Screen Reader Accessibility Study of Interactive Maps

Sayed Kamrul Hasan[1[0000-0002-9474-5796]] and Terje Gjøsæter[1,2[0000-0002-1688-7377]]

[1]Oslo Metropolitan University, Oslo, Norway
sayedkamrul@live.com
[2]University of Agder, Kristiansand, Norway
terjeg@uia.no

Abstract
Digital maps have been an integral part of modern life. 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? Maps by nature have to rely on graphical medium to present their 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 study, we have conducted a systematic literature review to discover the research gaps of accessibility in digital maps, focusing on map exploration based on screen reader technology. To discover further accessibility issues from users, we conducted semi-structured interviews with participants with varying degrees of visual impairments. The result from these data indicates that interactive maps are not screen-reader accessible at all. There is an apparent research gap in alternative text accessibility in maps and interview participants commonly agreed with multiple accessibility issues on contemporary interactive maps on diverse platforms.

Keywords: Interactive Maps, Screen Reader, Accessibility, Universal Design

1 Introduction

People from all walks of life use digital maps in 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. With 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 of maps over the year, questions remain how much work has been done on improving maps, so they 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 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 [1] 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. 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). In the digital world, acute vision-impaired users rely on assistive technologies like screen readers and braille displays to interact with electronic devices. So, if the current maps in digital forms cannot be used without or even with assistive technologies, they cannot be considered accessible to visually impaired users. 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. In this research paper, we will investigate research gaps and various accessibility issues currently found on digital interactive maps. The research questions investigated in this paper is as follows:

1. How much research has been done so far towards accessible designing of digital interactive maps to accommodate the screen reader user group?
2. What are the common accessibility issues experienced by the impaired user groups in digital maps?

The rest of the paper is organized as follows. Section 2 establishes the theoretical platform for the research through reviews on various sections related to digital maps and their accessibility. Section 3 covers the methodology and section 4 the result of the study. The findings are further discussed in section 5 of the paper with a conclusion.

2 Literature Review

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 [2]. 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 [3]. 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 society [4]. Hearing Aid, Screen reader, or braille display are examples of commonly used Assistive technologies. Universal design is a major focus of this paper. 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” [5]. 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 principles point out all potential design limitations that need to be addressed to achieve an inclusive design and suggest ways to maximize the usability of any designs under development and indicate affecting variables along the way [6].

In the web technology part of the ICT world, the Web Accessibility Initiative (WAI) taskforce developed accessibility guidelines: Web Content Accessibility Guidelines (WCAG) for creating accessible web content. The latest rendition of WCAG, 2.1 [7] 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 a governmental push for creating accessible web content across the world: the European Union and countries like the United States, Canada, Australia, etc. are also all imposing WCAG conformity laws.

2.2 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 [8], 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. This paper focuses on 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[9], 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. Based on visual acuity, WHO [9], categorizes blindness into the following groups: normal vision (0.8≥) moderate low vision (0.3≤), severe low vision or legal blindness (0.12≤), profound low vision (0.05≤) and, near-total or total blindness (0.02≤). 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 Deaf blindness.

2.3 Maps Design Evaluations

Several papers have attempted to evaluate currently available online maps and maps in web applications. Calle Jiménez and Luján-Mora [10] 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 thus inaccessibility ensues. Medina, Cagnin and Paiva [11] have conducted a thorough investigation to determine the accessibility of a few of the most popular web application maps. Their thorough assessment 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. The 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 from 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 activities 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. So how the digital maps should be designed to accommodate as many user groups as possible? In the paper [12] “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.

3 Methodology

3.1 Research Design Approaches

Action Research. According to Lazar, Feng and Hochheiser [13], research 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 policy-makers. Action research is a research methodology whose root can be traced back to social science [14] and being successfully preferred, revised, and adopted for HCI based research[15] in recent times. Hayes [15] 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.

Qualitative 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 [16]. 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 [17]. 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, Feng and Hochheiser [13] 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 and interviews.

Thematic 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 [16]. 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 [13]. Along with data analysis, grounded theory can be applied to the 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 [18] which is performed in 6 steps respectively: familiarity with data, initial code generation, theme searching, theme reviewing, theme defining, and finally, writing up.

3.2 Systematic Literature Review

A systematic literature review is conducted to seek the answer to the first research question. SLR was designed to explore specifically the state of the study on text alternate and screen reader accessibility of interactive digital maps. 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 [19] discovered that only 10% of them truly follow a proper protocol. This systematic review has been designed based on a well-documented and vastly accepted SLR procedure, PRISMA Statement [20]. 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, as illustrated in **Fig. 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.
- Universal Design, covering Universal Design, design for all, and accessibility
- ICT covering Web, technology, digital, mobile, smartphone, computer, internet.
- As the primary objective, "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.

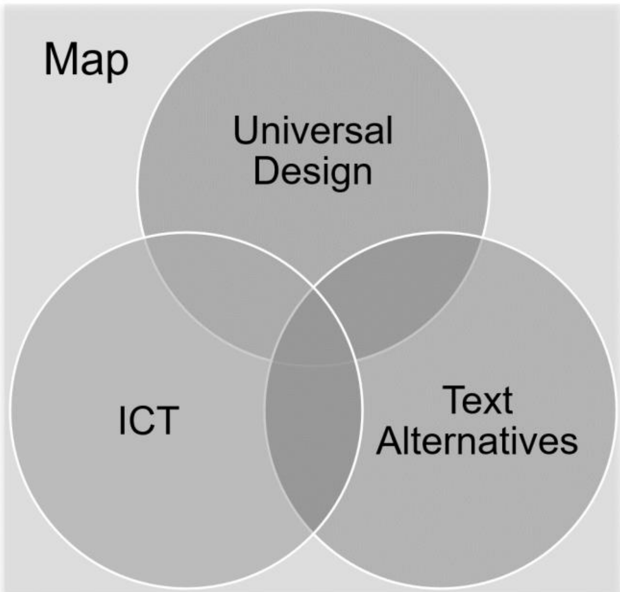

Fig. 1. Venn Diagram of SLR Search Criteria

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 were 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"

3.3 Semi-structured Interview

To obtain end-user perspectives and explore the second research question, semi-structured interviews were conducted with participants of various levels of limited visual ability. According to [13], 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 at 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. The semi-structured interview was chosen because while interviewees have more freedom to answer 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 [16, 21]. We also considered several challenges [13, 16] 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. 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 the researcher's subjective bias. This issue is dealt with by the researcher's quality and interrater validity check during the data analysis period.

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. The closing portion of the interview focuses on end-user suggestions on designing and developing more accessible digital maps to cater to their ability needs. After designing the interview guide, pilot interviews were conducted and 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.

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. Participants were acquired 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. 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 [22]. Four interviews were conducted with five participants in total (see **Table 1**). Three interviews were in a one-on-one setting while 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. Handling of user data was done under the supervision of the Norwegian Centre for Research Data (NSD).

Table 1. Participant list - Coded

Participant Code	Gender	Age	visual ability
1M	Female	20	profound low vision
2S	Female	35	severe low vision
3T	Male	51	total blindness
4L	Male	54	total blindness
5B	Female	26	profound low vision

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 study, 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. 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.

4 Results

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. See **Fig. 2.** Systematic Literature Review PRISMA Flowchart Diagram for an outline of the selection process. 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 they lasted through the filtering process.

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 [23], accessible map design recommendations[24], barriers in currently available digital maps [10], accessibility assessment [25], challenges in designing accessible maps [12], 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 [26], voice instructions [27], and audio-hepatic feedbacks [28, 29]. One solution from 2013 made use of multisensory interaction with sonification, vibration as well as text to speech technologies [30] while on the other hand Schmitz and Ertl [31] based their prototype mainly on vibration to reach out to the deaf-blind community.

To successfully absorb the information of the maps for 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 research, the most compelling solution comes from Afzal, Maciejewski, Jang, Elmqvist and Ebert [32] 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 emergencies [33] [34]. Sonification is also used under this category to explore weather maps [35] and indoor maps [36].

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 [37, 38], interactive 3D printed maps [39, 40], with use miscellaneous interactive accessibility objects like WiiMote [41] and Tangible Reels [42] suggested for accessibility.

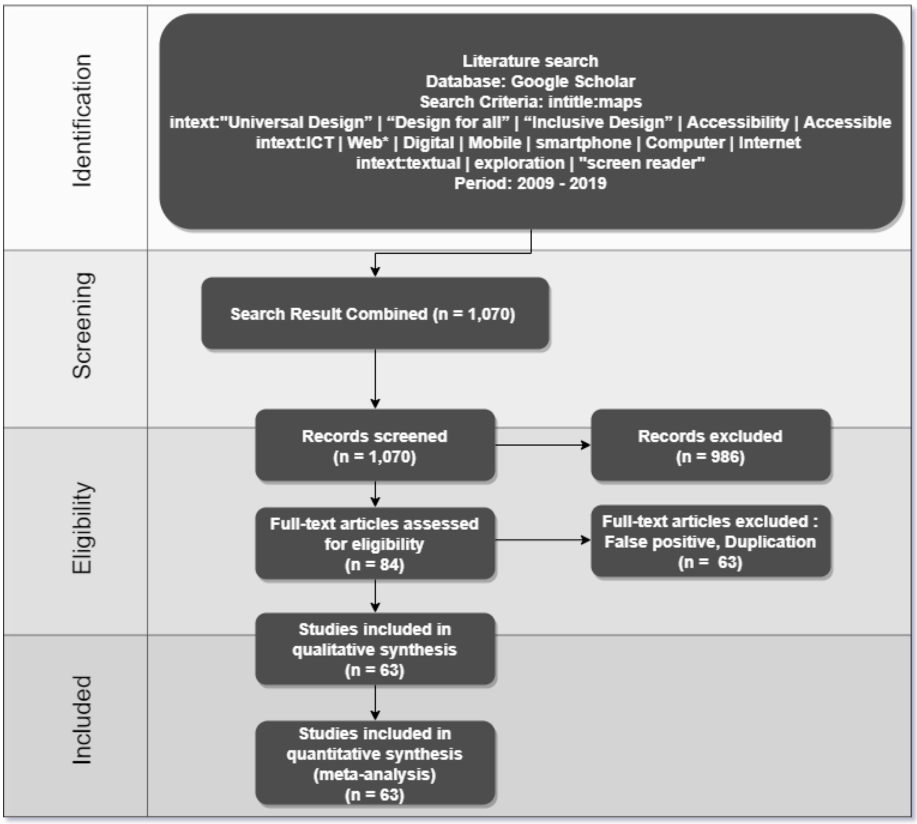

Fig. 2. Systematic Literature Review PRISMA Flowchart Diagram

Involving the end-users with limited abilities who use maps to gather accessibility data and develop accessible maps system in digital form has also been discussed on several occasions. For example, Rice, Jacobson, Caldwell, McDermott, Paez, Aburizaiza, Curtin, Stefanidis and Qin [43] 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 [44] developed a system of Combining paper maps and smartphones in the exploration of cultural heritage using augmented reality. **Table 2** further shows an overview of the categorization of papers according to their primary study area.

Table 2. 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

4.2 Interviews

Purpose and preferences. We started our interviews by 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 map trends. Navigation was the primary purpose of using digital maps as answered by all participants. 5B utilizes the Google assistant function also to get traffic updates and approximate travel time and distance to destinations. 3T informed he has experience using digital tactile maps for indoor navigation and wants it to be developed further. Interestingly, Participants 1M and 5B 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 is 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 their 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 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 the smartphone's location services and maps 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 the 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 hardly ever works. 2S, on the other hand, requires a bigger screen to properly read information, so she mainly uses Google maps on a desktop or laptop, sometimes on her tablet but never on her smartphone.

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 it. 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.

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 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 the current map design. She feels map elements have a very low color contrast ratio between elements and she finds it hard to distinguish. 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 to 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

5.1 Systematic Literature review

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 (see **Fig. 3**). This gives insight that accessibility research 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.

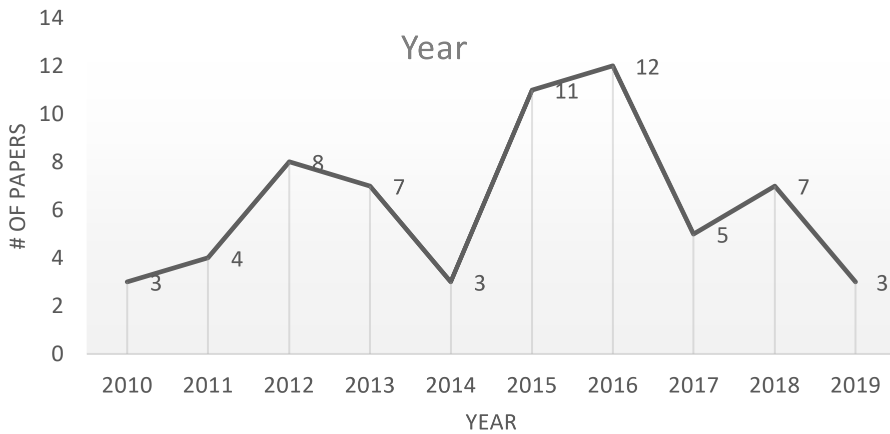

Fig. 3. Number of publications of last one decade

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 [23], “design for all” was also mentioned once [28], 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 accessibility based on a user’s abilities and attributes are essential to close the digital divide gaps.
- The 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

5.2 Interviews

Based on the interviews it seems that for most participants any interaction with digital maps comes from Google maps. We also 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. None of the participants seemed satisfied with keyboard interaction with the interactive maps they tried. But even when they are using their preferred maps apps on mobile devices, limitations of what can be done overshadow their expectation. Turns out the only thing it is good for is 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. Participants reported it is also 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.

5.3 Limitations

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 [45] with easy accessibility, convenience, and advanced search query feature. But later study by Gusenbauer and Haddaway [46] 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 [46] 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 the 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.

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 user groups with other visual impairment like color blindness or tunnel vision could have pointed out more accessibility issues with interactive maps and even propose accessibility improvements.

6 Conclusion

The purpose of this paper was to discover the Research gap and accessibility issues of interactive maps. 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 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 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 map accessibility and adopting universal design in the map’s development process.

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