively.

I am grateful to several people for helping me complete this thesis. First and foremost, I would like to express my gratitude to Terje Gjøsæter for being an amazing supervisor. It would have been impossible to finish this thesis so smoothly without him always being there, checking and ensuring I am following my thesis plan. I will always cherish those productive yet casual meetings with him. I am also grateful to Attila Bekkvik Szentirmai and Donald Shahini for being two awesome companions both academically and personally. I would also like to thank all the interviewees who were kind enough to give their time, opinions, and some amazing ideas.

Finally, I would like to thank my fiancée Lamia Akter, for her mental and emotional support even from 7,000 km away and for enduring me. Completion of this research was a milestone and I am looking forward to the next chapter of our life. I would like to dedicate this work to my parents because I would not be where I am today without their sacrifices.

Sayed Kamrul Hasan
Oslo, 15 September 2020

Abstract

Digital maps have been an integral part of modern life. We use digital maps online and offline on our smartphones, tablets, computers, kiosks, etc. Whether to venture into an unknown location, check the latest traffic update, update on the weather forecast, we come across digital maps every day. While maps have successfully evolved into digital form from paper and other physical mediums, how much evolution present-day digital maps have observed to ensure accessibility and implementation of universal design principles? Relying exclusively on the fundamental medium to present information on the maps essentially creates a barrier to several groups of people. Maps by nature have to rely on graphical medium to present its information content. But the users who have temporary or permanent and limited to no visual ability are excluded from reading maps for this reason. In this thesis, we have conducted a systematic literature review to discover the research gaps of accessibility in digital maps, focusing on map exploration and screen reader technologies. We then selected several most visited websites in Norway featuring digital maps and performed accessibility evaluation using relevant WCAG guidelines with accessibility compliance experts. To discover further accessibility issues from users, we conducted semi-structured interviews with participants with varying degrees of visual impairments. The result from three data collection indicates that interactive maps are not screen reader accessible at all. There is an apparent research gap in alternative text accessibility in maps and both expert accessibility evaluators and interview participants commonly agreed with multiple accessibility issues on contemporary interactive maps on diverse platforms. Based on interview feedback and accessibility expertise, several interactive maps design recommendation was introduced and discussed as a solution.

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List of Acronyms

Acronyms	Phrase
AT	Assistive Technology
ATAG	Authoring Tool Accessibility Guidelines
GIS	Geographic information system
GPS	Global Positioning System
HCI	Human-computer interaction
NSD	Norsk senter for forskningsdata
POI	Points of Interest
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SC	Success Criterion
SLR	Systematic Literature Review
SVG	Scalable Vector Graphics
UAAG	User Agent Accessibility Guidelines
UD	Universal Design
UI	User Interface
WAI	Web Accessibility Initiative
WCAG	Web Content Accessibility Guidelines
WHO	World Health Organization

1. Introduction

From the earliest example of mapping in 25,000 BC inside caves in Eastern Europe (Wolodtschenko & Forner, 2007) or contoured map on clay tablet by ancient Babylonians to contemporary interstellar cartography attempt of Mars surface (Stooke, 2012) for future colonization mission, converting perceivable geographical information into comprehensible form has been an integral achievement on the progression of mankind. Contemporarily maps are used for navigation, topography, meteorology, astronomy, architecture, politics, etc. Due to the digitalization of every aspect of modern life and our reliability on the digital lifestyle, more and more people use maps in digital form (Hurst, 2013) over other conventional methods like paper-based maps. People from all walks of life use digital maps on their daily life for example to find the nearest grocery store, view the public transport map of a city, or understand the severity of a natural disaster of a location. The ever-rising popularity of smart devices from desktop to handheld, all sorts of maps now can be accessed by the push of a button or tap on the screen as long as the device is on the internet. But throughout all the evolution maps has observed over the year, questions remain how much work has been done on improving maps, so it can be used by as many people as possible. People with a diverse range of physical, psychological, and socio-economic properties. In other words, how much accessible and universally designed today's digital maps are? When it comes to accessibility in using digital maps for navigational purposes, there is a tremendous amount (Khamgaonkar, Vishwakarma, Warkar, Mishra, & Selokar, 2020) of work has been done to ensure people with various impairments can travel from point A to point B conveniently and safely. But when it comes to reading the content of the maps or exploring an interactive map, there is much room for improvement.

1.1. Scopes and motivation

Maps by nature rely on conveying spatial information through the use of graphical representation. Any point or co-ordinate in a map only makes sense when its physical location can be depicted successfully using relevant surrounding location information like distance, direction, and the elements in between through illustrations. This necessity of presenting spatial information in illustrative form may create barriers for users with a varied level of ability and scenarios. One obvious user group affected by today's digital maps are users with different categories of vision impairments (Corn & Erin, 2010). Users with low visions would struggle to read maps in both physical and digital form without the aid of glasses or contact lenses. Legally blind users, on the other hand, cannot read traditional physical or electrical maps at all. In physical form, they need to rely on alternative maps with tactile and auditory feedback. In the digital world, acute vision-impaired users rely on assistive technologies like a screen reader, braille display, VoiceOver, etc. to interact with electronic devices. So, if the current maps in digital forms cannot be used without or even with assistive technologies, it cannot be considered accessible to visually impaired users.

Apart from permanent impairments, there are situations where impairments are temporary because of recovering injuries or situational disabilities (Gjøsæter, Radianti, & Chen, 2019). A user might have inflicted injury to their eyes and recovering from it by wearing eye patches. A room filled with smoke due to fire causing a user experiencing temporary blindness for that situation and time. In such hazardous cases, temporary impairments may contribute to a user's inability to interact with electronic devices, especially in our case – digital maps.

There are also case where information is conveyed using maps which would make more sense to be presented in textual format. Especially relevant for thematic maps that produce statistics information, sometimes the amount of data that need to be presented through a geographical illustrative form is too massive to be scaled inside the map borders, too scattered across maps, or the map's limited real estate cannot accommodate crucial information like labels and symbols. These inconveniences can result in both information loss as well as information overload when a user is interpreting the information on the maps (Ericson, 2011).

The inaccessibility in maps becomes even more consequential during emergencies. In the event of catastrophic natural disasters like floods or hurricanes, a mass of populations is required to take refuge in emergency shelters. It then becomes crucial to locate the most convenient shelter nearby. If an evacuee must rely on finding that information from digital maps only and unable to use the map due to inaccessibility, in an extreme case it may lead to fatal consequences. In line with accessing meteorological maps, a user might need to use a weather map online to explore critical weather information, imminent and past natural disaster data, or just simply wants to find out the wildfire risk factors of a suburb. If the information is presented only in convention graphical map format without alternative or accessibility options, a user with limited vision might be excluded from accessing the service.

1.2. Problem Statement

In analog form, various alternative solutions have been proposed to make paper and other mediums of physical maps readable. One of the most common being braille-based solutions (Zeng & Weber, 2011) where printed maps will have braille text for easier readability. More modern alternative prototypes utilize the use of raised line tactile feedbacks (Watanabe, Yamaguchi, Koda, & Minatani, 2014) and even 3D modeling of the map on a plain surface (Holloway, Marriott, & Butler, 2018) featuring buttons on the 3D models for audio description. In terms of maps in digital form, as web service or as an app, Ducasse, Brock, and Jouffrais (2017) has conducted thorough research on the accessibility of digital form of maps reviewing both tangible and intangible accessibility solutions. According to their paper, they have found researchers have proposed prototypes, assistive and adaptive technologies, and design recommendations to make maps more accessible to use for users with visual impairments.

But one of the biggest accessibility issues with maps on the web is that the elements of the maps are not readable by screen readers. Users can explore the map elements like infrastructures, terrains, water bodies, etc. but the graphical elements, as well as the text elements, are not readable by a screen reader. It is suspected, very few studies would be found regarding how digital maps can be converted into a textual format, so it is accessible for screen readers. In this thesis paper, we will investigate research gaps and various accessibility issues currently found on digital maps. We will also explore the possibility of a practical solution on how the existing graphical maps can be converted or presented into a textual format so screen reader users can read the contents of interactive digital maps, making digital maps more universally designed in the process.

1.3. Research Questions

Based on the problem statement, three research question has been raised to establish the groundwork for this thesis. All three questions lead to separate research path by which different prospect of the research has been tackled.

RQ1: How much research has been done so far towards accessible designing of digital maps for the screen reader user group?

This question is answered in the very early stage of the thesis work. During the literature study, an additional systematic literature review has been conducted with the following keywords: intitle:maps intext:"Universal Design" | “Design for all” | “Inclusive Design” | Accessibility | Accessible intext:ICT | Web* | Digital | Mobile | smartphone | Computer | Internet intext:textual | exploration | "screen reader"

RQ2: What are the most common accessibility issues currently present in digital maps?

For this investigation, accessibility evaluation using WCAG 2.1 guidelines has been performed with three accessibility experts on six of the most visited websites in Norway containing interactive maps. To obtain end-user perspectives, semi-structured interviews were also conducted with participants of various levels of limited visual ability.

RQ3: What new design element or change to the existing elements could make the digital map more accessible for screen reader users?

As a third method, suggestions for creating screen reader accessible digital maps will be proposed based on data acquired from the previous two research question study.

2. Literature Review

This chapter will establish the theoretical platform for the research through a literature review on various sections related to digital maps and its accessibility. A careful study has been conducted on how maps in general have evolved to accommodate usability to a broader range of users. The literature review has been structured to first construct the understanding of digital accessibility concepts like universal design, WCAG, ATAG, etc. Then the review delves into understanding the fundamental concepts of maps in both physical and digital forms. How maps have evolved in physical form to introduce and develop accessibility over the years. The next section outlines the study on digital maps accessibility – several papers that reviewed accessibility is discussed. We reviewed what sections they covered, how they conducted their study, and what they have found. The following section covers the study of researchers who pointed out the barriers of digital maps, the challenges of designing accessible maps, and a thorough discussion on recommended resign choices map makers should consider when developing digital maps. In the final section of review on maps accessibility, some notable prototypes and solution that has been presented to solve the issue of inaccessibility in maps online and offline is evaluated. The literature review concluded by introducing various user groups who might find reading maps difficult and how they interact with maps with their adverse ability.

2.1. Accessibility and design guidelines

Accessibility is an attribute and the Cambridge Dictionary defines it as the quality of approaching, reaching, obtaining, and understanding something easily (Cambridge Dictionary, 2013). Accessibility is generally associated with people with special needs and their right to independent, equal, and full social living. This includes full access to the physical environment, mobility, information, and communication (Lawson, 2018). The design and development of accessible products and services should cater to all user groups so they can use them with or without a need for assistive technologies. Assistive technology (AT) in turn is an umbrella term for special-purpose devices and services used by persons with limited ability as an enabler to ensure full participation in the society (de Witte, Steel, Gupta, Ramos, & Roentgen, 2018). Hearing Aid, Screen reader, or braille display are examples of commonly used Assistive technologies. Universal design is a major focus of this thesis subject. Assistive technology is a dividing factor between Accessibility and Universal Design. Accessibility is achieved through good design and development of a product or service that enables direct (non-assisted) or indirect (assisted) access. Whereas “Universal Design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design” (Mace et al., 1997). So, the design goal of universal design is to ensure the accessibility of as many user groups as possible regardless of their ability while avoiding the need for assistive technology. Universal design is achieved through the following seven principles: 1. equitable use, 2. flexibility in use, 3. simple and intuitive use, 4. perceptible information, 5. tolerance for error, 6. the low physical effort, and 7. size and space for approach and use (Mace et al., 1997). These principles were created to point out all potential design limitations that need to be addressed to achieve an inclusive design. Furthermore, they suggest ways to maximize the usability of any designs under development and indicate affecting variables along the way (Story, 2001). Another appealing reason to advocate for universal design is cost efficiency. Designing with the goal of maximum inclusion eliminates the need for post-development cost and configuration requirements.

Each of the seven principles of universal design contains four or more guidelines to ensure successful design implementations. Yet this can be argued that these guidelines are not metrically specific. For example, the four guidelines of principle six: Low Physical Effort are:

6a. Allow user to maintain a neutral body position.
6b. Use reasonable operating forces.
6c. Minimize repetitive actions.
6d. Minimize sustained physical effort.

As detailed as these guidelines are, the metric for “reasonable” and “minimize” has not been defined. To address this issue at least in the web technology part of the ICT world, the Web Accessibility Initiative (WAI) taskforce developed three notable accessibility guidelines: Web Content Accessibility Guidelines (WCAG) for creating accessible web content, Authoring Tool Accessibility Guidelines (ATAG) for creating web authoring software that produces accessible content and User Agent Accessibility Guidelines (UAAG) for creating accessible user agents like web browsers or media players (Brewer, 2004). WCAG is the relevant guideline for this thesis and the latest rendition 2.1 (WCAG 2.1, 2018) was utilized for the accessibility evaluation of online maps. Following WCAG 2.1 contributes toward legally accepted accessibility for a wide range of impaired user groups: vision, auditory, speech, motor, cognitive, etc. The success of WCAG guidelines resulted in governmental push for creating accessible web content across the world. Norwegian policymakers have a history of encouraging equal participation by all members of society and the latest introduced regulation, titled: “Regulations on universal design of ICT solutions” enforces all web contents must abide by WCAG 2.0 and vending machines to be universally designed by 1st January 2021 (Begnum, 2016). Beyond the national border, the European Union and countries like the United States, Canada, Australia, etc. are also all imposing similar WCAG conformity laws.

2.2. Maps Basics

Maps are the collection of graphical elements on a surface put together by a mapmaker that works as a unit to convey spatial information to map readers. According to Dent (1972), When it comes to ensuring visual balance and clarity of the maps on printed formats, it is necessary to place the map elements carefully and strategically. These maps elements can also be called maps layouts and these can be (Yusim, 2019):

- The title of the map that defines the context of the map. This can be subject, type, geographical location, etc.
- A legend list that points out which data element inside the map represents which information.
- A scale or ruler to indicate the relative measurement of a map in comparison with the real world
- A compass indication, almost always indicating to the north in order to give the map a directional orientation to real world
- Geographical data like:
    a. Points: this represents one-dimensional data, i.e. pinpoint of an exact location
    b. Lines: this represents two-dimensional data like borders. Roads, junctions, etc.
    c. Areas: this represents three-dimensional data like land, mountains, ocean, etc.

Based on the above-mentioned elements, below is an example of a map that was constructed by combining three layouts: the triangles symbolize the points, the second layer with an aqua-colored shape represent a water body of an area and the third layer indicate the border of the map for this particular area. The combined layout also contains a legend, compass, and descriptive text.

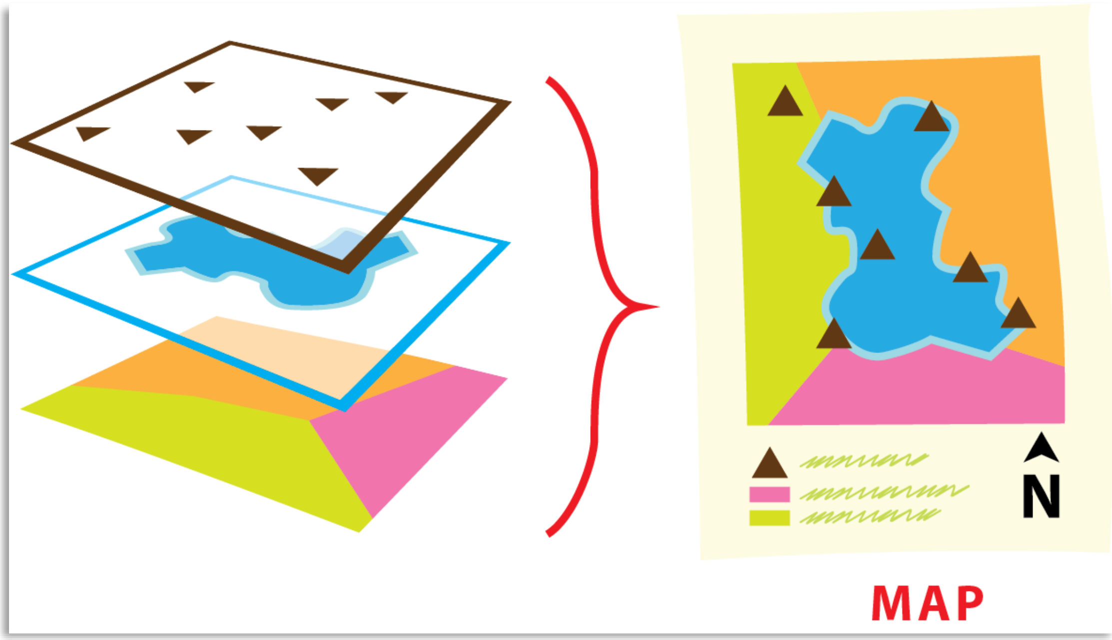


Figure 2-1: 1Different layers of map combined to create a whole map

Conveying geographical data is only one category of maps as there are many types of maps. These can be weather maps, political maps, wealth maps, even an indoor floor plan in graphical format is a map. Dent (1972) argued any map has two components of data that it tries to provide. The geographical data is provided using spatial information like location, borders, etc. and thematic data is provided with symbols on the map that serves a special purpose for the theme of that map. For example, the temperature in weather maps or the distribution of coal mines in wealth maps. Map designers efficiently combine these two components into a single plane, so readers can absorb the information without further reference. This is the success of a mapping system that, maps can convey a lot of information within a single outline using the language of graphics, visual variables, and a limited amount of text.

Digital maps are when these spatial and relative thematic data is compiled and converted into a virtual format so it can be accessed using electronic technologies like computers, smartphones, or even specially made for blind users pin-matrix display (Zeng & Weber, 2015). Digital mapping systems has opened so many new windows of practical uses of age-old physical maps. Nowadays digital maps can be used for GPS (Global Positioning System) navigations, weather forecasts, scientific studies, and much more.

2.3. Maps Accessibility

Several papers have analyzed accessibility on digital and physical maps to understand the extent of research on the subject and listed various prototype solutions. For the scope of this thesis only maps that are presented in intangible virtual format i.e. digital format is discussed. For this purpose, when Ducasse, Brock, and Jouffrais (2018) covered their study on digital map accessibility they categorized digital maps into two categories: a) Digital Interactive Maps – whose all map components and functionalities are in digital form, and b) Hybrid Interactive Maps – whose map components are combinations of digital and physical objects. They further subcategorized Hybrid Interactive Maps into i) Tangible Maps; ii) Interactive Tactile Maps and iii) Refreshable tactile maps. Under these categories, they analyze all the conceivable prototypes solution they found on the research field for example: maps explorable using keyboard, like "iSonic (Zhao, Plaisant, Shneiderman, & Lazar, 2008), using a joystick (Picinali, Afonso, Denis, & Katz, 2014), using finger, like TouchOver (Poppinga, Magnusson, Pielot, & Rassmus-Gröhn, 2011), interactive 3D printed maps (Rener, 2017), tangible reels (Ducasse, Macé, Serrano, & Jouffrais, 2016), etc. The conclusion has come from their (Ducasse et al., 2018) analysis is that while Digital Interactive Maps are adoptive, inexpensive, portable, and updatable but lack of tactile cues is a major disadvantage for those who need to rely on non-visual exploration. On the other hand, Hybrid Interactive Maps offer hepatic and tactile reference due to associating raised line paper, raised pin display or 3D printed prototypes, etc. but they are very expensive and inflexible.

Where Ducasse et al. (2018) did a conclusive literature review on digital maps accessibility, Marques and Graeml (2018) have done a systematic literature review with the exact keywords "accessible maps" with the underlying goal determining how ICT system is being used to ensure mobility of the citizen and how the use of collective intelligence from the citizen can be contributed to creating accessible mapping system. For their systematic literature review, Marques and Graeml (2018) used AIS Electronic Library, IEEE Xplore Digital Library, ACM Digital Library, Portal de Periódicos da CAPES, and Google Scholar databases and filtered down to 43 papers for deep investigations. While their study does not explicitly contribute to the subject of this thesis work, but they have pointed out a crucial point. They have determined that very little work has been done for users with visual impairments when it comes to building an accessible mapping system even though reliance on visual capability is crucial for maps that are not universally designed. Another SLR (Kvitle, 2017) was conducted focusing only on a specific user group of visual impairment - color vision deficiencies to get the state of the art information and future work barriers of map designing for color-blind users. Their review revealed most maps are designed without considering the challenges color blind users might face. So, in general, digital maps are not accessible to color blind users either. They also suggested this issue can easily be fixed during the maps design process if designers use simulation methods to observe their maps through the eye of a vision deficiency user and redesign the map to increase inclusiveness.

2.4. Maps Design Evaluations

Several papers have attempted to evaluate currently available online maps and maps in web applications. Calle Jiménez and Luján-Mora (2016) has uncovered the general barriers that are found on any typical static maps - maps that are presented as an image file. The biggest barriers are the absence of alternative text as well as texts inside the image of the map that cannot be read by a user with low vision and screen reader. Secondly, if the map design did not consider color blind users, it would have a color combination that cannot be properly read by color blind users. User exclusion can also be created if the functionality of the map image file presented and the website, in general, cannot be operated by a keyboard. They also indicated if multiple image files are used to represent a single map, it creates a mosaic effect and inaccessibility ensues. Medina, Cagnin, and Paiva (2015a) have conducted a thorough investigation to determine the accessibility of a few of the most popular web application maps. Their thorough evaluation included heuristic expert evaluation, automated evaluation as well as final user testing with users of limited visual ability. They employed eight experts and evaluated Google Maps, OpenStreetMap, Yahoo! Maps, Bing Maps and MapRequest using WCAG 2.0 accessibility guidelines. They scoped their evaluation to all the success criteria of Level A conformance level. Expert evaluation revealed Google Maps violated the greatest number of success criteria 18 – out of 24 criteria inspected. On the other hand, OpenStreetMap and MapRequest violated only 4. The other two web maps service scored averagely, abiding by 16 and 14 success criteria, respectively. But according to WCAG, if a website breaks one success criteria under a conformance level, it violates the whole conformance level so none of the evaluated maps conforms to even level A. Their automated accessibility checker tools confirmed the result from expert evaluation to be correct. For maximum accuracy, they evaluated the above-mentioned web maps with 5 different checkers: AChecker, Total Validator, CynthiaSays, TAW, and AccessMonitor. Along with WCAG, these tools also check for accessibility form other guidelines like Section 508, HTML, XHTML, CSS, BITV as well as for spelling errors. From the result of WCAG guidelines, none of the websites met conformance level A criteria. Finally, for the user evaluation, visually impaired users from the Institute for Blind Florivaldo Vargas - ISMAC, located in Campo Grande, State of Mato Grosso do Sul, Brazil volunteered to test only Google Maps for accessibility. Google Maps was chosen due to its popularity and ease of use. Participants were given 9 activities to perform in Google maps. While most activities were performed 100% successfully two activity had a 0% success rate. These are 1) access photos of a given address and read their descriptions; 2) use the zoom feature on the map. switch between "Map" and "Satellite" views using the website tools had only a 50% success rate. These results point out a few of the critical accessibility issues of online maps.

So how the digital maps should be designed to accommodate as many user groups as possible? On the paper (Froehlich et al., 2019) “Grand Challenges in

Accessible Maps", the authors pointed out map data and design is meaningless if the broad users cannot access it. They indicated map interaction functionality should not be limited to keyboards and pointing devices, rather it should also be supported by eye-tracking or one switch interfaces and should incorporate other senses like haptics and olfaction. Sabine Hennig, Zobl, and Wasserburger (2017) have given their recommendation on how to design maps that would be appropriate for visually impaired users.

Points:

- Popular and well-known icons, symbols, and glyphs should be used
- Different colors and icons should be used for different features
- There should be an appropriate color contrast between different layers of the maps like foreground symbols and background areas.
- The appropriate size for the icons and glyphs should be used based on different variables such as symbol complexity, viewing condition quantity of the symbol, etc.

Line:

- The width of the should be sized in a way that it can independently stand out in the color contrasts of surrounding map elements
- Choice of color for the line should also be carefully selected so it does not blend into the background
- For the optimal reading of the map, different types of lines should be represented by different colors
- Different types of lines can also be represented by different thicknesses of the lines.

Area:

- Area outline should be represented in a dark color
- Same as points and lines, the area should use an appropriate color scheme with current brightness and contrast to present its identity

- Different color and/or pattern can be used to differentiate one area from another

Text:

- The color contrast between text and the background as well as text and surrounding text should be of an appropriate level. Black color text on a white background has been suggested to be most optimal.
- Well known and accessible font family like san serif should be used
- Italic and underlined text styles should be avoided
- If necessary, only the first character should be capitalized all the following characters should remain in lower case.
- For optimal viewing, the text should be of appropriate size, preferably 12 to 18 point-type
- Texts should be left-aligned
- Should not be any overlapping other text and map elements.

2.5. Notable Prototypes and Solutions

When it comes to presenting graphical information of the digital maps into a textual format or offering a textual alternative, there have been few research papers published on this concept. The most compelling prospect of this concept comes from the work of Afzal, Maciejewski, Jang, Elmqvist, and Ebert (2012) where they were able to introduce an algorithm in conjunction with the OpenStreetMap project. Their algorithm combines textual and special data into a visual map where the text is the only element of the map used for points, lines, areas as well as labels. The algorithm provides high flexibility in configuration to the users and can be tweaked in the web service. It follows an interesting design principle to generate typographic maps. Before loading the maps, the web service prompt user for their preferred visual attribute of the map like font size, color, and weight on each layer of the map. They are also asked about how the graphical elements will be rendered. The border and area are rendered differently on the map. The text is generated along the line of the path for the border and on the body of the map for the area. They used SVG (Scalable Vector Graphics) to implement this concept. According to the author, this map is most practical in the context of traffic, demographic, or even crime-related information. They have acknowledged while their web service can render typographic maps from any part of the work in the OpenStreetMap platform, the presented map is static, so it cannot be explored interactively.

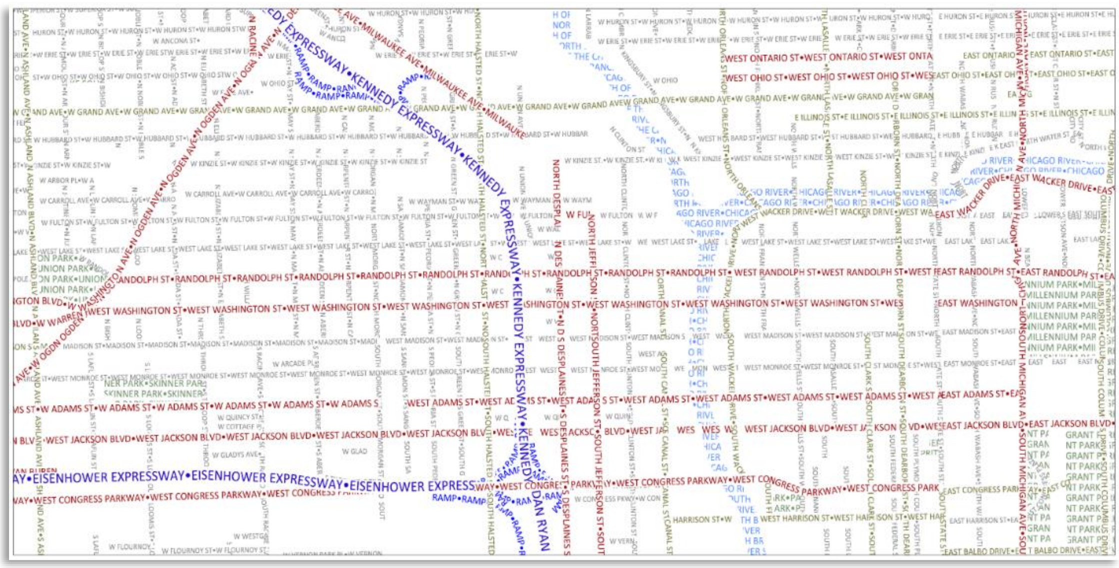


Figure 2-2: Dynamically generated Typographic map for Chicago, IL, based on Afzal et al., 2012

Another work by Calle Jiménez and Luján-Mora (2015) who also based their digital maps accessibility on SVG technology in conjunction with crowdsourcing to gather accessibility data. To be more specific, they utilized “SVG Tiny” codes to embed the accessibility data in the map so the screen reader can read the description from “SVG Tiny” codes. The code contains <title> and <desc> for including data for screen reader as well as <g> for organizing the data in layers. Unfortunately, this prototype also only works with static digital maps. So, the research field is open to implement these concepts in dynamic and interactive maps.

2.6. User Diversity and Visual Impairment

Several factors contribute to the user diversity that engineers and designers must consider while developing universally designed products, services, and environments. According to Story, Mueller, and Mace (1998), these can be diverse user ability, among-user diversity, situational diversity, technological diversity, etc. Ability based user diversity stem from varying ability in vision, audio, motor, cognition, mental, etc. Even when these physical and mental abilities are not a factor, culture, socio-economic background, education can create further diversity among users. Situational diversity can be triggered by weather conditions, physical location, stressful or emergency state, etc. In this thesis we are motivated by screen reader accessibility and alternative text accessibility of interactive maps, so the user diversity based on visual ability is further investigated.

The World Health Organization stated in their 2011 world report(WHO, 2011), disability is not an attribute of a person. It is caused when a person with impairment cannot participate in society equally and fully due to environmental and attitudinal barriers. It is important that persons with any level of visual ability are addressed equally and their visual impairment does not characterize their identity. The World Health Organization classifies an individual’s visual acuity in the following manner:

Table 1: WHO terminology for impairments of visual acuity

WHO Category of Vision	Degree of Impairment	Visual acuity	Synonyms / alternative definition
Normal Vision	None	0.8 or better	range of normal vision
	Slight	less than 0.8	near-normal vision

Low Vision	Moderate	less than 0.3	moderate low vision
	Severe	Less than 0.12	severe low vision - legal blind
Blindness	Profound	less than 0.05	profound low vision or moderate blindness
	Near-total	less than 0.02	severe or near-total blindness
	Total	No light perception	total blindness

Aside from visual acuity, there are other variations of impairments like color blindness, photophobia or Light sensitivity, tunnel vision, blind spot, or in severe cases Deafblindness. Based on the visual ability, users relies on several techniques on the web to receive information (Abou-Zahra, 2017):

- Changing text and image size.
- Changing or customizing fonts, colors, and spacing.
- Using screen reader for synthesized text-to-speech and audio transcription of audio and video content.
- Using refreshable Braille display for text.

Hussain, Chen, Mirza, Chen, and Hassan (2015) stated the importance of feedbacks, especially auditory feedback for visually impaired users. They found both clear audio instruction and short audio queues were necessary for developing a proper navigation system for this user group. Another study (Panchanathan & McDaniel, 2015) suggested continuous feedback has produced better operation and navigations of software interfaces. For efficient software use, these feedbacks should not only be reactive, they also need to be proactive (Shimomura, Hvannberg, & Hafsteinsson, 2010). Their research also talked about the significance of mental workload. The brain capacity of processing information is limited and providing excessive input information can be overwhelming. Their recommendation is offering “small, reversible incremental steps” as well as hierarchical and sortable design. A similar agreement was reached by another group or researchers, claiming visually impaired users will opt for braille paper prototypes over user interface if the UI is complex. Ability to get quick overview and navigation of the interface is important to them and paper protype provided a better alternative (Miao, Pham, Friebe, & Weber, 2016). They discussed further navigational issues that originate from poorly labeled and unlabeled content as well as poorly structured and unstructured elements.

3. Methodology

This chapter describes the approaches and actions taken to conduct the research. Section 3.1 describes the methods used for both collecting and analyzing the data. For data collection, qualitative research has been conducted, obtaining data from a systematic literature review, accessibility evaluation of selected existing digital maps, semi-structured interviews with selected participants. The research was initially designed around grounded theory (Adams, Lunt, & Cairns, 2008) which allowed for progressive and involving data analysis from the very early stage of the data collection phase. In section 3.2, all data collection methods and processes are explained in detail. A systematic literature review was performed during the literature review phase to obtain secondary data focusing on screen reader accessibility studies. Accessibility evaluation using WCAG 2.0 guidelines with expert evaluator was also performed. For an in-depth evaluation of existing issues with the inaccessibility of digital maps, interviews were conducted with participants with varying degrees of vision impairment. The technique used for the analysis of collected data is described in section 3.3. The chapter is concluded by describing the steps taken to conduct the research with all ethical considerations.

3.1. Research Design Approaches

According to Lazar, Feng, and Hochheiser (2017), researching in human-computer interaction is fascinating and complex. They find it fascinating because there are abundant research questions that need to be answered and yet these questions change over time as technologies progress. On the other hand, complexity in HCI research stems from two variable factors. Firstly, the research subject –human beings, who are habitually complex. Secondly, because of the above factors, HCI based research might not rigidly follow conventional frameworks of research approaches. In our HCI research study, we investigate the technological and social gaps left behind during the advancement of digital maps and we try to measure the gap and suggest possible solutions to fill the gap for digital maps designers, implementers, and policymakers. Action research is a research methodology whose root can be traced back to social science (Lewin, 1946) and being successfully preferred, revised, and adopted for HCI based research(Hayes, 2011) in recent times. Hayes (2011) suggested Action research shares common ground with HCI researchers: working with community partners, being involved in fieldwork, and designing and developing a solution in an iterative fashion. A definition of Action research from the book "Guiding school improvement with action research" by (Sagor, 2000) gives even more transparent reasoning about why our research should adopt action research methodology:

"*(Action research) is a disciplined process of inquiry conducted by and for those taking the action. The primary reason for engaging in action research is to assist the "actor" in improving and/or refining his or her actions."*

In our thesis research, we are conducting an inquiry into the inaccessibility of digital maps and exploring the possibility of making digital maps more accessible for future design iterations and implementations.

We have chosen action research for our research methodology. (Sagor, 2000) has listed the looping steps of conducting action research:

1. Selecting a focus
2. Clarifying theories
3. Identifying research questions
4. Collecting data
5. Analyzing data
6. Reporting results
7. Taking informed action

We have already discussed the first three steps of the process during the introductory parts of our paper. In this chapter, we will discuss our research strategy for data collection and analysis. In the following chapters, results from the research will be reported and analyzed. Step 7, taking informed action will be done by presenting the design suggestions for accessible digital maps.

3.2. Data Collection

Scientific studies rely heavily on quantifiable data from experimental method approaches. But due to the social aspect of HCI based research studies, data might be too subjective to quantify, complex to experimentally manipulate, and challenging to ethically conduct (Cairns & Cox, 2008). We might not even have a predictable and assumable research question for our HCI agenda before even starting the research let alone determine quantifiable variables. Also understanding how different user groups individually and collectively perceive and experience usability and accessibility can be very subjective to collect and analyze in a quantitative manner (Pace, 2004). The answer to our problem is collecting qualitative data in the form of interviews, focus groups, observations, usability testing, accessibility evaluation, media content, etc. which is a norm in social science studies. Lazar et al. (2017) argued while we are collecting and analyzing subjective data in HCI research,

“Qualitative methods do not aim to eliminate subjectivity—instead, they accept that subjectivity is inherent to the process of interpreting qualitative data, and they strive to show that interpretations are developed methodically to be consistent with all available data, and representative of multiple perspectives.”

In our research, we collected qualitative data through a systematic literature review, interviews, and expert accessibility evaluation.

3.2.1. Systematic Literature Review

During the literature study of relevant topics for this thesis, a systematic literature review was conducted on the state of the study specifically on text alternated and screen reader-friendly accessibility of interactive digital maps. A Systematic review was necessary as the early state of the art research suggested an evident lack of adequate study on the topic. A procedural, repeatable, and definite review can be a reference point for future academics and contributors alike. Systematic reviews are fundamentally systematic yet Moher, Tetzlaff, Tricco, Sampson, and Altman (2007) discovered that only 10% of them truly follow a proper protocol.

The systematic review in this thesis has been designed based on a well-documented and vastly accepted SLR procedure, PRISMA Statement (Moher, Liberati, Tetzlaff, Altman, & Prisma-Group, 2009). PRISMA Statement provides a 27-item checklist and four-phase flow diagram to procedurally complete review. To capture the most relevant paper for analysis, the search criteria has been divided into four categories:

1. "Maps" as the primary topic searched with "intitle", to cover all and any work related to maps. Initially, synonyms for maps: cartography, GIS (Geographic Information System), spatial was included within the search parameter of "intitle" but the returned result was beyond a manageable scope. Then, the above-mentioned synonyms were also included as a subcategory for maps as an "*intext"* search, but the result omitted a large number of relevant results. Eventually, the synonyms for maps were removed completely for this systematic literature review.
2. Universal Design, covering Universal Design, design for all, and accessibility
3. ICT covering Web, technology, digital, mobile, smartphone, computer, internet.
4. As the primary objective of the thesis topic, "textual", "exploration" and "screen reader" keywords have been included "intext" with OR function to capture paper related to map exploration, textual accessibility, or maps that can be accessed using screen readers.

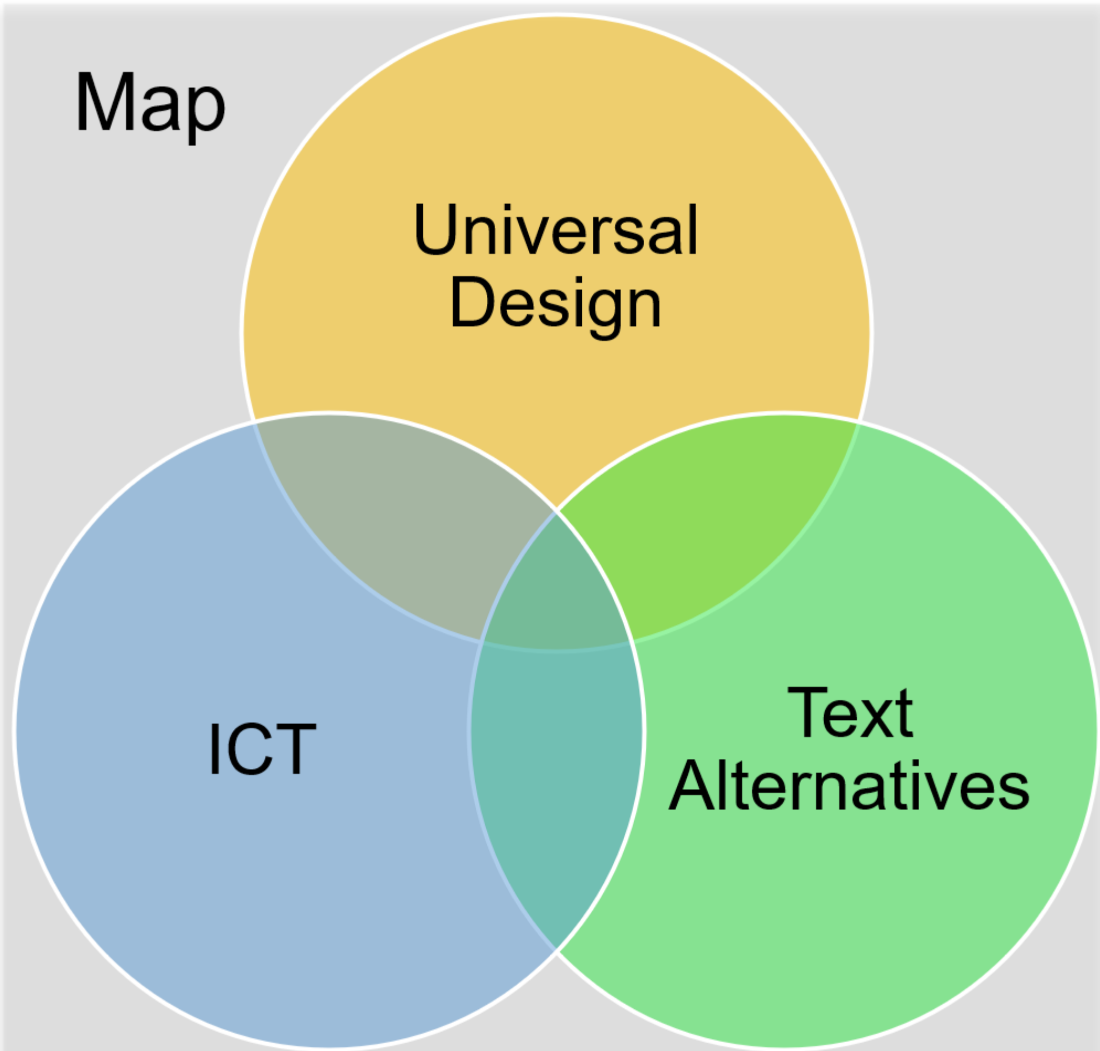


Figure 3-1: Venn Diagram of SLR Search Criteria

The paper publication date for the search was kept to the last decade, between 2009 to 2019. The date range 2009 ~ 2019 was chosen because WCAG (Web Content Accessibility Guidelines) 2.0 became a World Wide Web Consortium (W3C) recommendation at the end of 2008. Only English papers were searched. Google Scholar (https://scholar.Google.com) was used exclusively for the search database. Following was the exact search keywords used for the search:

intitle:maps intext:"Universal Design” | “Design for all” | “Inclusive Design” | Accessibility | Accessible intext:ICT | Web* | Digital | Mobile | smartphone | Computer | Internet intext:textual | exploration | "screen reader"

3.2.2. Digital Maps Accessibility Evaluation

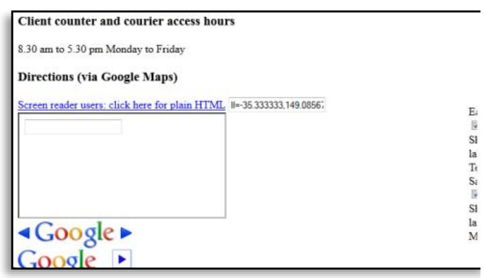
An exhaustive accessibility investigation on several web-based maps performed by Medina, Cagnin, and Paiva (2015b) provided a clear image of the lack of accessibility on digital maps. While their investigation employed expert evaluators, automatic accessibility checker tools, and end-users, their expert and automatic review were based on the previous revision of WCAG, WCAG 2.0(WCAG 2.0, 2008). Their success criterion conformance level was also scoped to single-A standard only. The digital maps that they have chosen to investigate were also limited to maps as web services. For these reasons, we felt the necessity of expanding on their evaluation to the latest revision of WCAG, 2.1, while including the success criterion most relevant to digital maps accessibility regardless of the conformance level and investigate several most visited websites in Norway that contains digital maps. The evaluation was performed by the author of this thesis along with two additional experts, experienced with ICT accessibilities as well as web accessibility guidelines.

3.2.2.1. Success Criteria

WCAG 2.1 consists of 61 success criteria under four principles and 12 guidelines. Considering we are evaluating the accessibility of interactive digital maps integrated into selected websites, we determined on all success criteria are not relevant for evaluation. For example, Success Criterion 1.4.2 Audio Control, even though it is a conformance level A success criterion, none of the selected maps or their websites contain audio playback making “Success Criterion 1.4.2 Audio Control” irrelevant for this evaluation process. Following are the success criteria chosen for our review:

Table 2: Applicable success criteria with description

WCAG SC	Test	Description
1.1.1: Non-text Content	Alternative text	The graphical and interactive content of the interactive maps

		provides alternative text. This includes but is not limited to Legends, buttons, POI, borders, location name, etc.
1.1.1: Non-text Content	Accessible alternative	A more accessible alternative to the original map is provided. This can be an additional text-based segment on the same page where the map resides or a link to the accessible alternative.
1.1.1: Non-text Content	The map stays on the page when stylesheets are disabled	To ensure the webpage can deliver the digital map without relying on style sheets. Style sheets are meant to be used for content presentation styles.  Figure 3-2: Non-text Content
1.3.2: Meaningful Sequence	The map is displayed properly without a stylesheet	With the stylesheet turned off, the map does not disappear but does the maps is displayed correctly? E.g. map contents do not overlap, repeated, arranged in a meaningful sequence, etc.

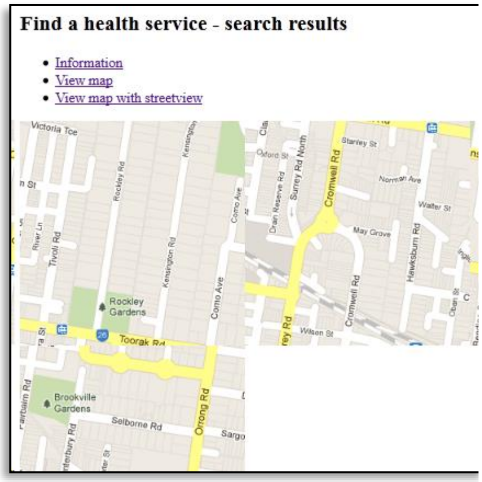
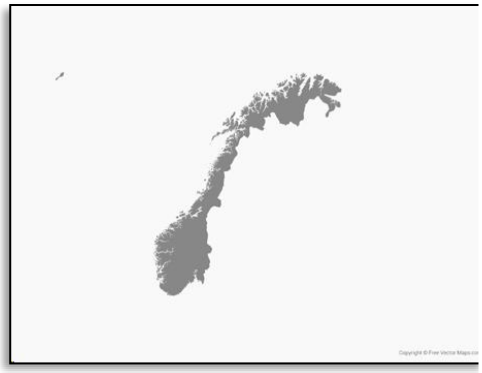
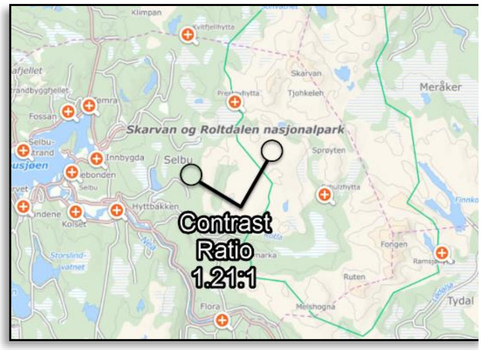
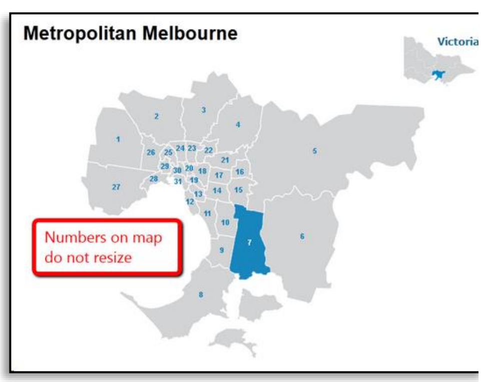
<table>
<tr><td></td><td></td><td>

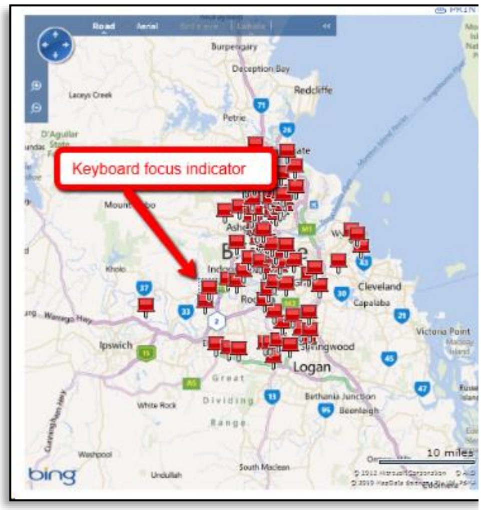
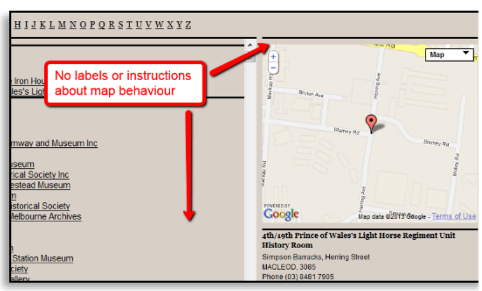
Figure 3-3: Meaningful sequence</td></tr>
<tr><td>1.3.2: Meaningful Sequence</td><td>No additional text appears without stylesheet</td><td>With the stylesheet turned off, the map does not disappear but do additional texts in a form of plain texts, links, or bullet points appear that were not present when stylesheet was on? If Additional texts appear, do the texts serve meaningful or accessibility purposes?


Figure 3-4: Meaningful sequence 2</td></tr>
<tr><td>1.4.1: Use of Color</td><td>Usage of color/shape/shade/location alone to convey information</td><td>The contents of the map must not be relayed using only one information. It should be a combination of multiple information queue to meet the need of users with varied and limited visual ability needs</td></tr>
</table>

		 Figure 3-5: Use of Color
1.4.3 Text Contrast	Text to map color contrast ratio	The contrast ratio between and map graphics and text inside the map must be at least 4.5:1. It is so users with low vision that does not use color-contrast enhancing assistive technology can read the map properly.  Figure 3-6: Text contrast
1.4.11 Non-text Contrast	Between graphical content's color contrast ratio	Different graphical contents within the map must be of a contrast ratio of 3:1. This also includes various interactive elements like a zoom button or clickable object in the map so that objects or subtle map information is not blended in.

		 Figure 3-7: Non-text contrast
1.4.4: Resize text	Text size can be changed inside the map	As the interactive map is zoomed the text size should also be zoomed up to 200% without the use of assistive technology and losing functionality. Even though this falls under AA conformance level, considering we are dealing with interactive maps and zooming is a vital function to properly absorb information of digital maps, this success criterion should be regarded as a critical issue  Figure 3-8: Resize text
2.1.1: Keyboard	The map is keyboard accessible	A crucial accessibility requirement for users with screen readers or those who

		must rely on keyboard navigation. The success criterion states all functionality of the web content must be operable through a keyboard interface.
2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	While the map being operable with a keyboard, focusing elements of the map using a keyboard, the focus can also be moved away using the keyboard only with standard exiting methods. The exiting method can be tab key, escape key, etc.
2.4.3 Focus Order	The Map element focus follows a meaningful sequence.	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	When focusing on various elements of the maps using a keyboard or screen reader, there should be a highly visible focus indicator. Although this is an AA issue, its impact on users is very high.

		 Figure 3-9: Focus Visible
3.3.2: Labels or Instructions	Labels or instructions about the map interaction has been provided	When the map is integrated into a webpage, various interactive buttons should be present with labels or instructions. This includes the title and purpose of the map, instruction on how to interact with the map, etc.  Figure 3-10: Labels or Instructions
(Guideline) 4.1 Compatible	Screen reader compatibility	The map can be used with a screen reader. This means a screen reader can read out the content of the maps in a meaningful and useful way.

(Guideline) 4.1 Compatible	screen magnifier compatibility	While the screen magnifier is activated, the map is as interactive as while the screen magnifier is not activated
(Guideline) 4.1 Compatible	Voice command compatibility	The map can be controlled by operating system integrated voice command feature and 3rd party speech recognition software

3.2.2.2. Selection of website

We decided to perform the WCAG accessibility evaluation on a few of the most visited websites featuring interactive maps based on reputable sources. Alexa Internet is a privately owned and most recognized (Stephen, 2019) web traffic analysis website. Selected within top 10 rankings, the following three websites are the top three websites that contain digital maps visited in Norway according to Alexa ranking (Alexa, 2019) as of 18th Nov 2019

Table 3: Selected websites with maps from Alexa ranking

Ranking	Website	Description
4	www.ssb.no	Statistics Norway is the national statistical institute of Norway and the main producer of official statistics, responsible for collecting, producing, and communicating statistics related to the economy, population, and society at national, regional, and local levels. The https://kart.ssb.no/ subdirectory of the website offers a varied range of statistics information provided in an interactive map powered by Asplan Viak Internet AS.
6	www.oslo.kommune.no	The site is the official webpage for Oslo Municipality web services ranging from

		waste management, education, healthcare, transportation. We selected https://www.oslo.kommune.no/english/schools-and-education/primary-and-lower-secondary-education/find-your-primary-school/ subdirectory of the website that helps visitor explore for primary schools within Oslo municipality.
7	www.visitnorway.com	It is the official travel guide website to Norway authorized by The Ministry of Trade, Industry, and Fisheries. When Scrolled down from the home page of the website, there is an integrated map powered by Google map data that offers travel distention information like top attractions, famous fjords, sustainable journeys, etc. through interactive digital maps. While the map can be explored for whole worlds, interactive information available on the map is within the Norwegian border.

www.similarweb.com is another and more accurate (Prantl & Prantl, 2018) web traffic analytic tool that offers categorized web traffic information based on the type of website linked to geolocation. According to their ranking (SimilarWeb, 2019), the following three are the most visited web-based GIS services in Norway as of 18th Nov 2019

Table 4: Selected websites with maps from SimilarWeb

Ranking	Website	Description
1	www.marinetraffic.com	MarineTraffic is the world's leading provider of ship tracking and maritime intelligence. The website provides a live interactive map of monitoring of the

		vessel movements across the world including Norwegian coasts.
2	siste.eiendomspriser.no	The site provides housing prices and real estate markets with monitoring and notification service including the housing market, price development, sold homes, housing price statistics, housing price development, and property prices in Oslo and Norway through the cartographic medium.
4	www.webcams.travel/map	The website offer service to explore and locate webcams publicly accessible through the internet.

The third and fifth most visited map-based website in Norway according to the SimilarWeb ranking is maps.Google.com and openstreetmap.org respectively. We are skeptical about Google maps being ranked lower than www.marinetraffic.com and siste.eiendomspriser.no. Both Google maps and OpenStreetMaps have been evaluated for WCAG accessibility in many research papers (Sabine Hennig et al., 2017; Medina et al., 2015a) so for the scope and originality of this research, we will not be checking those maps for accessibility. Also, to note, it was not possible to explore beyond top-five ranking on the SimilarWeb site as further ranking information is blocked behind a paywall.

3.2.2.3. Experts Evaluators

To ensure the richer validity of the accessibility evaluation, the accessibility check was done by the researcher of this thesis along with two additional experts who are also experienced in WCAG accessibility evaluation from previous projects. After completing the evaluation by all three evaluators, a group meeting was organized to compare results and discover inaccessibility patterns of digital maps for this thesis. A quantifiable and countable metric cannot be implemented in this evaluation. The WCAG success criteria are measured through only metric “met” or “not met”. These two are the only two scores used for the evaluation process.

3.2.3. Semi-structured Interview

According to (Lazar et al., 2017), the Most convincing argument for proceeding with the interview research method is, it allows researchers to “go deep” through asking a wide range of exploratory questions concerning the problem in hand and allowing them to expand on their answers. Based on the responses, interviewers can discover new territories of topics to explore, flexibly discuss interesting and important agendas and acquire an increased understanding that might not be possible with other methods of data collection, namely questionnaires or surveys. Depending on how much liberty an interviewer can have of asking questions and how much liberty the interviewee can have of answering those questions, interviews can be structured in three formats(Lazar et al., 2017). A fully structured interview session will maintain a structured and rigid line of questioning leaving no room for follow-up questions or expansion on answers but with a favorable tradeoff: easier data collection and analysis. On the opposite pole, unstructured interviews do not have a well-defined question structure and lets interviewee decide the course of the interview. Third and the choice for this thesis is the semi-structured interview. The semi-structured interview was chosen because while interviewees have more freedom answering questions, interviewers have more room for asking structured, probing, and follow-up questions allowing them to have more insight about the topic while maintaining a well-scheduled interview guide (Cairns & Cox, 2008; Lazar, Feng, & Hochheiser, 2010). We also considered several challenges (Cairns & Cox, 2008; Lazar et al., 2017) of conducting interviews for data collection. The open-ended nature of the responses from the semi-structured interview can be time-consuming to collect and difficult to analyze. We used carefully designed and a very appropriate method - thematic analysis for analyzing interview data while scoping our participant number to a manageable quantity. When a rapport is built with the interviewer, the interviewee is prone to release sensitive personal data. At the beginning of the interview, we briefed interviewees about the project and what sorts of response we expect from them, so they are more careful about their answers. For extra precaution and ethical consideration, participation identity was kept anonymous and their data highly secured. Also considering the interview is a qualitative approach and qualitative data is subjective, data collection might be prone to researcher's subjective bias. This issue will be dealt with researcher's quality and inter-rater validity check during data analysis period.

3.2.3.1. Interview Question selection

Several research goals are expected to achieve from the interviews. The primary goal of the interview is to validate and confirm the claim that, digital maps in general lack many aspects of accessibility issues. Considering digital maps rely on conveying information predominantly through visual cues and our selected interview participants have varying degrees of visual impairments, we suspect digital maps inaccessibility will be mentioned throughout the interviews. We also want to study our interview participants' experience using digital maps – the purpose they use it for, preference on the device they use it on, and preference on the providers of digital maps. Several questions are designed to be asked related to assistive technologies. We want to discover the assistive technologies they use; challenges they may face when using them on digital maps and if they apply any personally learned workaround techniques to mitigate those challenges. Digital maps may offer various accessibility features. One portion of the question sets has been added to learn our participant's familiarity with those accessibility features and how useful they find those in their use of digital maps. At the closing portion of the interview, if the opportunity sees fits, we also expect to conduct a small brainstorming session. We will be exploring if they have any valuable suggestions on designing and developing more accessible digital maps to cater to their ability needs.

After designing the interview guide, pilot interviews were conducted with a fellow researcher with a similar thesis topic and with another participant from a completely different academic background. Minor adjustments were made after the two pilot interviews. Pilot testing with fellow researchers helped discover new questions and remove a few questions which determined to be trivial for the interview. On the other hand, the second pilot testing helped rephrase the questions by removing jargon and improve the structure of the guide. The interview guide has been attached in Appendix 2.

3.2.3.2. Recruitment process

Considering the emphasis on screen reader accessibility in our research topic, the primary attributes pursued during the recruitment process were participants with severe low vision to total blindness. We also ensured participants have experience using digital maps on a regular basis. Refer to section 3.4 Ethical consideration, the recruitment process could not be started before approval from the Norwegian Centre for Research Data (NSD). NSD application requires submission of a well-documented interview guide and consent form. A significant amount of time was lost while awaiting approval after applying to NSD. But the interview could not be conducted as planned (e.g. recording interview session) without approval due to legislation and ethical conduct. For this reason, very limited time was available for the participant recruitment process. We started our recruitment process by reaching out to various relevant groups in social media as well as Norges Blindeforbund - a blind and visually impaired interest and service organization in Norway. We got a response from Blindeforbund that they forwarded the interview recruitment invitation letter within their community. For the complexity and rarity of our selected participant group, we were open to expanding beyond face to face medium and conduct phone calls and online video calls if given the opportunity. The number of participants required for semi-structured interviews depends on the research subject. For semi-structured qualitative studies, recruitment numbers can occasionally be as low as one but commonly 10-12 people (Blandford, 2013). According to the grounded theory principle (Adams et al., 2008), The recruitment process of this research continued throughout with ongoing data analysis until a conclusive set of the result was constructed.

3.2.3.3. Interview protocol

The preferred location for conducting the interviews was chosen to be within the university campus. But due to the limited ability of our selected participant group, we indicated in the recruitment invitation letter that we can travel to the preferred location of the participants to conduct interviews including their preferred choice of time. Upon request from the interested potential participants, we also sent a summary of the interview question they will be asked. The interview has been designed to last for 30-45 minutes. Compensation in the form of cash, gift card, or electronic money transfer has been offered. Before starting the interview, participants were explained about the thesis project, the interview process, and what we expect to gain from their participation. We also briefed them about their privacy and the treatment of their data. Details about these can be found in the "ethical consideration" section of this report. Notes were taken during the interview then reviewed immediately after the interview while the memory is fresh. This was done to ensure the qualitative data from cryptic shorthand and poor handwriting has been extracted effectively.

3.3. Data Analysis

Over the years verities of techniques for analyzing qualitative data have been tested in HCI research namely grounded theory, conversational analysis, discourse analysis, and thematic analysis (Cairns & Cox, 2008). At the beginning of our research, we decided to follow the grounded theory technique where data is analyzed as soon as an analyzable amount of data is available (Lazar et al., 2017). Along with data analysis, grounded theory can be applied to data collection approach and we believed this is the most appropriate research method for our study as we were uncertain about the accessibility and technology gap in digital maps and had to explore and discover the research gap and formulate research question through systematic literature review. But as we progressed through our research, we realized, the qualitative data collected through the systematic literature review and accessibility guideline evaluation are unconventional. Analyzing such data through the lenses of grounded theory will be complex and time-consuming. During the second phase of our research and onward, data analysis was carried out using the more simplified version of data analysis - thematic technique. The variation of this technique we chose is from Braun and Clarke (2006) which is performed in 6 steps respectively: familiarity with data, initial code generation, theme searching, theme reviewing, theme defining, and finally, writing up.

3.4. Ethical consideration

It is a researcher's responsibility to consider all possible ethical issues during research. According to The Norwegian National Committees for Research Ethics, this entails conducting the research study with transparency, liability, and credibility. Researchers and researching institutes also have responsibility for the safety and privacy of research subjects. Researching bodies must respect what the participants have consented to and ensure the study is completed without the mistreatment of participants and the environment. The study should aim towards the development of society and the success of the study should be disseminated to the general public. On the other hand, any unethical activity needs to be reported to the proper channel (Mikkelsen et al., 2016). Careful steps have been taken to ensure this research study is progressed abiding all proper ethical conducts and local laws.

Researching on accessibility issues of digital maps and prototype testing takes a qualitative approach to data collection. This involves semi-structured interviews with participants of limited visual ability. Although in the final thesis report, the participants remain anonymous, contact information, basic personal information, and audio recording of the interview are temporarily stored in digital format during the data collection and analysis phase. According to Norwegian legislation, it is required to obtain approval from the Norwegian Centre for Research Data (NSD) due to the above-mentioned handling of collected data(NSD, 2019). The application was submitted to NSD and approved after a lengthy process. The application was submitted with the interview guide and consent form. The interview guide was slightly altered after the original submission to NSD, but the integrity of the privacy legislation is kept intact.

During the interview phase, participants were explained about the treatment and protection of their collected data at the beginning of the sessions. They were ensured that their contribution will be anonymous in the published report as all data that can be linked to participants will be destroyed after data analysis. They were also briefed on the process of how they can withdraw or remove their relevant data during the project lifecycle. To ensure the participants can complete their input safely and stress-free they were informed they can stop their participation at any time and withdraw the data recorded so far. Once ensured participants understood what they are consenting to, they were asked to sign the written consent form or verbally consent to the researcher depending on their ability.

Utmost measures were taken to ensure that the collected data remain secure and anonymous. For analysis purpose, only age and severity of the visual impairment was recorded. In the thesis paper, participants were identified with a serial number associated with their related collected data. The first interview taken before the NSD approval was not audio recorded. Google transcription app, "Live Transcribe" was used to live transcribe the interview session as well as taking hand notes. The interview sessions after the NSD approval were recorded in the audio format using a smartphone. Only the built-in recording app was used, no 3rd party apps were involved during the recording session. The smartphone was fingerprint locked with a six-digit PIN as the fail-safe security. The interview audio recording was immediately transferred to a secure university server after the interview session. The audio recording was transcribed manually without any involvement of 3rd party transcription software. Once completed, the audio files were permanently deleted from all containers. It was also ensured any personal and sensitive info was left out during transcription. The consent form has been attached in Appendix 3.

4. Results

This chapter discusses the results found from all three data collection process. As the grounded theory research technique was adopted for this thesis, data analysis was performed in parallel with data collection. So, the presented individual results also include preliminary data analysis.

4.1. Systematic Literature Review

As of Central European Summer, Time 1:41 PM Saturday, May 11, 2019, 1,070 results were presented by Google Scholar. All search results have been inspected manually for relevance and authenticity. Initially, the title and the abstract were inspected and if they do not give enough information about the relevancy then the full text of the paper was skimmed through. After going through all search result, in the end, 84 paper was selected for further thorough study. Later, 21 paper was further excluded due to duplications, false-positive maps terms like biology-related maps, heat maps, network maps, historical maps, etc. Finally, 63 papers were eventually selected for the literature review. The quality of the papers was not assessed. All 63 papers were considered as long as it lasted through the filtering process. All the papers have been presented in Appendix 1.

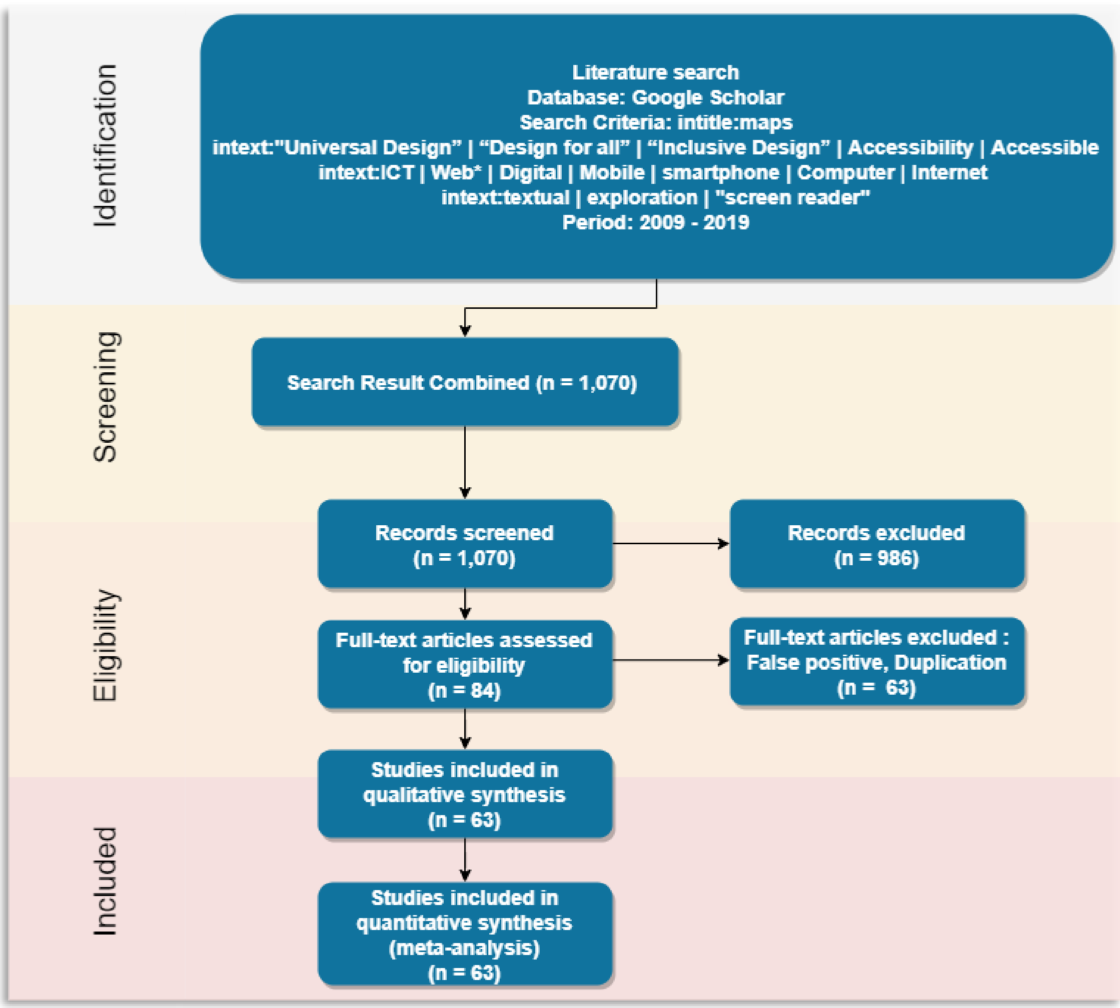


Figure 4-1: Systematic Literature Review PRISMA Flowchart Diagram

Selected papers have been divided into six categories based on the nature of the paper or technology that has been used to present an accessibility option into digital maps. Predominantly, a large portion of the papers is on reflection on the accessibility of maps. These papers can be about literature review (Kvitle, 2017), accessible map design recommendations(Sabine Hennig et al., 2017), barriers in currently available digital maps (Calle Jiménez & Luján-Mora, 2016), accessibility assessment (Balciunas & Beconyte, 2015), challenges in designing accessible maps (Froehlich et al., 2019), etc.

When it comes to developing prototype solutions in maps accessibility, 12 papers have been discovered where their solution comes from substituting vision with two other functioning senses: hearing and touch. Solutions were ranging from sonar (Kaklanis, Votis, Moschonas, & Tzovaras, 2011), voice instructions (Lohmann, Kerzel, & Habel, 2012), and audio-hepatic feedbacks (Geronazzo, Bedin, Brayda, Campus, & Avanzini, 2016; Poppinga et al., 2011). One solution from 2013 made use of multisensory interaction with sonification, vibration as well as text to speech technologies (Kaklanis, Votis, & Tzovaras, 2013a) while on the other hand Schmitz and Ertl (2010) based their prototype mainly on vibration to reach out to the deaf-blind community.

To successfully absorb the information of the maps for the purpose of exploration, visualization or an alternative solution is necessary. 9 papers were found that suggest alternative processes that can be used to visualize and explore map contents. Aligning with this thesis project, the most compelling solution comes from Afzal et al. (2012) where they developed a design technique to convert the map element into text. A number of the prototypes under this category cater to the indoor floor plan for navigation, exploration, and emergency situations (Paladugu, Tian, Maguluri, & Li, 2015) (Calle-Jimenez & Luján-Mora, 2016). Sonification is also used under this category to explore weather maps (Weir, Sizemore, Henderson, Chakraborty, & Lazar, 2012) and indoor maps (Su, Rosenzweig, Goel, de Lara, & Truong, 2010).

One set of papers categorized into introductions of an interactive and non-interactive tangible object to create accessibility of maps. Prototypes with swell or raised line paper on interactive touch screen display (A. Brock & Jouffrais, 2015; A. Brock, Truillet, Oriola, Picard, & Jouffrais, 2012), interactive 3D printed maps (Simonnet et al., 2018; Taylor, Dey, Siewiorek, & Smailagic, 2016), with use miscellaneous interactive accessibility object like WiiMote (Zeng & Weber, 2015) and Tangible Reels (Ducasse et al., 2016) suggested for accessibility.

Involving the “crowd” – users with varied abilities who use the maps to gather accessibility data and develop accessible maps system in digital form has also been discussed on several occasions. For example, Rice et al. (2013) talk about

Using crowdsourcing to report obstacles like broken road, uneven curb, or temp closure on road due to construction via various crowdsourcing techniques like social media and then referenced in a crowdsourced mapping system.

Alternative reality like augmented, virtual, or mixed reality has also been observed to be incorporated to create accessible maps. Bujari, Ciman, Gaggi, Marfia, and Palazzi (2015) developed a system of Combining paper maps and smartphones in the exploration of cultural heritage using augmented reality.

Table 5: SLR papers Categorized according to a study area

Area	**Papers**
Maps accessibility reflections	01 ~ 19
Audio - tactile solutions	20 ~ 31
Data visualization solutions	32 ~ 40
Tangible prototypes	41 ~ 54
Crowdsourcing to gather accessibility data	55 ~ 59
Alternative reality prototypes	60 ~ 63

4.2. Findings from Digital Maps Accessibility Evaluation

The accessibility was done by all three accessibility experts individually. Once all evaluations were completed, a group discussion meeting was organized. Results from each evaluation were compared with each other. Success criteria with conflicting verdicts were discussed and evaluated again to reach a common agreeable verdict of met or not met. All experts were involved in the data analysis segment of this accessibility evaluation process. Based on the thematic technique of data analysis, all nominated success criteria were converted into codes and then procedurally assorted into individual themes. Findings from the evaluation are discussed below according to themes.

4.2.1. Text Accessibility (SC 1.1.1; 1.4.4)

To determine whether the graphical contents inside the maps of our selected websites are text accessible, we used NVDA(NonVisual Desktop Access) screen reader software for windows. Statistics Norway's website seems to somewhat provide some text alternatives for the POI on the map. When hovering or clicking on the maps statistics data POI, it provides the north-east co-ordination of the location. It might not be very meaningful without visual context, but we considered it to be an acceptable text alternative. Looking for primary school information in the Oslo Municipality website’s map directory, when hovering on POI, it only read out the total number of school’s locations in that area. But clicking and zooming in and clicking on singular school POI, no information is provided. Trying to navigate to the map section of the Visit Norway website with NVDA screen reader software literally crashes the website. We verdict Marine Traffic website’s map to meet the text alternative success criterion because the map’s various POIs are clicked, screen reader read out detailed information about those POIs. Eiendomspriser and Webcams.travel websites on the other hand do not provide any meaningful text alternative for POI.

Evaluating whether any of the selected websites provide an alternative map in form of text description or a link to a more accessible map, none of the websites met the criteria. Although one argument can be made in favor of Statistics Norway that the website inherently provides statistics data. The map web app is just a supplementary service for visualization. Also disabling all style sheets in the Eiendomspriser website, an “Accessibility links” headline appears at the top of the website but clicking on the link has no consequences.

None of the websites sustained any of their functionalities as soon as all style sheets are disabled. The map completely disappears from Statistics Norway and Marine Traffic websites. The other four websites showed a broken and non-functional version of the map.

4.2.2. Maintaining meaningful sequence (SC 1.3.2; 2.4.3)

More violations revealed for Oslo Municipality, Visit Norway, Eiendomspriser, and Webcams.travel website when investigated further for functionality. Although full maps remained for Visit Norway, a portion of the website remains for Eiendomspriser and a fair bit of map loads for Webcams.travel and Oslo Municipality, all the maps are still completely broken and cannot be interacted.

Figure 4-2: Webcams.travel websites’ map after style sheet disabled

Investigating whether the additional text appears after style sheets have been disabled, we could not find any meaningful or accessible text appear.

Looking into the success criterion 2.4.3 focus order, we tried to navigate all the websites using the tab button, only Oslo Municipality and Webcams.travel can be navigated into the body of the maps explored using the tab and keyboard arrow buttons. The focus order never reached the interactive map's contents when the tab navigation functionality was checked on the other four websites where

4.2.3. Color accessibility (SC 1.4.1; 1.4.3; 1.4.11)

All the maps analyzed, we discovered they have all been designed to convey as little information as possible. The default view of the Statistics Norway map is completely in greyscale. The POIs of all the other websites have no text on the map until clicked. The default view of the map in the Statistics Norway website shows a greyscale map of Norway. Also, in the Marine Traffic website, although the interactive graphical content is of high contrast, the map itself is monochromic and lacks contrasting visual information. So, we determined these two websites violate success criterion 1.4.3. Statistics Norway and Marine Traffic also violate SC 1.4.11 Non-text Contrast as text color and color of the body of the map have a contrast ratio of less than 3:1.

4.2.4. Keyboard accessibility (SC 2.1.1; 2.1.2; 2.4.7)

As discussed during success criterion 2.4.3, except for Oslo Municipality and Webcams.travel, none of the other websites can even be navigated into the map using a keyboard. Even when navigating Oslo Municipality and Webcams.travel with keyboard, since the graphical content of the maps is not properly text altered, navigating with the keyboard still makes those two websites unusable. The focus indicator on Webcams.travel is also barely visible. Not only the focus indicator on Oslo Municipality is thinly outlined, but the focus indicator also does not stay after switching to each focus, it only flickers and goes away.

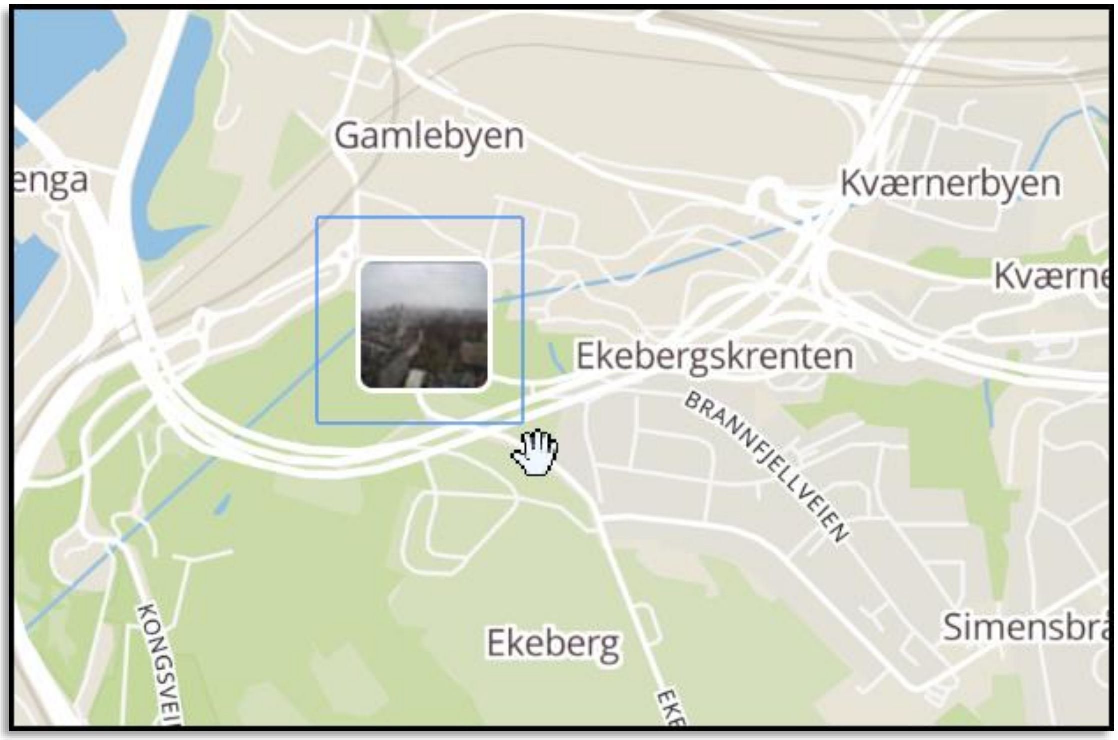


Figure 4-3: Low visibility focus indicator on Webcams.travel map

4.2.5. Labels and Instructions (SC 3.3.2)

This success criterion only applicable for the Oslo Municipality and Visit Norway websites since the maps on those two websites have been integrated as a layer as opposed to the other four websites where maps are the stand-alone service for the web address. Both the websites do not meet this criterion as they both lack an adequate amount of information and labels for the integrated map.

4.2.6. Assistive compatibility (Guideline 4.1)

Validating our research agenda once again, we have found none of the websites compatible with screen reader assistive technology. None of the maps is properly compatible with keyboard navigation and any or meaningful text alternative is not included for the graphical elements of the maps. Navigating all the maps using voice command was also difficult and none of the websites allowed satisfactory accessibility. On the contrary, testing all websites for use with magnifier enabled seems to possible.

4.3. Findings from the Interview

The number of interviews conducted four with five participants in total. Three interviews were conducted in a one-on-one setting. The third interview was conducted as a group interview with two participants as per their request. For anonymity and simplicity in referencing, each participant was given the following codes in the table. The participants were arranged according to the sequence the interviews were conducted. Transcriptions of all the interviews can be found in Appendix 4.

Table 6: Participant list - Coded

Participant Code	gender	age	visual ability [WHO]
1M	F	20	profound low vision
2S	F	35	severe low vision
3T	M	51	total blindness
4L	M	54	total blindness
5B	F	26	profound low vision

4.3.1. Participants

As the first participant, 1M was the perfect recruitment. She traveled to our interview location from a completely different and remote city. She was new in our city and traveled alone. Because of these, we were able to ask questions about the usefulness of digital maps when traveling to a new city and traveling alone with her limiting visual ability. We also had the opportunity to escort her from the train station to our interview location. Even while escorted, she was still using Google maps apps on her Apple iPhone to be updated about her location. This allowed us to observe her and take mental notes so we could discuss it during the interview.

The second participant, 2S was also profoundly unique on her own accord. She was the only participant who did not rely on any screen reader for her digital lifestyle. Screen magnification is the only form of accessibility she requires due to her visual condition. She is also the only participant whose current visual ability is an alteration from an accident that occurred later in her life. This variation gave us an insight into how user behavior changes on digital maps as visual ability readapts.

Our third interview with participants 3T and 4L was a group interview with two expert-level digital map users. They are both trainers and consultants for inclusive education in the visual impairments department. They have used and tested numerous digital maps on multiple platforms. They have also used and advocates for the installation of physical tactile maps for indoor navigation in public facilities. They use braille display as their daily driver for absorbing digital information and text accessibility is crucial for them as digital citizens. Due to the commonality of attributes, it was practical to accept their request to have them together for an interview and their feedback on the current state of digital maps was substantially significant. We also received several conclusive redesign suggestions for digital maps on map exploration using a touch screen and keyboard from them.

Due to a lack of local response, we reached out to international potential participants. There were quite a few interests but due to our prerequisite for recruitment, only one participant was selected. The final interview with 5B was conducted remotely online. She was also ideal recruitment as she added several variable feedbacks and niche design suggestions. Since she lives in a digitally disadvantaged location, digital maps are not available to use for walking navigation and public transport commutes. Her digital maps use is limited to the non-graphical features of Google maps, she also employs tactile feedback from her smartphone, so we were able to gather data related to the use of vibration to use digital maps.

4.3.2. Purpose and preferences

We started our interviews asking our participants about their purposes and preferred platforms of using digital maps, to associate digital maps to their personal experience as well as acquire sample data on digital maps trends. Navigation was the primary purpose of using digital maps as answered by all participants. 5B also utilizes the Google assistant function to get traffic updates and approximate travel time and distance to destinations. 3T also informed he has experience using digital tactile maps for indoor navigation and wants it to be developed further. Interestingly, Participants 1M and 5B also tried using digital maps for "looking around" and "searching for places" respectively which can be considered a map exploration attempt. They expressed their frustration at the very beginning of the interview that trying to explore digital maps are impossible**.** This is because of their very limited visual ability, their reliance on screen readers, and digital maps not being accessible to screen reader users. 4L quoted: "Digital Maps are not accessible at all".

Asking about which digital maps they use; Google maps was the general answer. Even when the interviewees use Apple devices, which have its own dedicated maps system, they still prefer Google maps. 1M explained, she found Google maps to be comparatively more accessible than apple maps. As more experienced users, 3T and 4L also mentioned a few more digital maps they have tried and tested. This includes Taxifix for calling a taxi, iMarka for ski maps, Blindsquare for voice-assisted navigation and exploration, etc. 3T demonstrated, Blindsquare can be used to gather information about the surrounding in the real world. it uses smartphone's location services and map data from Foursquare and OpenStreetMap databases. The app also has a rich algorithm to determine and audibly suggest the most relevant point of interest nearby of the user. Arguably, while Blindsquare is 3rd party solution and for exploring a user's surroundings in the real world, these features should be integrated into most popular digital maps like Google maps and allow users to explore maps on the device itself.

The devices on which the participants use the digital maps turned out to be divisive. Three out of five interviewees have tried to use the Google maps on the desktop, found it completely inaccessible, and exclusively use it on their smartphones. 1M tried using Google maps once on a desktop during a presentation, but her screen reader registered the map just as a “graphics” and she never tried again. 4L informed he rather prefers to search for addresses on his desktop with a braille display, as he can absorb information faster through that, but it never worked. 2S, on the other hand, requires a bigger screen to properly read information, so she mainly uses Google maps on desktop or laptop, sometime on her tablet but never on her smartphone.

4.3.3. Assistive Technologies

For the next section of the interview, we asked about the user experience of digital maps with various input-output devices and the accessibilities they offer. Unsurprisingly, most participants expressed their reluctance of using keyboards for any digital map purposes since they mostly do not use it on a PC. Those who tried have pointed out the problems of keyboard accessibility. Participant 5B informed in Google maps, while she can use a keyboard to search for addresses, that is all she can do. She cannot explore any content on the maps using a keyboard. We informed her, the body of the various web maps like Google Maps, OpenStreetMap or Bing Maps can be browsed using keyboard arrow keys by default. But when she tries to do the same with any screen reader software enabled on her PC, it did not work for her. Voicing the same problem 4L further commented “it would be great if for instance to be able to use the arrow keys to move step by step, street by street” instead of moving the whole map. Only one participant from our interviews uses a mouse when looking at digital maps. Due to her visual ability, 2S can navigate through digital maps using a mouse alone as long as the mouse cursor is set to a very large size and high contrast color. She is also the only interviewee who can make use of the operating system’s built-in screen magnifier tools as she can read text on the screen if it is large enough.

On the mobile devices, all of our participants have experience with touch screen accessibility of digital maps but only one of them found it useful. 2S uses her fingers for zooming in to read the maps on her tablet and she is satisfied with touch screen technology. Comparing her experience to desktop, 5B found Google Maps as an app is far more accessible than in the desktop as a web map service.

When 1M on the other hand tries to read the contents of Google maps with iOS screen reader VoiceOver, it just gives her random incomprehensible numbers. Group interview 3T expressed his frustration with a lack of feedback from his smartphone and touch navigation. Recalling tangible tactile maps where he can feel the layout of the map, touching maps on a mobile device has no similar interaction capability. Additionally, dragging with finger to another location, the entire map moves with the finger causing him to lose any sense of direction. Accessibility of voice command to search for addresses seems to come down to the platform our interviewees are comfortable with. For example, those who use Apple devices prefer Siri whereas android users are happy with Google Assistant. Desktop user 5B uses Dragon NaturallySpeaking when she is on her PC and it can be conveniently used to find for addresses. As an assistive output device on a smartphone, screen reader TalkBack service on Android cannot read anything on the map itself. Braille display is even further away from digital maps accessibility as agreed by both 3T and 4L.

4.3.4. Accessibility Challenges

In this section of the interview, we asked our participants about the more distinctive difficulties they might have faced when using digital maps. We asked about language accessibility, whether the system can detect and set their preferred language of choice automatically. Most of our participants use English as their preferred language and have reported no issue with language compatibility. Although the group interview revealed, many digital maps are designed exclusively for the English language. 4L informed us that “A problem with these virtual assistants is that much of the features are available in English”. Using those maps with the non-English language selected, the screen reader reads out in odd accents. Every language has its unique name for significant locations. They also reported some of the maps do not respect this rule and only display the international name. Asking about the capabilities of apps or browsers to undo mistakes, 5B found it is hard to undo mistakes as a screen reader user. She ordinarily starts the whole process over whatever she was trying to do instead of finding a way to undo. On the PC, she refreshes the web browser, and on the smartphone, she closes and reopens the app. She also talked about unexpected behavior experienced from Google apps where the app crashed several times or while walking with navigation on, the app took her in the wrong direction. 4L also experienced similar unexpected behavior but he considers these are because of their limited visual ability instead of the apps.

One thing all participants had a positive experience with was the search functionality. Whether on a web browser or as an app, their preferred maps were able to find the specific location they are searching for. If they type the address correctly or say the address clearly, Google maps or apple maps would find the place. Asking about the percentile success rate to one interviewer, she confirmed she was able to find the place 95% of the time. However, the final question we asked all our participants exposed the grim reality that summarizes their user experience. The question "Did you ever felt a lack of control when using maps" was collectively responded with "all the time". Analyzing this response can interpret that while most of these popular digital maps have a rich algorithm to search through the database in the backend when it comes to the accessible and inclusive user interface, there is still a lot to improve.

4.3.5. Personal suggestions

Before concluding the interviews, we asked the participants for suggestions and recommendations on how we can design more accessible digital maps. Our first interviewee expressed the same desire that we are trying to achieve with this master's thesis. She stated screen readers love texts so if there is a way to make an alternative digital map that is text friendly and can be read by screen readers it would be very helpful for her community. She further recommended; the map does not need to be part of the main feature. It can be integrated as an alternative text-friendly layer for screen reader users.

2S has voiced her struggles with the color contrast ratio of current map design. She feels map elements have a very low color contrast ratio between elements and she finds it hard to distinguish.

Brainstorming during the group interview with 3T and 4L introduced a crucial idea on digital map exploration on a smartphone with a screen reader on. A significant issue raised by 3T was when Google maps app is opened on the smartphone, screen readers like VoiceOver or TalkBack never speak the current location. Afterward touching on the map returns no feedbacks. 4L suggests that as soon as the app is opened, a screen reader should be able to speak the current location where the user is. Then, when the user touches on a different location on the smartphone, the screen reader should be able to speak the location name where the user touched. Based on this touch-speak interaction, even a user with impaired vision would be able to draw a mental map of the location. As discussed earlier, 4L also suggested how a keyboard user on a browser can explore the map using arrow keys.

Our final interviewee is fond of vibration-based messages that some apps provide. Google maps provide no such tactile feedback functionality. She proposed Google maps to include vibration-sensitive feedback that is only triggered while the screen reader is on. She further clarified it could be one buzz for basic interaction, two buzzes for more specific interactions, and a burst of buzzes for advanced interactions. She gave us another interesting suggestion while we were discussing the redesign challenge that even if a screen reader can read the content of the map, questions remain which element is read and in which direction. She thinks “if even the most basic point of view was readable on the digital maps, we could draw a picture in our mind of the map layout”.

5. Discussion

In this section, the results from all three methods are further analyzed to figure out the common denominators of maps accessibility issues and examine any contradicting results. Seven redesign suggestions were presented including both screen reader and visual accessibility of interactive maps. The chapter concludes by discussing the limitations of this thesis and narrating closing statements.

5.1. Analysis

Thematic analysis based on the technique from Braun and Clarke (2006) was performed. Once all data is familiarized, code generation was undertaken distinctively for each method. Predefined search criteria of investigating research gaps in screen reader accessibility are considered codes from SLR analysis. Codes for accessibility evaluation were formulated from WCAG guidelines and success criteria while for interviews, it was extracted from open coding. During the theme searching step, themes for Systematic literature review were developed studying research papers. Interview data codes were converted into common themes and then compared and matched with WCAG codes to generate themes of accessibility evaluation section. During the theme review process, much of the themes from SLR were discarded due to irrelevance with the thesis subject. All themes were then defined and analyzed independently. Finally, a consolidated analysis was constructed to reflect on what changes are required in future interactive map design.

5.1.1. <u>Systematic Literature review</u>

When the publication timeline for the papers was investigated, it is apparent most of the research put into making digital maps accessible came from the middle years of the last decade. 2016 has observed the highest number of papers published whereas 2010, 2014, and 2019 have seen only three papers published based on our search criteria. This gives insight that research into accessibility has received some attention several years ago but now it has lost its research appeal. Also considering a large number of filtered papers reflect on maps barriers, design challenges, literature review, etc. as opposed to generating solutions, it indicates that universal design or accessibility in digital maps is still a new concept that needs further research.

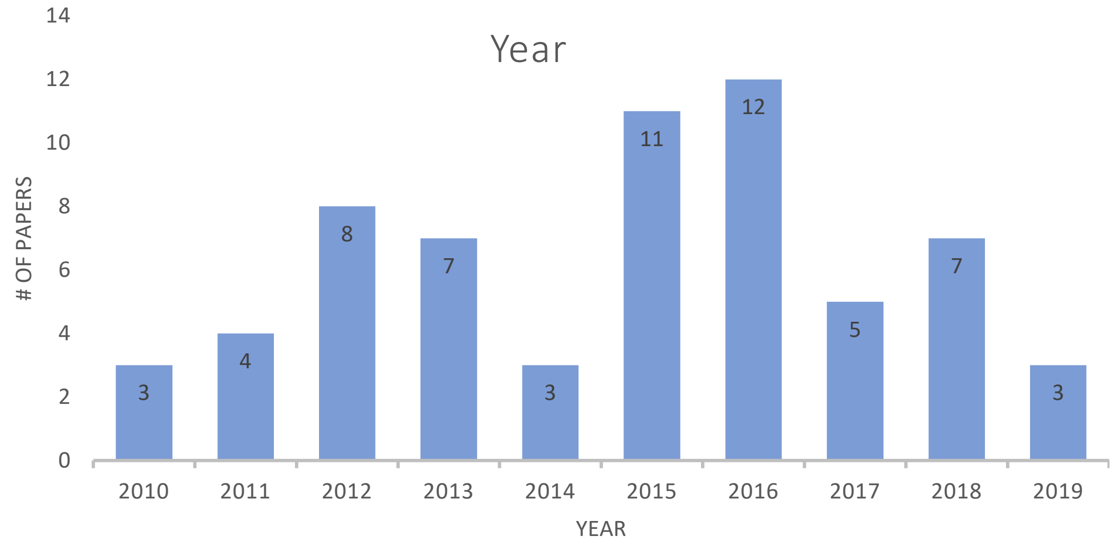


Figure 5-1: Number of publications of last one decade

After carefully reviewing all the selected papers in the systematic literature review following noteworthy patterns and research gaps has been revealed:

- Of all the 63 papers, the term “universal design” has been mention once (Kvitle, 2017), “design for all” was also mentioned once (Poppinga et al., 2011), and no mention of “inclusive design whatsoever in the body of any paper. Although all these terms can be found on a few of the paper’s reference list. We can conclude that while accessibility on maps in a digital map is an old concept and actively on research, the concept of universal design has not been applied to digital maps as profoundly as one would expect.
- It was observed during the paper filtering process, numerous papers cover research agendas related to physical accessibility like accessible cities, infrastructures, transports, etc. Moreover, numerous false positives related

to the term “accessibility” was filtered upon further study as it was being referred to the study on the inaccessibility of information in the sense of political, privacy, security barrier. This significantly implies that more research on the accessibility based on a user’s abilities and attributes are essential to close the digital divide gaps.

- This systematic literature review search criteria omitted any keyword related user groups specifically based on their physical and mental ability to find out when researchers work on the accessible digital maps, what user groups do they work on. It was discovered only visually impaired users, limited sighted to totally blind, color blinds, as well as deaf blinds, are the primary focus user groups for accessibility. Other user groups with possible limited abilities like elderly, motor system impairments, minimal educational background, etc. are not considered for universal design in digital maps. Future research can include these diverse user groups.
- Many alternatives and prototype solutions to use digital maps were introduced. Yet, a screen reader accessible solution was not discovered through this systematic literature review. This indicates a significant research gap in the universal design of ICT and digital accessibility

5.1.2. Accessibility Evaluation

Continuing from the final analytic point of SLR, Text accessibility evaluation draws a similar conclusion. None of the websites evaluated has screen reader accessibility. Even when some of the map web services partially offer screen reader readable contents, it reads without a context. Additionally, screen reading on the map is triggered only when the mouse cursor is hovered on the readable elements, meaning it is dependent on partial (mouse) or total (touch) motion-based interaction rather than switch-based interaction(keyboard). A map designer can always offer an option to refer users to an alternative link or section on the website where crucial information of the map is summarized into the text as non-graphical substitutes. Our research discovered several websites with such an alternative. But the popular digital maps website that we investigated did not have such alternatives. For the sake of the evaluation, we disabled all style sheets of the websites to see what contents remain, how dependent the maps are to graphical elements and whether disabling stylesheets can trigger screen readability to some extent. Although none of the websites returned positive results, we must admit, maps are inherently graphical medium, map designers are heavily focused on visual information and WCAG evaluation does not always reflect real-world implementations.

Another sign of screen reader accessibility is tab navigation of a website. Out of all the web map services, only two maps can be accessed using the keyboard tab button and navigated using arrow keys. Yet, the extent of what can be achieved once the selector is moved inside the maps is very limited to none. Users with limited motor skills might opt for speech recognition user interaction over mechanical one and we discovered none of the evaluated maps can be used with a voice command. Moving away from the maps screen readability itself, we further discovered the absence of instructions and label indicator information of the maps. Lack of such complementary information creates accessibility gaps among users from different ICT skill level. Even when it comes to the users who can use maps with eyesight alone, there are ranges of the micro and macro level of accessibility violation. If we summarize our whole evaluation process, it can be concluded: “accessibility compliance not met”.

5.1.3. Interviews

Several contradictions against accessibility evaluations were revealed upon analysis of the interview data. Our map selection for evaluation was based on most visited interactive maps websites and excluded evaluating one of the most used maps – Google maps. But based on the interviews it seems that for most participants any interaction with digital maps comes from Google maps. Also, for the scope of our research, we focused the evaluation on PC users and website-based map services. We discovered that our participants tend to use google maps on their mobile devices as an app. One reason for choosing mobile devices can be Attributed to keyboard inaccessibility. As expected from the evaluation process, none of the participants seemed satisfied with keyboard interaction with the interactive maps they tried. But even when they are using their favorite maps apps on mobile devices, limitations of what can be done overshadow their expectation. Turns out the only thing it is good for is literally touch typing an address to search for navigation purposes. Using a touch screen for screen reading the map contents and exploring the map contents is impossible. Another contradicting result against evaluation is voice interaction. We found voice commands to be inaccessible, but participants think it is possible to search for addresses with virtual assistants like Google Assistant or Siri. Further analysis shows the underlying reason for being satisfied with the voice input lies in the motivation for using maps. Navigation is the primary purpose of using Google Maps for all interviewees. This does not mean they are not interested in exploring the map content with a screen reader. Some of them tried, failed, and never tried again. Throughout the interview sessions and interview data analysis process a constant theme of dissatisfaction among all participants was observed. Consequently, all participants were able to suggest creative ways to improve interactive map accessibility.

5.1.4. Summary

After analyzing the systematic literature review and discovering the research gap in screen reader accessibility of interactive maps, we went into the accessibility evaluation and interview process expecting similar results. We detected a clear absence of alternative text in interactive maps as well as any other form of accessible alternatives. Likewise, we observed a common dissatisfaction among participants when it comes to using maps with a screen reader. Later data collections revealed significantly more accessibility and usability issues that could not be projected from the systematic review. These issues, which were established as a theme for the analysis process produced identical arguments about inaccessibility in some cases. Issues like keyboard inaccessibility, low color contrast inside the maps, non-resizable text, and lack of other forms of magnification options were unfolded through both WCAG evaluation and participant feedback. In contrast, some issues analyzed from these two methods were mutually exclusive. Experts evaluating the maps found the inadequate presence of maps legends and symbols. They also marked the keyboard tab function for both navigation order and focus visibility to be inaccessible. These issues were never raised during the interview sessions. Moreover, experts considered the voice command function on maps to be impossible to use. But interviewees had no complaints against Google Assistant, Siri, or 3rd party desktop alternatives. There was multiple discussion about touch accessibility, haptic feedback, language settings during interviews that were not investigated during accessibility evaluation due to the scope of the thesis. Even within different participants, there is a discrepancy where one participant might find the lack of a feature an issue whereas another participant never felt the need. This signifies the point that specific issues affect specific user groups. Map designs should pertain to "flexibility in use" – the second principle of universal design. One success criterion check was to disable all stylesheets and check the extent of remaining functionality. Maps are fundamentally a graphic dependent medium. Disabling style sheets means removing graphical and interactive functionality. Some evaluation objectives might look relevant in a formal setting but do not always reflect real-life issues.

5.2. Redesign Suggestions

Several accessibility design improvements can be derived from this research; from the SLR, from the WCAG evaluations, and from the user group interviews. In this section of the thesis, we will present our cases of these redesign recommendations. Van Welie (2001) discussed several alternative approaches to executing redesign in his dissertation. One of these approaches is to identify the specific interface element that requires revision and perform a micro-level design upgrade. While this approach requires less time on the drawing board, it has the potential of disrupting the stable operational consistencies and might not even solve the UI issue completely. Alternatively, Designers might target a whole section of the interface in question and substitute, adjust, or add the necessary elements. While designers might still run into similar issues as with micro-level redesigns, they have more control over the integration process with the rest of the interface. The final possible approach is a full redesign of the interface with more severe tradeoffs like tedious redesign process, user training, increased negative feedback, etc. Echoing the last approach, Johnson, Johnson, and Zhang (2005) commented “Redesigning interfaces is not only time consuming, but costly and frustrating for both the users and designers”. This makes sense because the redesign process involves researching the user group, their typical interaction with the system, and may involve designers from different departments of expertise working together. For the scope of this thesis, only general redesign suggestions will be discussed. Followup works like redesign approaches, usability testing and further iteration process will not be exploed.

5.2.1. Alternative Text

The complete lack of alternative text is the biggest barrier to interactive maps being read as well as explored by users with severe low vision to total blindness. Even when maps rely on graphical contents to convey information, graphics are not the only element to successfully read it. For example, the name of the roads, buildings, stores, forests, countries, etc. are all written on the maps as text because even someone without any visual impairments has to read the name of a location. So, to make maps more inclusive for visually impaired users, map designers have to add the alternative text for every single element they add to their maps. This simply means adding one extra step during a new map design process where after adding an element, manually adding the alternative text of that element that can be read by a screen reader. Following is an illustration of what alternative text can be included and to what extent. As a foundation, whatever text that can be seen on the map need to be text altered. All icons that can be seen also need to be text altered with a relevant description. For example, Grocery, public transport stoppage, restaurant, zoo, etc.

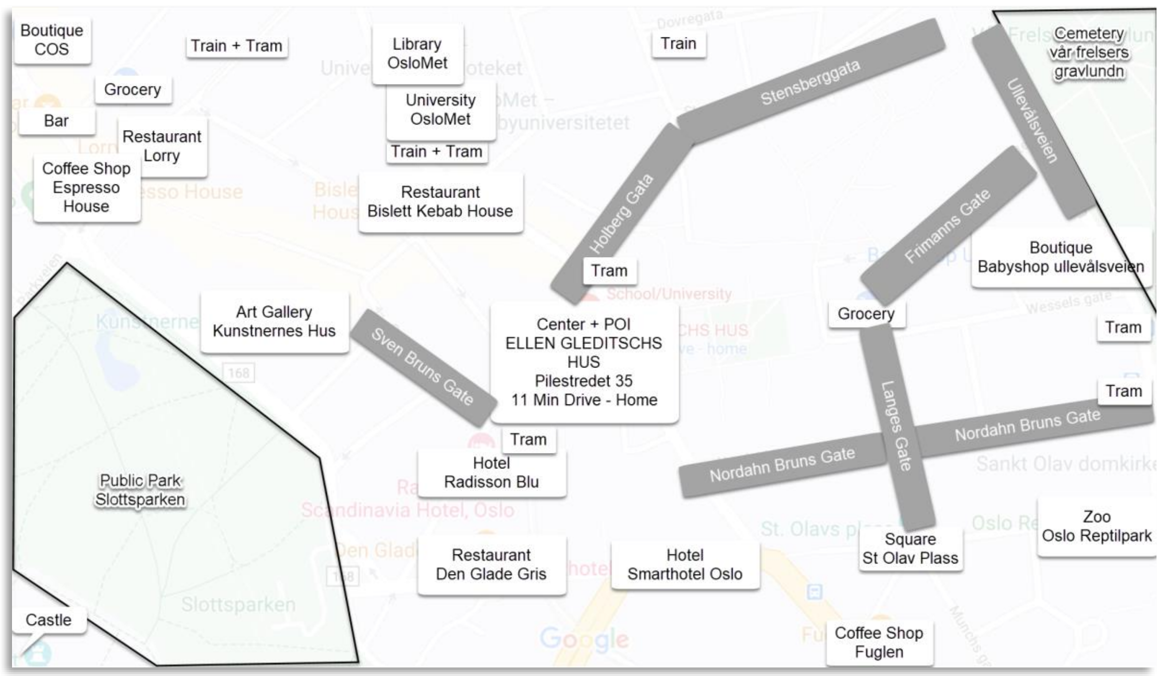


Figure 5-2: Alternative Text Backend View

5.2.2. Screen Reader Interaction

Once all elements of the maps are screen readable, the question arises how these elements will be read to the user by a screen reader. Screen readers are designed to read texts in a linear fashion for a given phrase or paragraph. Maps on the other hand are anything but linear. Places on the maps are mostly non-linear, randomized, and unorganized due to the complexity of geography and Anthropology. Even if the screen reader is programmed to follow a direction pattern when reading maps – left to right, top to bottom, from center to clockwise or anticlockwise, several factors would make it impractical. If the map has too many locations, for example, a map of a city – the screen reader will suffer from information overload regardless of what direction the map is read. Additionally, even if the map does not have an overwhelming number of places like a map of the countryside, simply reading out the name of places is not map exploration. Research has shown (Jensen & Lisman, 1996), a human can store on average seven list items in its short term memory. That means the user will start forgetting names after the seventh location is read.

Interviewer 4L suggested, the best way for a screen reader to read map elements is to touch and read. According to his recommendation for the Google maps app, the system should be programmed to have the screen reader read the name of the places where the user places their finger. This way after placing a finger in several locations and having the location names read, the user can easily draw a mental map of the location. Then as the user moves to a different location on the maps by dragging their finger, the screen reader should instantly read the name of the place nearest to the center. This way users can start drawing a mental map of the newly moved location on the map. By applying this technique, the user will not only be able to read the map but also be able to explore. While the interview participant talked about the mobile app, this method can easily be applied for desktop users. The mouse cursor will play the role of the touch finger. The mouse click can replace finger touch while click + drag can substitute touch and drag.

Figure 5-3: Screen Reader Map Interaction

Another issue especially with populous locations is the concentration of numerous POIs in one location. For example, there could be an office building, a hotel, a restaurant, and a tram stoppage all concentrated in one small portion of the screen. When a finger is touched or mouse clicked, should screen reader read all these POIs or a few or just one? If a few or one, which ones are prioritized to be read? Participant 3T suggested a good solution to this issue during the brainstorming session. He suggested the solution already lies in the way interactive maps work. Interactive maps like Google maps are designed with a combination of many layers. As the users zoom in and zoom out, relevant POIs automatically appear and disappear. This way map readers can focus on the POIs most relevant for specific layers. Similarly, for screen reader users, the screen reader will only read the texts and icons that appear on a specific zoom layer. So, when a user for example has zoomed out to national or international borders, the screen reader will read country, state, or city names. Likewise, when the user has zoomed in the street blocks level, the screen reader will read the name of the establishments.

Figure 5-4: Zoom layer and screen reader - Read what is shown

5.2.3. Keyboard Exploration

While keyboards do not offer much freedom of two-directional interaction as mouse or touch, it can still be used besides the mouse or independently for the map interactions. Many popular maps already support keyboard arrow keys-based navigation on the maps. Google maps on the web for example provide advanced arrow key navigation. It allows the users to focus on a block of the map and randomly (or uses internal algorithm) lists all the relevant POIs on that block. Users can select a POI using keyboard digits associated with that POI. Alternatively, users can move to adjacent blocks in direction and a new list of POIs is created. Users can also zoom in and out functions using keyboard "+" and "-" buttons. This way users can potentially explore any part of the globe simply using a keyboard.

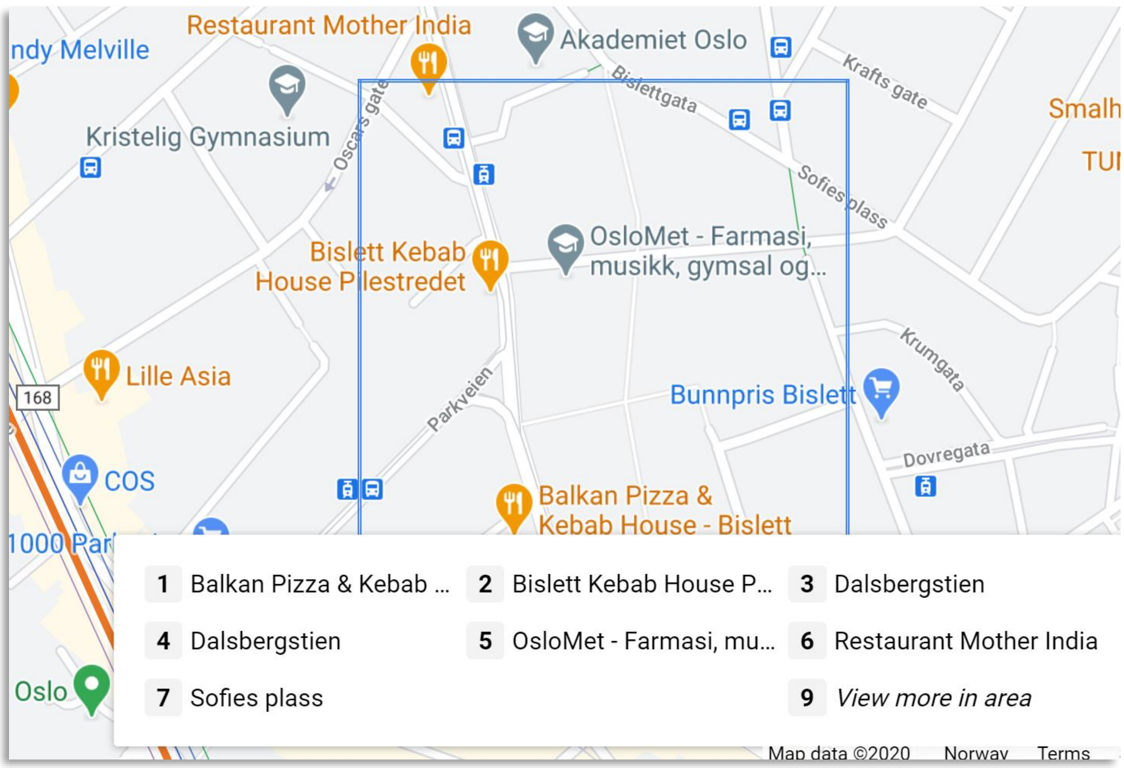


Figure 5-5: Google Maps Keyboard Navigation Example

But as participant 5B demonstrated, as soon as any screen reader is used while trying to navigate with the keyboard, arrow keys do not respond anymore. This points out the lack of screen reader integration with online maps and should be investigated by the interactive maps providers and solved. Another visual accessibility issue that needs to be addressed is the focus indicator. As shown in figure 5-5, The keyboard focus indicator is noticeably narrow and uses a very similar color as a few of the text on the maps. Users with low vision might find it difficult to properly utilize this feature. The focus indicator should have bolder lines and a unique distinguishable color.

5.2.4. Haptic Vibration Assistance

As interviewee 5B suggested, haptic feedback can aid the visually impaired users to interact with the maps especially on mobile devices more efficiently. Vibration-based haptic feedback is already used natively almost on mobile operating systems. Many apps and games inventively use this technology to simulate the real-world feel or communicate with the user. For example, a camera app called “Halide” keeps vibrating until the camera is straight while in grid mode. The racing game “GRID Autosport” simulates engine humming, bumps, breaks, etc. Given the users with severe visual impairment are more sensitive to haptic senses, they can be mostly benefitted if these maps apps can include various haptic vibrations. The modern haptic vibrations are two dimensional – making use of both vibration patterns and intensity. A combination of these two variables can produce several unique interaction feedbacks for the users. We propose the following guide as a starting point to integrate haptic vibration feature on interactive map apps:

- Touch on blank space on the map – soft single buzz
- Touch on a POI – strong single buzz
- Drag finger to move to a different location – soft double buzz
- Zoom out - strong double buzz
- Zoom in - strong triple buzz

5.2.5. Accessible Color Contrast

Maintaining an accessible color contrast ratio seems to be a recurring issue with maps. Google Maps, Apple Maps, and Bing Maps, three of the most used maps – all suffer from low color contrast ratio for both “text – background” as well as “Foreground – background”. Interview Participant – 2S has pointed out this issue as well. An argument can be made that there are many built-in and 3rd party solutions to simulate higher contrast but that is not a universal design solution.

Map designers should not favor artistic integrity over inclusive design choice.

Figure 5-6: Before and After Contrast improvement Comparison

5.2.6. Integrated Text resize function

A built-in option to resize the text on the map is another critical accessibility feature that needs to be added. Currently, the only solution, at least on the browsers, is changing the zoom size of the browser window that automatically resizes everything inside the map including the text. But for better accessibility, interactive maps should also have an integrated function of resizing text. One possible suggestion is to have three text size buttons that users can choose from based on their ability and situation.

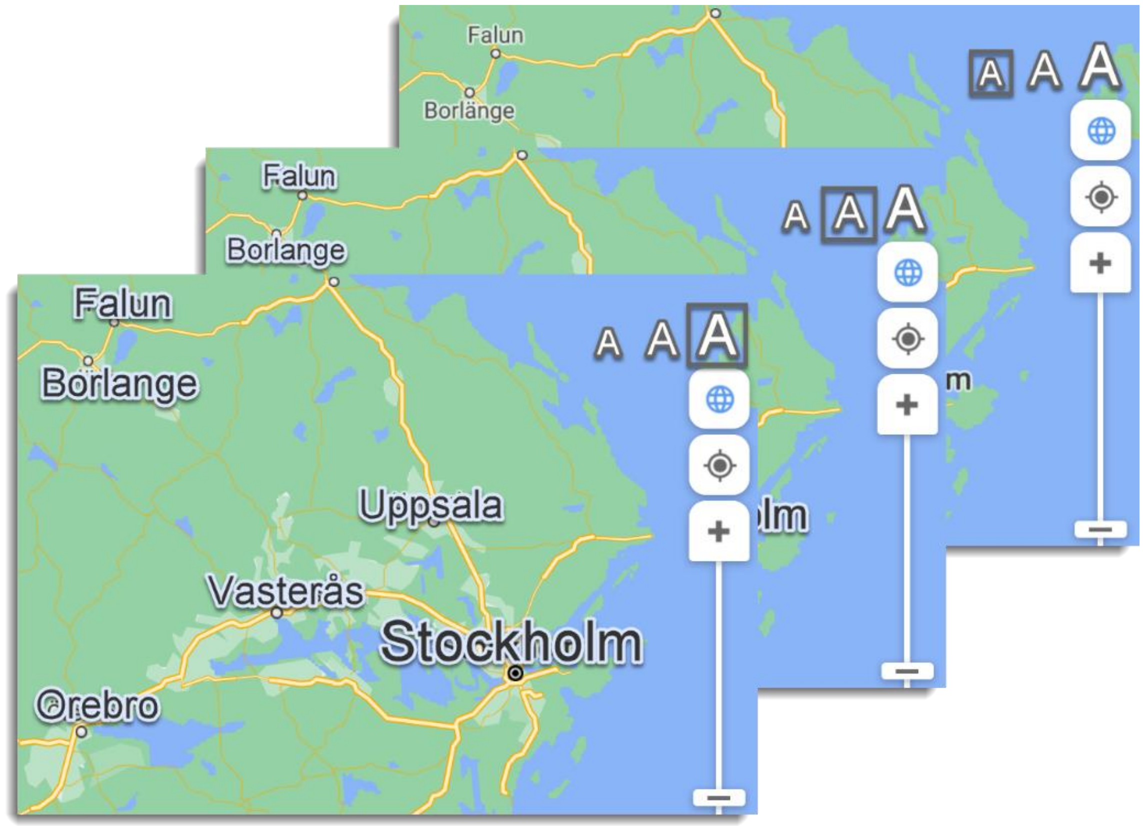


Figure 5-7: Built-in zoom function example

5.2.7. Map Guide

Any interactive map should include a map legend feature where all the icons, landscape element, road types, etc. is listed separately and can be accessed through a “map legend” button. Some map databases like Google maps have a massive list[1] (1 Full List: https://www.blog.Google/products/maps/Google-maps-gets-new-look/
) of icons and listing all items can be overwhelming. This issue can be addressed by following the simple rule discussed in section 5.2.2, “Read what is shown”. Map legend should dynamically show only the elements present on the map for a certain layer and zoom level.

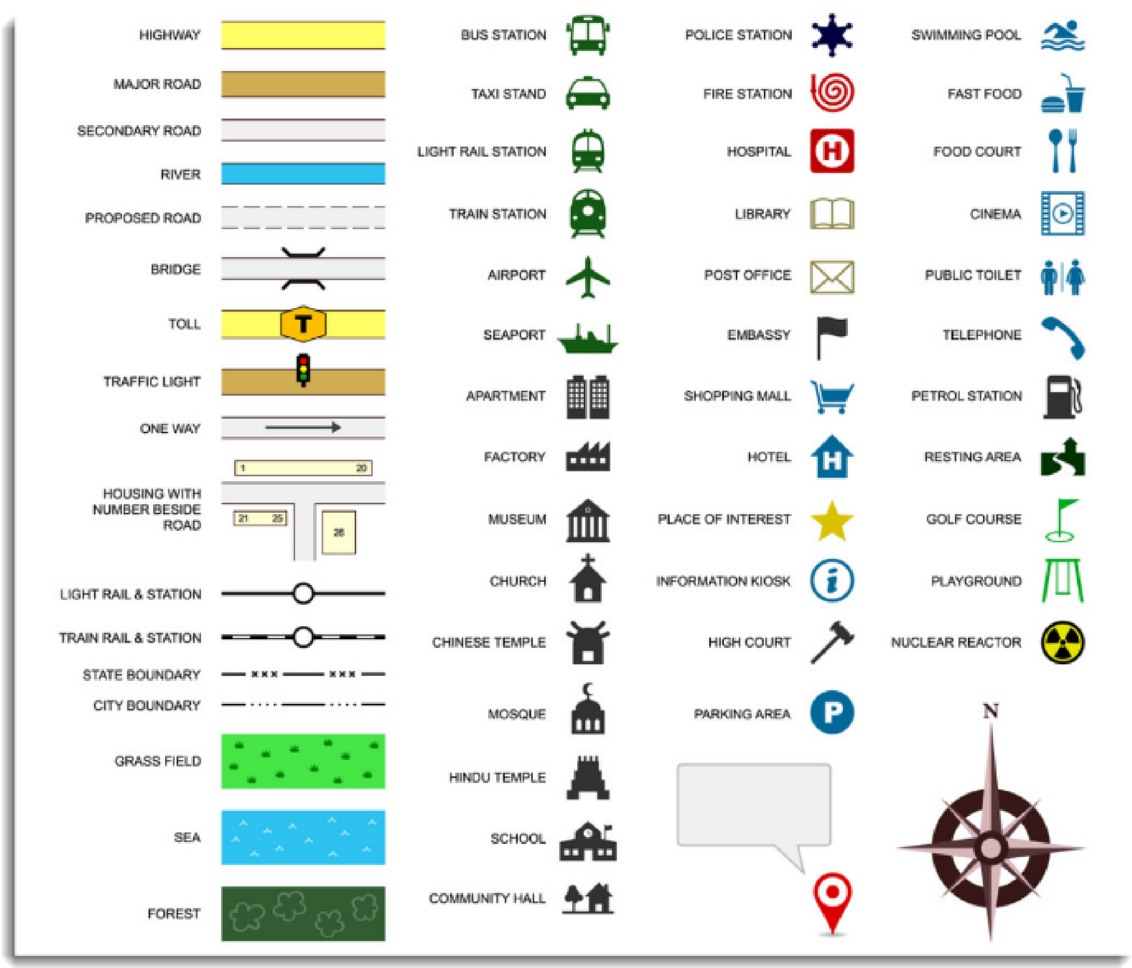


Figure 5-8: Generic Map legend Example

5.3 Limitations

Despite careful early planning of the thesis project, there are several limitations of the thesis that can be considered for potential criticism. Google Scholar was chosen as the only database source for the systematic literature review. It was decided because Google Scholar has the largest database, 389 million documents as of August 2018 (Gusenbauer, 2019) with easy accessibility, convenience, and advanced search query feature. But later study by Gusenbauer and Haddaway (2020) showed Google scholar is not the most suitable database for systematic literature review. They reported Google Scholar search algorithm is “more concerned with tuning its first results page”, making it more appropriate for the exploratory search for users interested in few initial search results. Yet the biggest issue with Google scholar is retrieval failure. Google Scholar has been found to report duplicate, repeated, and identical search results. This makes any future replication of the SLR search result impossible. Gusenbauer and Haddaway (2020) later sympathized with the users of Google Scholar defending, users are usually guided towards Google Scholar for its convenience over strategic consideration, being unaware of its shortcomings.

Another potential criticism point is the decision to include “maps” as a title in the search result. Forcing database to only show documents with “maps” on the title can be seen as a divisive decision but it was done because having “maps” as intext generates query return in a six-digit number which is not manageable to filter through. Also, the plural word maps were chosen over “map” because the initial study showed searching with “maps” gave more relevant and manageable query returns. Furthermore, the SLR can be considered already slightly outdated as it was conducted 16 months before the submission of this thesis and since only the English language was inspected, SLR is susceptible to language bias.

The number of participants for the semi-structured interview can be considered adequate as participants were able to validate the results found from SLR and accessibility evaluation. However, due to the nature of this thesis, the sample group was limited to individuals with severe low vision to total blindness. This sample group was enough to formulate accessible design suggestions for screen reader users. However, variable visual acuity is not the only user group who interact with digital maps and including users group with other visual impairment like color blindness or tunnel vision could have pointed out more accessibility issue with interactive maps and even propose accessibility improvements. This thesis only offered redesign suggestions to extend the accessibility of interactive maps and promote universal design choices. Initially, it was planned to develop design low fidelity and possibly high-fidelity prototypes based on these suggestions and conduct usability testing. But due to shortage of time and unforeseen circumstances related to the ongoing Covid-19 pandemic, the prototype development and the testing plan was later withdrawn. So, while the newly introduced design recommendations are appealing and seem practical solutions on paper, further study is required as well as the development of prototypes and conducting user testing to understand the real-world implications of these suggestions.

5.4 Conclusion

The purpose of this thesis was to discover the Research gap and accessibility issues of interactive maps and provide possible solutions. The current study has revealed that despite providing a massive geographical information database with a vast array of features, interactive maps both in websites and mobile app platforms seem to fail in the accessibility department. Not only do these tend to be screen reader inaccessible, but often many visual accessibility requirements also fall short. The investigation indicates that these issues originate from the lack of interest from researchers towards richer digital maps accessibility and map maker's lack of effort towards universal design. Fixing these accessibility issues does not involve “going back to the drawing board and starting from scratch”. Minor modification to the existing maps systems or adding a few extra steps for new systems can be sufficient enough to make interactive maps inclusive for substantially more user groups and reduce the gap between user ability and system demand.

The first research question was answered through a systematic literature review. We found a substantial research gap in screen reader accessibility of digital maps specifically for exploring the body content of these maps in addition to using for navigational purposes. Even after a rigorous filtering process, the remaining 63 papers either discuss accessibility issues or propose various prototype solutions nonrelated to screen reading. Furthermore, the concept of universal design is nonexistent on these reviewed papers. Answer to the second research question was formulated from two separate and thorough methods of investigative data collection. The most suitable evaluation tool, WCAG 2.1 guideline was used with three expert evaluation to discover accessibility issues on six contemporary interactive maps. Then to explore if any accessibility issues that were not discovered through expert evolution, regular users of these contemporary maps were interviewed with semi-structured question sets. Results from both these data sources were compared, matched, and corroborated. Data analyzed from all three methods along with the researcher's expertise on universal design study were applied to answer the third and final research question. It was observed that instead of modifying or adding a design element, internal functionality revision is the key to screen reader accessibility of interactive maps. These functionalities are: adding alt text for each element on the map, adding the feature of touch or click to read the body text or icon description on the map, fixing the screen reader with keyboard navigation function, and providing sophisticated haptic vibration feedback. This thesis goes beyond text alternative accessibility and also proposes three more redesign suggestions: improved contrast, integrated text resize buttons, and inclusion of a dynamic map legend button.

There are several further research potentials from this thesis. The systematic literature review explores only a small fraction of the database for interactive map accessibility. It is possible to find promising prototypes and solutions regarding this from a new SLR with a different set of keywords and with a more suitable database. Even though the accessibility evaluation was in-depth, for the scope of the thesis, the evaluation was performed only on the desktop platform. Evaluation of maps mobile apps should also be evaluated in the future. Moreover, even though the latest available WCAG guideline, 2.1 was used, a newer set of guidelines 2.2 and 3.0 are on the horizon (Rathfux, Thöner, Kaindl, & Popp, 2018). It opens possibilities for future evaluation with these newer guidelines. As discussed in the previous section 5.3 Limitations, only accessibility improvement suggestions were proposed. Based on these suggestions, prototypes can be developed and perform usability testing on targeted user groups.

The Map is a staple artifact of human history that has been used for centuries and continued to be used and evolved with civilization. Cartography is witnessing a major technological migration as we move from physical medium to the virtual medium of information. Subsequently, this is introducing a vast number of diverse users with diverse abilities, environments, and situations. As engineers and researchers, it is our responsibility to ensure that all members of the society are included in the technological migration process and not left out with outdated technology. The best way to ensure this is continuous research on maps accessibility and adopting universal design in the map's development process.

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APPENDIX 1: Systematic Literature Review Papers List

#	Year	Title	Authors
01	2015	Evaluation of web accessibility on the maps domain	(Medina et al., 2015a)
02	2015	Investigating accessibility on web-based maps	(Medina et al., 2015b)
03	2016	Web Accessibility Barriers in Geographic Maps	(Calle Jiménez & Luján-Mora)
04	2012	Providing web maps for everyone. Understanding users and their requirements	(Sabine Hennig et al., 2012)
05	2015	From open geographical data to tangible maps: improving the accessibility of maps for visually impaired people	(Ducasse, Macé, & Jouffrais, 2015)
06	2010	Usability Evaluation of Web-based GIS Applications: A Comparative study of Google Maps and MapQuest	(Khan & Adnan, 2010)
07	2016	Usability and Accessibility of Web Maps: Considering New User Groups and their Requirements	(S Hennig, Vogjer, & Wasserburger, 2016)
08	2018	ICT as a tool to foster inclusion: Interactive maps to access cultural heritage sites	(Marconcini, 2018)
09	2018	"Towards “Tourism for All” – Improving Maps for Persons with Reduced Mobility"	(Nowak Da Costa & Bielski, 2018)
10	2015	Research on User Preferences for the Functionality of Web Maps	(Balciunas & Beconyte, 2015)

11	2016	Understanding Spatial Pattern Cognition from Tactile Maps and Graphics	(Perdue & Lobben, 2016)
12	2015	How user-friendly are online interactive maps? Survey based on experiments with heterogeneous users	(Poplin, 2015)
13	2018	Accessible Interactive Maps for Visually Impaired Users	(Ducasse et al., 2018)
14	2017	Accessible maps for the colour vision deficient observers: past and present knowledge and future possibilities	(Kvitle, 2017)
15	2017	Accessible Web Maps for Visually Impaired Users: Recommendations and Example Solutions	(Sabine Hennig et al., 2017)
16	2018	Design of an Architecture for Accessible Web Maps for Visually Impaired Users	(Calle-Jimenez, Eguez-Sarzosa, & Luján-Mora, 2019)
17	2019	Grand Challenges in Accessible Maps	(Froehlich et al., 2019)
18	2011	Making Visual Maps Accessible to the Blind	(Buzzi, Buzzi, Leporini, & Martusciello, 2011)
19	2018	SIG: Making Maps Accessible and Putting Accessibility in Maps	(A. M. Brock et al., 2018)
20	2011	HapticRiaMaps Towards Interactive exploration of Web World maps for the Visually Impaired	(Kaklanis et al., 2011)
21	2013	A Mobile Interactive Maps Application for a Visually Impaired Audience	(Kaklanis et al., 2013a)
22	2013	Enriching Graphic Maps to Enable Multimodal Interaction by Blind People	(Senette, Buzzi, Buzzi, Leporini, & Martusciello, 2013)

23	2011	TouchOver map: audio-tactile exploration of interactive maps	(Poppinga et al., 2011)
24	2013	Open Touch/Sound Maps: A system to convey street data through haptic and auditory feedback	(Kaklanis, Votis, & Tzovaras, 2013b)
25	2010	Making Digital Maps Accessible Using Vibrations	(Schmitz & Ertl, 2010)
26	2014	Verbally Assisting Virtual-Environment Tactile Maps: A Cross-Linguistic and Cross-Cultural Study	(Lohmann, Yu, Kerzel, Wang, & Habel, 2014)
27	2014	Audio Tactile Maps (ATM) System for the Exploration of Digital Heritage Buildings by Visually-impaired Individuals - First Prototype and Preliminary Evaluation	(O'Sullivan, Picinali, Feakes, & Cawthorne, 2014)
28	2016	Interactive spatial sonification for non-visual exploration of virtual maps	(Geronazzo et al., 2016)
29	2017	Cognitive maps of individuals with blindness for familiar and unfamiliar spaces: Construction through audio-tactile maps and walked experience	(Papadopoulos, Koustriava, & Barouti, 2017)
30	2019	Automatic derivation of on-demand tactile maps for visually impaired people: first experiments and research agenda	(Touya, Christophe, Favreau, & Ben Rhaiem, 2019)
31	2019	Comparing Interaction Techniques to Help Blind People Explore Maps on Small Tactile Devices	(Simonnet, Brock, Serpa, Oriola, & Jouffrais, 2019)
32	2012	Spatial Text Visualization Using Automatic Typographic Maps	(Afzal et al., 2012)
33	2012	Development and Evaluation of Sonified Weather Maps for Blind Users	(Weir et al., 2012)

34	2015	A practical example of a collaborative learning experience for engineering students: How to build accesible indoor maps	(Calle-Jimenez, Sanchez-Gordon, Rivera-Pastrano, & Luján-Mora, 2015)
35	2016	Accessible Online Indoor Maps for Blind and Visually Impaired Users	(Calle-Jimenez & Luján-Mora, 2016)
36	2016	BlindWeb Maps – An Interactive Web Service for the Selection and Generation of Personalized Audio-Tactile Maps	(Götzelmann & Eichler, 2016)
37	2015	Towards building an automated system for describing indoor floor maps for individuals with visual impairment	(Paladugu et al., 2015)
38	2010	Timbremap: Enabling the Visually-Impaired to Use Maps on Touch-Enabled Devices	(Su et al., 2010)
39	2012	Three-dimensional maps for disaster management	(Bandrova, Zlatanova, & Konecny, 2012)
40	2011	The usability of selected base maps for crises management—users' perspectives	(Konečný, Kubíček, Stachoň, & Šašinka, 2011)
41	2016	Customizable 3D Printed Tactile Maps as Interactive Overlays	(Taylor et al., 2016)
42	2016	Tangible Reels: Construction and Exploration of Tangible Maps by Visually Impaired Users	(Ducasse et al., 2016)
43	2012	Design and User Satisfaction of Interactive Maps for Visually Impaired People	(A. Brock et al., 2012)
44	2015	Exploration of Location-Aware You-Are-Here Maps on a Pin-Matrix Display	(Zeng & Weber, 2015)

45	2013	From perceptual supplementation to the accessibility of digital spaces: The case of free exploration of city maps for blind persons	(Tixier, Lenay, Gapenne, & Aubert, 2013)
46	2012	Verbally Assisted Virtual-Environment Tactile Maps: A Prototype System	(Lohmann et al., 2012)
47	2012	Interactively Displaying Maps on a Tactile Graphics Display	(Schmitz & Ertl, 2012)
48	2014	Interactive Tactile Maps for Blind People using Smartphones? Integrated Cameras	(Götzelmann, 2014)
49	2015	Interactive audio-tactile maps for visually impaired people	(A. Brock & Jouffrais, 2015)
50	2018	Accessible Maps for the Blind: Comparing 3D Printed Models with Tactile Graphics	(Holloway et al., 2018)
51	2018	Maritime Buoyage on 3D-Printed Tactile Maps	(Simonnet et al., 2018)
52	2016	LucentMaps: 3D Printed Audiovisual Tactile Maps for Blind and Visually Impaired People	(Götzelmann, 2016)
53	2017	The 3D Printing of Tactile Maps for Persons with Visual Impairment	(Rener, 2017)
54	2016	MapSense: Design and Field Study of Interactive Maps for Children Living with Visual Impairments	(Brule et al., 2016)
55	2013	Crowdsourcing techniques for augmenting traditional accessibility maps with transitory obstacle information	(Rice et al., 2013)
56	2013	A Crowdsourcing Platform for the Construction of Accessibility Map	(Cardonha et al., 2013)

57	2015	Using Crowdsourcing to Improve Accessibility of Geographic Maps on Mobile Devices	(Calle Jiménez & Luján-Mora, 2015)
58	2013	Digital Media (ICT) for development. The use of crowd sourcing maps as a tool for citizen empowerment and engagement. Case study of Map Kibera Project	(Gedgauda, 2013)
59	2017	Enriching the metadata of European colonial maps with crowdsourcing	(de Romas)
60	2015	PathS: Enhancing Geographical Maps with Environmental Sensed Data	(Bujari et al., 2015)
61	2016	Combining paper maps and smartphones in the exploration of cultural heritage	(Bujari et al., 2015)
62	2012	Mercator Atlas Robot: Bridging the Gap between Ancient Maps and Modern Travelers with Gestural Mixed Reality	(Marfia, Roccetti, Zanichelli, & Varni, 2012)
63	2016	Mobile User Experience in Augmented Reality vs. Maps Interfaces: A Case Study in Public Transportation	(Kamilakis, Gavalas, & Zaroliagis, 2016)

APPENDIX 2: Interview Guide

Before the interview is commenced, interviewees will be asked if they have thoroughly read the information letter along with the consent form to ensure they know their rights and our treatment of their personal data. Once confirmed, the consent forms will be signed. After this formality, a brief description of the project and their participation role will be orally presented. It will also be reassured that they can stop the interview at any time they desire and decline to answer any question without the need to provide any explanation. They will also be asked if they have any question before the interview is officially started.

1. Experiences with Digital maps
    a. For what purposes do you use digital maps? E.g, see the weather, finding points of interest like closest grocery shop, finding a city, directions?
    b. What sorts of digital maps have you tried using? E.g. Google maps, apple maps?
        i. If multiple, do you prefer one provider over others? If yes, why?
    c. On which platform do you use maps? E.g., Desktop, tablet, mobile, others?
        i. If multiple, do you prefer one platform over others? If yes, why?
    d. Has any system ever offered you a non-graphical alternative to the digital maps? E.g. additional link to a text-based alternative.
2. Assistive technology questions:
    a. Do you or did you ever use maps with keyboards? If yes,
        i. Tell me about your experience
        ii. Ever encountered mousetrap?
        iii. The focus button follow a meaningful sequence
    b. Do you or did you ever use maps with touchscreens? If yes,
        i. Tell me about your experience
        ii. Challenges faced when using digital maps with touchscreens
    c. Do you or did you ever use digital maps with screen readers? If yes,
        i. Tell me about your experience

        ii. Challenges faced when using screen reader as display

   d. Do you or did you ever use maps with any of the following technology and if so, your experience:
        i. Braille display
        ii. Voice command
        iii. Screen magnifier
        iv. Any other input device

3. Accessibility features of digital maps
   a. When you load a digital map on websites or as a mobile app, does it automatically switch to the language of your phone or PC?
   b. Did you ever have to learn something new in a digital map and how was the experience?
   c. When you make mistakes while using digital maps,
   d. How helpful do you find the search feature of digital maps
        i. Usability with your assistive technology
        ii. Finding the location you searched for
4. Challenges and solution
   a. Map focus, content or screen changes unexpectedly
   b. Did you ever felt a lack of control when using maps
   c. Have you ever experience where your desired digital map is usable on one device and not in other. E.g. can use it on smartphone but not on desktop
5. Opinions and suggestions for improvement regarding lack of accessibility in digital maps

The participants will then be introduced with a prototype of web map designed to be more accessible towards screen reader users. Participants will be given a series of tasks to perform on the prototype and will be asked the following questions.

APPENDIX 3: Consent Form

Are you interested in taking part in the research project:

Evaluation of accessibility in interactive maps and design recommendation to enhance screen reader accessibility?

This is an inquiry about participation in a research project where the main purpose is to discover how much geographical information presented in digital form is meeting the accessibility requirements of user groups with various degree of visual impairments. Participants will also take part in testing a prototype of a map that reproduces dynamic maps with text-focused based format and give their feedback accessibility improvement and point out the barriers. In this letter we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project

Digital maps have been an integral part of modern life. We use digital maps online and offline on our smartphone, tablets, computer, kiosk etc. Whether to venture into an unknown location, check the latest traffic update, find out the weather forecast of surrounding cities on the television we come across digital maps every day. While maps have successfully evolved into digital form from paper and other physical mediums, how much evolution present digital maps have observed to ensure accessibility and implementation of universal design principles? One of the biggest features that digital maps have to offer actually creates a barrier to a number of group of people. Maps by nature have to rely on graphical medium to present its information content. But the users who have temporary or permanent and limited to nonvisual ability are excluded from reading maps for this reason. In this thesis, we delve into finding out how much research has been done in the field of cartography to ensure accessibility and universal design. Then we will conduct hands-on evaluations of a few weather-based digital maps websites using expert, automatic and end-users. We will also have an attempt on developing a digital map prototype where the map's graphical information can be converted or presented into textual format. We will also ensure the prototype follows the guidelines and principles of WCAG and universal design. The research questions of this thesis as bellows

RQ1: How much research has been done so far towards inclusive designing of digital maps?

RQ2: What are the most common accessibility issues currently present in digital maps?

RQ3: What new design element or change to the existing elements could make the digital map more accessible?

This is a master's thesis research process. Participants data collected here are absolutely for research purposes only and will be destroyed after the end of the research project.

Who is responsible for the research project?

Oslo Metropolitan University is the sole institution responsible for the project.

Why are you being asked to participate?

This project focuses on researching the usability and accessibility of digital maps for users with various degree of visual impairment. You have been requested to take part in this project as you have identified yourself as a digital media user with visual impairment. You are part of our selection criteria group of five individuals with minor to major visual impairments.

What does participation involve for you?

Your participation will be divided into two sessions. For the first session, you will take part in an interview. The topic of the interview will the accessibility of digital maps. We will ask you question about how much easy you find currently available digital maps online for both dynamic and static maps. We will also inquire about what problems do you face when using digital maps. Finally, we will ask you about your suggestions on how maps can be redesigned to meet your ability needs. The interview will be semi-structured, and it will last for approximately 30 minutes. For the second part of your participation, you will be introduced with a digital map prototype. You will be given a small series of tasks to perform on the map. Once tasks are completed you will be asked to provide your understanding and feeling about the prototype. The second session is mainly an observation of your interaction with the prototype. The second part is expected to run for 30 minutes approximately. The interview session will be recorded in audio format. The audio file will be destroyed once it is transcribed on text. The observation of your interaction with the prototype will not be recorded in either video or audio format but notes will be taken during the observation. All data of your participation will be deleted at the end of the project.

Participation is voluntary

Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data

We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act).

I, the student of the thesis project, Sayed Kamrul Hasan, and my thesis supervisor, Terje Gjøsæter will be the only two persons responsible for handling your personal data during the life cycle of this project. All personal data will be kept securely ONLY in our university server. The interview audio will be recorded in a highly secure Android smartphone and will be transferred to the university after the interview session. Your personal data will be kept separated from the rest of the collected data and will be ensured that it can only be linked through arbitrarily assigned code saved in a secured excel file. For extended security, all your personal data and collected data will be encrypted. The transcription of your interview audio will be performed manually by me without any 3rd party software or online service. For the publication, the participants will remain anonymous. The participants will be identified as **1M**, **2S**, **3T**, **4L** and **5B**. Only age, occupation and visual impairment type will be indicated associated with the anonymous participants.

What will happen to your personal data at the end of the research project?

The project is scheduled to end 30th of June 2020*.* At the end of the project, all personal data, as well as collected data through interviews and observation, will be anonymised by deletion.

Your rights

So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?

We will process your personal data based on your consent.

Based on an agreement with Oslo Metropolitan University, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?

If you have questions about the project or want to exercise your rights, contact:

- Oslo Metropolitan University via Terje Gjøsæter by Phone: 67 23 88 97 or by e-mail: terje.gjosater@oslomet.no. Student, Sayed Kamrul Hasan by Mobile: 486 71 053 or by E-mail: s329933@oslomet.no
- Our Data Protection Officer, Ingrid S. Jacobsen by Phone: 67 23 55 34 E-mail: personvernombud@oslomet.no
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Yours sincerely,

Terje Gjøsæter Sayed Kamrul Hasan
Project Leader Student
(Researcher/supervisor)

Consent form

I have received and understood information about the project Universal design implementation of maps by converting geographical information into textual information and have been given the opportunity to ask questions. I give consent:

- to participate in the Interviews
- to participate in prototype interaction observation

I give consent for my personal data to be processed until the end date of the project, approx. 30th of June 2020

(Signed by participant, date)

APPENDIX 4: Interview Transcripts

4.1 Interview 1

Interviewer: All right we can start our interview now. So, as I explained to you This interview is more about the exploration of the map so my first question to you, is your experience with digital Maps, Meaning usually for what purpose do you use digital Maps for

1M: Digital Maps are not accessible at all

Interviewer: Thank you for saying that.

1M: If I were to use them, I would use them for the same purpose, you know, finding, look around, or things to do (laugh). But unfortunately. It does not give any apps for blind and visual impaired who depend on.

Interviewer: Do you use it for navigation, at least?

1M: I use it some time like GPS app but yeah things just don't work.

Interviewer: Not even for, obviously which would make sense, not even for looking for weather information in map view? Or exploring a city or a country? No?

1M: Nope

Interviewer: Okay. Cool. Well, when you do you use map which maps do you use? Google maps, apple maps?

1M: I used Google maps, I have tried using it, I have tried using apple maps as well and actually Google maps is better

Interviewer: Really?

1M: Yeah.

Interviewer: Wow! I thought Apple is more concerned about accessibility compared to Google! That's quite contradicting, thanks for pointing that out!

1M: You are welcome.

Interviewer: So that means if you must choose between Google maps and apple maps, you will choose?

1M: Google maps!

Interviewer: Okay. When you do use maps, for whatever purpose you use it for, where do you use it on? Like a desktop, laptop, tablet, smartphone?

1M: I mostly use it on my iPhone.

Interviewer: What about desktop?

1M: No

Interviewer: So, you have never tried using digital maps on desktop

1M: Wait, actually yes! I did try using it once but immediately gave up since it was not accessible with my screen reader

Interviewer: I agree. I tried using Google maps with a screen reader, it was horrendous!

1M: (Laugh)

Interviewer: I have to be frank; I loved the very first response you gave me about digital maps, you immediately mentioned digital maps are not accessible at all.

1M: I mean, I have to say you know!

Interviewer: Okay, I have one more question to you regarding experience with digital maps. Whenever you used digital maps as an app or especially on a website, did it ever happened to you where the app or website provided you with a link, like an alternative and more accessible version of the maps or the information of the map?

1M: No, never happened!

Interviewer: Now I will move into the next section of our interview Which is more about the assistive technology of the digital Maps. So since you mentioned that you never use digital Maps on desktops that means you have never used a keyboard with digital Maps. But you did mention you tried using desktop for digital Maps once so on that occasion did you use a keyboard, or you use only a mouse?

1M: No I did it use a keyboard and so on that occasion I was doing a presentation and I was looking at the map and was using a keyboard but it was not helpful at all cause to me it was just a picture so I was thinking what I'm going to do with this.

Interviewer: OK then I will skip the question regarding keyboards because it will not be relevant anymore.

1M: OK

Interviewer: What about touchscreen since you mentioned you use digital Maps usually on your Phone or tablet how do you, in general, find touchscreen usable with digital Maps

1M: so OK I use it on iPhone and you know there is this back button on the top left corner so but the actual map is On the middle right? So when I am um exploring Maps uh on my skin either it just keeps telling me all these numbers

Interviewer: What sort of numbers like longitude and latitude?

1M: I don’t know

Interviewer: Maybe they are co-ordination? Are those long numbers or short numbers?

1M: It changes all the time! And also when the maps something I searched for, it says it found these two items, for example, but it never mentions what it found!

Interviewer: Now tell me about experiences with a screen reader.

1M: So I use iPhone I don't know how it works with Android I never tried it but when I ask Siri to search for an address or tell me how to get to place It's actually a bit better than Google Assistant.

Interviewer: What about Braille display did you ever tried using Maps with Braille display I'm it might not make any sense but I'm just wondering Have you ever used

1M: no I haven't used it I don't know how it works

Interviewer: what about the screen magnifier

1M: It's no use for me

Interviewer: Any other input device that again mentioned that you used for digital Maps

1M: no nothing.

Interviewer: OK I'm done with the assistive technology related questions now thanks for your answers next few questions will be about the accessible features of digital Maps. So my first question is about the language so when you load a digital Maps on your phone or on website um does it load your preferred language I'm assuming you use Norwegian as your preferred language

1M: no I use English

Sayed: OK so that means it always load the language as English in digital Maps then

1M: yes

Interviewer: I also want to know about the learnability of digital Maps in general like did you ever have to learn something new like in any feature that you didn't know how to do and how any other digital Maps helped you with learnability like how easy to learn special feature or it never helped you with any information and you have to learn by yourself?

1M: I don't think I can give you too much information about that one all I can say I tried to use digital Maps as navigation, and it was not helpful in general. I spend a lot of time using digital Maps and it was never that much help anyway

Interviewer: The search feature I'm sure you use it all the time How is your experience with such feature or such button on digital Maps?

1M: I like the search button the search feature usually test only thing that works with me I use it with touch screen sometimes with voice command and I search for addresses and usually it finds the address

Interviewer: You speaking about challenges did you ever felt I know are you gonna say yes but I just want to hear from you did you ever felt lack of control when using digital Maps in general like you don't have any control over the use of the Maps

1M: Yes all the time yes Unfortunately

Interviewer: Does it ever happen to you when you have loaded a digital Maps on a website or on apps an all of a sudden the Maps change another location or energy another point or another area or it's froze or the left Maps completely shut down I'm asking about the album on expectancy of digital Maps here so it's behaving the way it's not supposed to behave

1M: Usually no because I use it all with iPhone and iPhone iOS is good with that but sometimes it gets frozen uh but usually nothing unexpected happens with Maps for me

Interviewer: Some positive response for a change

1M: Yeah!

Interviewer: Speaking about computability you mentioned you have used digital Maps on several platforms Phone tablet desktop so has it ever happened where one map is working on one device but when you move to another device it doesn't work at all that is difficult to use

1M: It depends. You know those people have multiple devices I sometimes it works might work on iPhone but it doesn't work on iPad Phone and iPad so not only a different platform in same company devices

Interviewer: So you're saying even with the same company but different devices it might not work sometimes

1M: Yeah!

Interviewer: And this brings us to our last question. What is your suggestion or recommendation of making Maps more accessible?

1M: I would say they could make 2 different kinds of Maps maybe the second Maps could be uh could have more text on it. it would be it's useful when screen reader moves through maps and it can read along the way. As you know, the screen reader loves text! So I suggesting designing kind of written map. It would be nice! Not sure how it will work. I realty don’t know.

Interviewer: Yeah this is exactly the challenge I'm facing because I am trying to design a digital Map prototype that would be accessible with a screen reader. Okay, this is the end of our interview. You have given me so many good points to talk about in my thesis. I really thank you for taking time participating in this interview.

1M: My pleasure. Good luck with your thesis!

4.2 Interview 2

Interviewer: Alright we can start the interview. First question, what are the main purposes do you use maps for?

2S: Navigation

Interviewer: Do you use it for anything else?

2S: No.

Interviewer: Can you read the content of the maps with your present visual ability or do you have to rely on any assistive technology like screen reader?

2S: As long as the font size is large, I can read it.

Interviewer: Okay, so scaling is important for you. If need to enlarge the content of the maps and then you can read it. That's great. Now, as far as using maps for navigational purpose goes, which digital maps do you prefer to use?

2S: I use Google maps as that's what I know.

Interviewer: So, I assume you use android device to use Google maps?

2S: I use an Apple iPhone, but I do not use maps on my smartphone. I do not see very well in small screen.

Interviewer: Interesting. So that means you use maps on desktop or tablet?

2S: I would use any large screen devices where I can zoom conveniently. So, Desktop yes, Laptop most likely and tablet as long as I can zoom enough to read.

Interviewer: What is your opinion about text alternative features in digital maps. Do you think the maps that you use offer enough text alternatives or you are mostly left frustrated due to lack of it?

2S: I do not look for text alternative, as I do not usually use screen reader. I look for zooming capability.

Interviewer: That makes sense. Alright, Now I will move on to the next topic where I will ask you about assistive technology related questions. So you told me you use maps on desktop usually, so do you mostly use keyboard or mouse when extracting information from digital maps?

2S: I prefer mouse.

Interviewer: Got it. What sort of difficulties do you face, if any, when using maps on desktop?

2S: Well, not that much. I have configured my mouse cursor to my convenience. I have changed the mouse cursor to a big pink icon. That is my biggest problem. I would not even be able to see the cursor if it is a small white arrow.

Interviewer: Interestingly I do a similar thing due to my own eye condition. I changed my mouse cursor to large inverted colored mouse cursor. Just wondering, why pink? Is it because of your eye condition and easier to detect or its just pink is your favorite color?

2S: I would also prefer orange or light blue. Any light colors, its easy for me to see.

Interviewer: Since you said you use mouse for maps, I will skip questions about keyboard. I will ask you about touch screen though. Tell me about your experience with touch screen on maps.

2S: Yeah, I use my fingers for zooming in and zooming out and it always works so no problem about from me about it.

Interviewer: Wow, you are a happy customer! And you don't use screen reader at all?

2S: Not so much.

Interviewer: Ever used it for maps?

2S: Nope.

Interviewer: What about voice command for maps?

2S: Nope, never used it either.

Interviewer: I did had question about screen magnifier but as you already gave enough details about it I will move onto the next question. Now I will ask you about accessibility features. Starting with language, do you find digital maps automatically detect your preferred or system default language. I am guessing for you that would be Norwegian.

2S: I never noticed. The maps would either load in English or Norwegian and since I am well familiar with both the languages, I just start using the maps without noticing the language.

Interviewer: I think this next question is significant to you. I assume you had to be reacquainted with everything after you recovered from the incident with your eyes. How was the transitional experience for relearning to use digital maps?

2S: It was a challenge like everything else. But as soon as I got used to using screen magnifier, using my PC and tablet for anything was not hard anymore. I would say same goes for Google maps.

Interviewer: Search features. How easy do you find the search features of any given maps? Do you always find the search options and find the places you look for?

2S: I almost always find the places I look for.

Interviewer: Almost always? So 80% success rate?

2S: I would say 95%.

Interviewer: Now I will move onto the final section of our interview. We will focus more into the challenges of using maps. Has it ever occurred to you where you are exploring one section of the map and unexpectedly the focus of the map is changed to another location? Or The app completely shut down or stopped working? Tell me about any bad experience you might had with using digital maps?

2S: Hardly anything unexpected happened with me. Even if anything did happen, I can’t remember. Then again I am not too much depended on maps so I suppose my answer should not be considered gold standard.

Interviewer: Did you ever felt like lack of control while using maps?

2S: Well that’s the problem with Google maps. I don’t have that much control so I don’t use it that much for navigation anyway.

Interviewer: Final question, do you have any personal suggestion or advices based on your experience of using all digital maps that wished was improved or implemented?

2S: Color contrast is an issue for me. Many maps has very low color contrast and it is hard to distinguish from one color identifier to another.

Interviewer: Yeah, that's a big issue. Anything else?

2S: No, can't think of anymore.

Interviewer: Alright, that concludes our interview. Thank you so much for your time.

4.3 Interview 3

Interviewer: Usually for what purpose do you guys use maps? Everything you can list would be awesome.

3T: We are using both digital maps and tactile maps. For example, You can have a tactile map of this building and that's easier than digital maps I think. But if you are exploring something outside, I think digital maps would be better, maybe.

4L: Have you tried Taxifix, Taxi ordering app in Norway?

Interviewer: No, Taxi is extremely expensive in Norway!

4L: But you can try the app anyway, its free. So, in that app, if I order with the Taxifix, then you can follow the taxi, and that's by a map on the screen. And on that map, you have no alternative text! So I don't know the street name, nothing! I don't know where the taxi is! Instead of this, what they could have implemented was solution where you at least got the street name at any given moment.

3T: Is that when you are waiting for a taxi?

4L: Yeah! It is when you are waiting for a taxi. That is how you know how many minutes it will take to get to your destination. Anyway, you also might have noticed I like to ski :D. There is an app call "iMarka" That also has a map it is totally inaccessible! Only thing, when you start the app, there is a search box. When you are finished with searching, you get a map. But with no alternative texts or any routes or tracks. So, the biggest challenge of using this app is not the app itself but the way the map has been implemented. There was text on the map and that text should be accessible.

3T: Do you know about Blindsquare?

Interviewer: Blindsquare? Yeah, I heard about it.

3T: In Blindsqure you can use your phone in different ways. You can….

** **3T** demonstrates how Blindsqure works. The app read out loud surrounding street names and distance of the street from user's current location based on the direction the mobile device is pointing towards.

3T: As you can see the app can appropriately locate my current location and tell me the surrounding street names based on where I point my smartphone.

4L: We are also missing, if we search for a restaurant or something, we get address and also get a map. I would be extremely use if the map also tell us all the text information on the map. Then we could orient ourselves and see okay here is restaurant, here is cinema for instant or something else.

3T: There is gadget which is called Vector Radar Track. It's a GPS device and a audiobook player and bit more. There you can plan a route and you can preview before your trip.

4L: Yes, but you also have preview on Google maps with more description.

3T: Oh yes. One of the things they are planning there at Google Maps, which they will in the next conference in Los Angles, US next week is that you shall be able to look around on a different place than where you are. For example you are typing an address in London then you shall be able to look around what surround that place. I think that is also possible in Blindsquare but I don't know how you do it because I have not checked the app well enough.

Interviewer: Yeah, as Lars was saying that is exactly is my goal with my Thesis. The actual text on the digital maps, screen readers cannot read them. I am working on how we can fix that, how we can improve that. That is one of my “dream” goal of this thesis.

4L: Google Maps was updated a few weeks ago because they had 15 years Jubilee. I have not explored the since then, so I don’t know if it had changed to help our issue.

Interviewer: The issue we have here is quite complex if you think about it. Because even if we program So that the content of the map is read out loud, the biggest challenge would be how it would read the contents. As you know map is not like a book so the starting point from where it would, from to what direction is the question. Hopefully, you can give me suggestion, what would be the best way the screen reader can read the content of the map?

4L: I think the best way would be to, on a mobile phone, when you hold a finger on a place, it should read that street name for instance. And if you move your finger, it should read the next item.

Interviewer: Yeah, that’s a good suggestion on the mobile device with the finger as the point of interest for reading content. What about desktop, where we don’t conventionally use touch technology. Where mouse and keyboard is used more?

4L: Well I wonder if I search on the PC, I use Google to search for a route from A to B, then I get a map but I would also like to have the route description. That should not be very complex?

3T: You have it on the app.

4L: Yes, you have it on the app but not on the PC.

Interviewer: What about weather maps. Have you used weather maps, or any other digitals maps you might have used?

4L: Weather maps?

Interviewer: You know for example yr.no, the Norwegian weather forecast website, there is also a map that shows weather forecast of different location in and outside of Norway visually.

4L: No, we did not need to use the maps. You can search for places and have the weather forecast read to you. Also, the website automatically determines your location.

Interviewer: Yeah, but the map on that website does not help with blind exploration of forecast of different location. For example, if you want to know the weather forecast of London only using the map in that website, you will not be able to.

3T: Then you will have to search for London manually!

Interviewer: Between Google maps and apple maps, from you experience, which one is better when it comes to accessibility?

4L: I do not have apple maps. I really would not know much about it. But **3T** might have some experience he can share?

3T: I have not explored Apple maps in such details, but their advantages and disadvantages with both I think. Earlier, I believed Google maps had more roads for walking as in more records of the pavements, but I think Apple maps is now also improving on that.

Interviewer: So, given the option between Apple maps and Google maps, I am assuming both of you would prefer Google maps?

4L: Well, as I say I do not use Apple maps, but I did use other navigation apps in the past. For example, “Get There” apple. I think it uses OpenStreetMap database.

Interviewer: Usually do you guys use digital maps on mobile devices or desktops?

4L: Never on desktop!

Interviewer: Never, huh? Any reason why not? Just so I can expand the answer.

4L: Because the desktop version of the maps is totally inaccessible.

Interviewer: Would you use it more if it were more accessible or is it just user habit that you tend to be drawn towards using mobile version?

4L: Yeah, I think I would have used more if it were accessible.

3T: It is faster to search on desktop.

4L: Because you have a keyboard. Maybe you have a braille display connected, so you have more power!

Interviewer: The next question you have already answered. It is about text alternative option of maps, which is not there, so thank you. I got that answered already.

3T: Going back to Apple maps, an advantage with apple maps is I can use Siri to make route for pedestrian for example. So that's fast and easy.

Interviewer: Okay, so you can get from Siri to make a route plan?

3T: Yes.

4L: Yeah, you can also do that with Google Assistant, but you might need to explore on that feature bit further.

Interviewer: Okay I will check it out and compare. Yeah, I usually do that too using Google Assistant. For example, I would say "Hey Google take me to the Stetpad" and usually I get voice description and instruction to that location.

3T: A problem with these virtual assistants is that much of the features are available in English but they are much better in English than in Norwegian.

Interviewer: That would have been one of my questions actually. So, you just answered that question! Yeah, many of these digital map's features are not on multilingual platforms. But you can also argue that it does come down to community contribution, as in how much you can contribute to these platforms.

Interviewer: Now we moved to the next topic. It is about assistive technology. So next few questions will be about that. So, starting with keyboard, please tell me any experience you might have using any digital maps with keyboard. I know you have already contributed enough on this topic, but I am just if you have any other comment that,

4L: All I can say, map is a picture, you cannot do anything with a keyboard as much as I know. But it would be great if for instance to be able to use arrow key to move step by step street by street if you in a town, but I don’t think that is possible right now but maybe you can look into it for your future project.

Interviewer: Exactly, in my opinion, it is all about how you can focus, I mean integrating keyboard navigation with arrow key is not the main challenge, the bigger challenge would be how it would focus on a specific point of view.

4L: I suppose you might get better response from someone who are more interested in using maps with keyboard some other type of disability user groups. Other user groups who need to be dependent on keyboard as input device.

Interviewer: Moving towards touch screen, please tell me about your experience with using maps using touch screen technology.

3T: One difficulty I can mention is lack of feedback. For example, with tactile maps, I can feel the maps, I can feel this road goes to that way, that road to this way. But in touch screen, when you touch on the map you might get on feedback but as soon as you drag your finger to another location, entire map will move with your finger. You lose the sense of direction.

Interviewer: What about screen reader? Any comment?

4L: Well, because of our condition, we are constantly using screen reader on mobile and other devices. There is nothing more to add to that.

Interviewer: Makes sense. Voice commands, can you share any bad experience you might had while using voice command?

4L: Last time I tried to get a route with car ride, we got the right way but smartest route. That's quite common, I think. I don't know why I got that bad route, but I got it.

Interviewer: Moving to the next and final section, you already have answered this question. So, you guys use Norwegian when you use your maps apps, so it always automatically read out in Norwegian?

4L: Yeah, but sometime the automatic translation is translated very badly. For example, my previously mentioned "Get There" has very bad Norwegian translation. Some apps do not even translate to Norwegian, for example an app called Lasarillo, which is fully English, no support for Norwegian. Even though I am okay with that, but a good translated app is always appreciated.

Interviewer: So, Lasarillo, is it a maps-based service?

4L: Yeah, it's a navigation service, navigation app.

Interviewer: Another big question, about the search feature, like when you are searching for an address etc. do you face any difficulties?

3T: Usually I am pretty satisfied with the search features of the maps. One issue I can mention from top of my head is the issue with confusions sometimes maps create when several addresses is closely located in a tight place like town houses and apartments. Navigation might say I have reached the destination, but my real destination could be the next door few meters away not the house I am in! Then again, this issue is more to do with the accuracy of the GPS services how it is implemented on the digital maps.

Interviewer: Yeah, that's true. Okay, has it ever happened to you where you are on one place on the digital map and all of a sudden, the focus of the map is moved to another location without your input of intension? Did you ever felt lack of control when using maps?

4L: Yes of course, all the time. But then again, we are heavily relied on touch screen and screen reader, so we need to be very careful where you put our finger and how we navigate on the map.

Interviewer: Also, I suppose more use interact with the maps using these assistive technologies, you get better at it, as you learn it along the way. More you use it, more you learn! Now speaking about compatibility of different digital maps across various hardware and software platforms, did you ever found any maps being usable in one platform but not similarly usable on another platform? For example, you found Google maps usable in your smartphone but found it harder to use when you moved to tablet.

4L: Its definitely harder to use in Desktop, that's for sure. I am not sure about tablet though.

3T: I believe it is similar to smartphone.

4L: The best navigation app I ever used was Wayfinder In a Symbian device many years ago.

Interviewer: Thank you so much for your time gentlemen. We are done with the interview.

4.4 Interview 4

Sayed: Okay, let's start the interview. How often do you use digital maps and for what purposes?

5B: As you know, usage of digital maps is a very recent development in Bangladesh. We did not have mainstream use of smartphone even 5 years ago. Now we use our smartphones for so many things in our daily lives. I use maps on my smartphone for a few things. The live traffic update on Google maps is very handy. Due to my condition, I am allowed to work from home five days a week but I need to commute to work every Friday to participate in the team meeting physically. I check the live traffic update before leaving my home for work. Dhaka's road is extremely unpredictable and checking the traffic update on my way to work has saved me on many occasions from being late. I also use Google voice assistance to get approximate distances and travel times to places I would visit locally and internationally.

Sayed: Anything else? Like, finding a point of interest like grocery shop or even a museum for example.

5B: Nah, not really I don't shop myself that much or travel. But yeah, sometimes I ask to Google voice assistance for nearest ATM machines when I am in an unknown place. I am sure Google pull that data from Google maps server.

Sayed: So, I assume you only use Google maps as the digital maps exclusively?

5B: Yeah, that's the only one I use really! I know there are few other apps people use like apple maps but in Bangladesh, only Google maps is the most popular. Also since I use an Android smartphone, Google maps is my only logical choice.

Sayed: You don't use Google maps in Desktop or tablets or any other hardware apart from a smartphone?

5B: I don't have a tablet, but I do use Google maps sometimes on my desktop while at work.

Sayed: Is there anything you do on Google maps in Desktop that you don't do in a smartphone?

5B: Not really, I have voice assistance software Dragon NaturallySpeaking. I use that for my purpose as I do with Google voice assistance. But I must say, using Google maps in a desktop is more tedious than using on my phone.

Sayed: Interesting. It's good that you have some experience with using Google maps on the desktop. I want to ask you the most basic question, the base of my thesis. Has Google maps ever offered you a non-graphical alternative to the digital maps? E.g. additional link to a text-based alternative?

5B: Nope. As a blind digital maps user, I always felt if the text on the maps were readable, I could have absorbed more information from maps like Google maps and they would be more accessible for my condition. I have read your thesis summary and agree, there should be more research on screen reader accessibility on digital maps.

Sayed: Thanks! And I feedback and Experience from users like you with varied ability to accomplish my thesis project. I now want to move onto the next section of my interview where I ask you about your experiences with various input-output devices. The first question is an interesting one, as you would be my first interviewee who I am hoping would be able to give me a more detailed response compared to previous participants. Okay, since you said you use Google maps on your desktop on a regular basis, I want to ask, how much your usage involves keyboards?

5B: Well, when I am on working on desktop, I exclusively use the keyboard.

Sayed: Great! Please tell me how satisfied you are with keyboard usage in maps.

5B: I would say I am unsatisfied as there is not much you can do with a keyboard as a blind user to navigate various features of Google maps. I can search for addresses, businesses and stuff and read the reviews. When I am navigating different things on the Google maps website using the tab button of my keyboard, the screen reader would narrate the objects I am focusing on. But when it comes to trying to focus on the map itself and wanting to explore the map to using arrow keys, it never works. I get no voice feedback on where I am on the map, there is no point indicating my current position on the map. And I have been told it only happens when I have screen narration software opens. My colleagues tested on my PC that you can go all directions on the map using keyboard arrow keys as long as my screen reader software JAWS or even windows narrator is not running. I think Google has a long way to go to make their maps on desktop keyboard navigation friendly.

Sayed: I see. So the keyboard trap, meaning not being able to navigate exclusively with keyboard exists on the main part of Google maps – the map itself! You mentioned focusing on different objects using the tab button, tell me about the focus sequence. When you are pressing tab button to navigate, do you think the focusing maintains a logical and practical sequence or the focusing is all over the place?

5B: I would say it's not helpful either. Yes, its sequential, as it focuses every single interactive and non-interactive object on the page. But as you know, since a website designed for maps service, a linear focus is not practical. The focuses should be designed in a way where the most used features of the page should be focused first and least important ones last.

Sayed: Good point! Okay, now tell me about your experience with the touchscreen. Using maps in your smartphone.

5B: The Google Maps app is far accessible than desktop service. Voice assistance helps a lot. I can do more on my phone than the desktop. But still, even in here, my android TalkBack service cannot read anything on the map. I wish if there was a pinpoint on the centre of the map and Google voice narrates where the pinpoint is so I can visualize where my pinpoint is. Then, as soon as I drag my finger on the screen and move to a new location on the map, TalkBack service narrates the current new position to me. Maybe name and type of location etc. I have also noticed the vibration feature is not helpful. There is no variation in vibration when I am using the app.

Sayed: Variation in vibration? What do you mean?

5B: Like for example, when I am doing different things with the touchscreen, the haptic feedback’s vibration pattern remains the same. It is just like, one buzz everything. One buzz vibration feedback anything I do. If there was say for example one buzz for basic interaction then two buzzes for more advanced interactions and a burst of buzzes for further advanced interactions that would be helpful. We are more sensitive to vibrations and that can help us with the app interactions.

Sayed: Yeah, that sounds like a good point! About the next question, you have talked a little bit already but since it is the primary goal of my thesis – to improve digital maps for screen reader users, can you please tell me a bit more about the challenges you face when using a screen reader for digital maps, which is Google maps in your case.

5B: Not sure what else I can say except for the fact that it's useless for me when I want to read what is on the map. I know the map is a picture thing and for someone unlucky like me there is not much I can read from a picture-based media, but if even the most basic point of views was readable on the digital maps, we could at draw a picture in our mind of how the map layout is designed.

5B: Most basic points?

Sayed: Okay, so as you know, maps can contain so much information: street names, street numbers, groceries, cinemas, parks, even lakes. Now having all the paces names individually read would be overwhelming for anybody. I could imagine it would be a nightmare in a metropolis! SO what I would suggest, instead of having text alternative to all point of interest, only most important POIs to be alternated on a certain plane. Maybe the main street, biggest establishment, park name etc.

5B: Wow, that was a brilliant point. I was wondering about that myself too. Having too much information to read at a certain time where it gets hard to absorb the information is also a form of accessibility and we call it information overload. Your suggestion of only offering text alternation for basic POIs on a certain layout of the map and then dynamically change the text alternative offerings as user zoom out and zoom in can be a good solution to that! Thanks for that suggestion!

Sayed: Any other input device you might be using for digital maps?

5B: Nothing I can remember of.

Sayed: Okay then. I will move to the next section of our interview. Here I will ask you more about the accessibility feature offered the different digital maps. Starting with language, I know you are native to Bangladesh but I am wondering what language do you prefer when using electronic devices and do the digital maps, Google maps in your case automatically switch to that language?

5B: Well I just use English on my computer and mobile phone and have no issue with the language when using Google maps.

Sayed: Fair enough. What about making mistakes when using maps? does the system understand you made a mistake or tell you how to undo the mistake or tell you how to recover from it?

5B: Yeah pressing the wrong button or touching in a wrong place on the phone is a common problem for me. When I do mistake its ordinarily hard for me to undo. To be honest, usually, I don't even bother to look for undo option, I simply start over as I found that most convenient. When I am on my pc, I just refresh the web page and in the mobile, I close the app and reopen.

Sayed: Okay. What about the search feature? Do you find the search feature helpful for your need?

5B: I do not have any issues with the search feature really. No matter whether it's searching by typing or voice search it usually finds what I am looking for. Sometimes, with voice search it gets challenging, but I am sure it's more to do with my English accent than the search engine.

Sayed: Okay then! Now for the final section of our interview. Challenges and solutions. Did you ever experience any unexpected changes while using Google maps in your phone or PC? Say for example, focus changes, screen changes.

5B: Well, I would not even notice that due to my lack of sight (laugh).

Sayed: Oh sorry. I have made a generalized question for all interviewees. Okay, disregarding my given examples, did you experience any unexpected changes during your use?

5B: The app crashed several times when using. Also, sometime when walking with the navigation on, the Google maps navigation gives me wrong directions. Maybe because it finds it hard to determine my location when it happens, I don't know.

Sayed: Yeah, I could imagine that. Our city (Dhaka) is very congested with so many streets and lanes and paths so its possible the GPS having a tough time pinpointing your exact position. Did you ever feel a lack of control when using Google maps?

5B: All the time. And it's not only limited to Google maps.

Sayed: The next question was about the discrepancy in user experience between desktop and mobile devices, but we have already discussed that. Well, we have come to the end of our interview. We have given me so many good suggestions and good answer about the experience you have using Google maps. Thank you. Is there anything else you would want to add to the interview?

5B: No, nothing much, I do look forward to reading your thesis and testing your prototype. Good luck with your thesis.

Sayed: Thanks!

APPENDIX 5: Accessibility Evaluation

5.1 www.ssb.no

WCAG SC	Test	Verdict
1.1.1: Non-text Content	Alternative text of the interactive map is provided	Met
1.1.1: Non-text Content	Link to a more accessible alternative to the original interactive map is provided	Not met
1.1.1: Non-text Content	The map stays on the page when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	The map is displayed correctly when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	No additional text appears when style sheets are disabled	Not met
1.4.1: Use of Color	Map does not use color/shape/shade/location alone to convey information	Not met
1.4.3 Contrast	the contrast ratio between and map graphics and text in the map is of at least 4.5:1	Not met
1.4.11 Non-text Contrast	Different graphical contents within map have contrast ratio of 3:1	Not met
1.4.4: Resize text	Text size can be changed inside the map	Not met
2.1.1: Keyboard	The map is keyboard accessible	Not met
2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	Not met

2.4.3 Focus Order	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content	Not met
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	Not met
3.3.2: Labels or Instructions	Labels or instructions about the behaviour of the interactive map has been provided before the Map	Not applicable
(Guideline) 4.1 Compatible	The map can be used using screen reader	Not met
(Guideline) 4.1 Compatible	The map can be used with screen magnifier on	Met
(Guideline) 4.1 Compatible	The map can be controlled by speech recognition software	Not met

5.2 www.oslo.kommune.no

WCAG SC	Test	Verdict
1.1.1: Non-text Content	Alternative text of the interactive map is provided	Not met
1.1.1: Non-text Content	Link to a more accessible alternative to the original interactive map is provided	Not met
1.1.1: Non-text Content	The map stays on the page when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	The map is displayed correctly when style sheets are disabled	Not met

1.3.2: Meaningful Sequence	No additional text appears when style sheets are disabled	Not met
1.4.1: Use of Color	Map does not use color/shape/shade/location alone to convey information	Not met
1.4.3 Contrast	the contrast ratio between and map graphics and text in the map is of at least 4.5:1	Not met
1.4.11 Non-text Contrast	Different graphical contents within map have contrast ratio of 3:1	Not met
1.4.4: Resize text	Text size can be changed inside the map	Not met
2.1.1: Keyboard	The map is keyboard accessible	Not met
2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	Not met
2.4.3 Focus Order	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content	Met
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	Not met
3.3.2: Labels or Instructions	Labels or instructions about the behaviour of the interactive map has been provided before the Map	Not met
(Guideline) 4.1 Compatible	The map can be used using screen reader	Not met
(Guideline) 4.1 Compatible	The map can be used with screen magnifier on	Met

(Guideline) 4.1 Compatible	The map can be controlled by speech recognition software	Not met

5.3 www.visitnorway.com

WCAG SC	Test	Verdict
1.1.1: Non-text Content	Alternative text of the interactive map is provided	Not met
1.1.1: Non-text Content	Link to a more accessible alternative to the original interactive map is provided	Not met
1.1.1: Non-text Content	The map stays on the page when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	The map is displayed correctly when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	No additional text appears when style sheets are disabled	Not met
1.4.1: Use of Color	Map does not use color/shape/shade/location alone to convey information	Not met
1.4.3 Contrast	the contrast ratio between and map graphics and text in the map is of at least 4.5:1	Not met
1.4.11 Non-text Contrast	Different graphical contents within map have contrast ratio of 3:1	Not met
1.4.4: Resize text	Text size can be changed inside the map	Not met
2.1.1: Keyboard	The map is keyboard accessible	Not met

2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	Not met
2.4.3 Focus Order	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content	Not met
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	Not met
3.3.2: Labels or Instructions	Labels or instructions about the behaviour of the interactive map has been provided before the Map	Not met
(Guideline) 4.1 Compatible	The map can be used using screen reader	Not met
(Guideline) 4.1 Compatible	The map can be used with screen magnifier on	Met
(Guideline) 4.1 Compatible	The map can be controlled by speech recognition software	Not met

5.4 www.marinetraffic.com

WCAG SC	Test	Verdict
1.1.1: Non-text Content	Alternative text of the interactive map is provided	Met
1.1.1: Non-text Content	Link to a more accessible alternative to the original interactive map is provided	Not met
1.1.1: Non-text Content	The map stays on the page when style sheets are disabled	Not met

1.3.2: Meaningful Sequence	The map is displayed correctly when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	No additional text appears when style sheets are disabled	Not met
1.4.1: Use of Color	Map does not use color/shape/shade/location alone to convey information	Not met
1.4.3 Contrast	the contrast ratio between and map graphics and text in the map is of at least 4.5:1	Not met
1.4.11 Non-text Contrast	Different graphical contents within map have contrast ratio of 3:1	Not met
1.4.4: Resize text	Text size can be changed inside the map	Not met
2.1.1: Keyboard	The map is keyboard accessible	Not met
2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	Not met
2.4.3 Focus Order	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content	Not met
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	Not met
3.3.2: Labels or Instructions	Labels or instructions about the behaviour of the interactive map has been provided before the Map	Not applicable
(Guideline) 4.1 Compatible	The map can be used using screen reader	Not met

(Guideline) 4.1 Compatible	The map can be used with screen magnifier on	Met
(Guideline) 4.1 Compatible	The map can be controlled by speech recognition software	Not met

5.5 siste.eiendomspriser.no

WCAG SC	Test	Verdict
1.1.1: Non-text Content	Alternative text of the interactive map is provided	Not met
1.1.1: Non-text Content	Link to a more accessible alternative to the original interactive map is provided	Not met
1.1.1: Non-text Content	The map stays on the page when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	The map is displayed correctly when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	No additional text appears when style sheets are disabled	Not met
1.4.1: Use of Color	Map does not use color/shape/shade/location alone to convey information	Not met
1.4.3 Contrast	the contrast ratio between and map graphics and text in the map is of at least 4.5:1	Not met
1.4.11 Non-text Contrast	Different graphical contents within map have contrast ratio of 3:1	Not met
1.4.4: Resize text	Text size can be changed inside the map	Not met

2.1.1: Keyboard	The map is keyboard accessible	Not met
2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	Not met
2.4.3 Focus Order	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content	Not met
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	Not met
3.3.2: Labels or Instructions	Labels or instructions about the behaviour of the interactive map has been provided before the Map	Not applicable
(Guideline) 4.1 Compatible	The map can be used using screen reader	Not met
(Guideline) 4.1 Compatible	The map can be used with screen magnifier on	Met
(Guideline) 4.1 Compatible	The map can be controlled by speech recognition software	Not met

5.6 www.webcams.travel/map

WCAG SC	Test	Verdict
1.1.1: Non-text Content	Alternative text of the interactive map is provided	Not met
1.1.1: Non-text Content	Link to a more accessible alternative to the original interactive map is provided	Not met

1.1.1: Non-text Content	The map stays on the page when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	The map is displayed correctly when style sheets are disabled	Not met
1.3.2: Meaningful Sequence	No additional text appears when style sheets are disabled	Not met
1.4.1: Use of Color	Map does not use color/shape/shade/location alone to convey information	Not met
1.4.3 Contrast	the contrast ratio between and map graphics and text in the map is of at least 4.5:1	Not met
1.4.11 Non-text Contrast	Different graphical contents within map have contrast ratio of 3:1	Not met
1.4.4: Resize text	Text size can be changed inside the map	Not met
2.1.1: Keyboard	The map is keyboard accessible	Not met
2.1.2: No Keyboard Trap	The map does not contain a keyboard trap	Not met
2.4.3 Focus Order	Placing of the interactive elements in the map is in an order that follows sequences and relationships within the content	Met
2.4.7: Focus Visible	The map has a highly visible keyboard focus indicator	Not met
3.3.2: Labels or Instructions	Labels or instructions about the behaviour of the interactive map has been provided before the Map	Not applicable

(Guideline) 4.1 Compatible	The map can be used using screen reader	Not met
(Guideline) 4.1 Compatible	The map can be used with screen magnifier on	Met
(Guideline) 4.1 Compatible	The map can be controlled by speech recognition software	Not met