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Physical barriers and where to find them

Karl-Martin Wigen

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Department of
Physical Geography and Ecosystem Science
Centre for Geographical Information Systems
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

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Department of Physical Geography and Ecosystem Science, Lund University

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Karl-Martin Wigen
Master Thesis, 30 credits, in Geographical Information Sciences
Supervisor Professor Lars Harrie
Department of Physical Geography and Ecosystem Science, Lund University

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Abstract

Movement-impaired groups, like wheelchair users, face challenges navigating sidewalks and pathways due to physical barriers such as curbs, stairs, and inclinations. However, existing navigation services often lack information about these barriers, hindering the ability to suggest optimal routes. Volunteered Geographic Information (VGI) offers a collaborative solution by harnessing volunteers' efforts to collect data for various projects. Despite its promise, VGI projects like OpenStreetMap struggle to effectively promote information about physical barriers and more open data is required for the development of navigation applications tailored to the user's needs. This research project aims to address these shortcomings by developing a framework to capture and visualize data points of potential physical barriers. Utilizing a clustering algorithm, the visualization of barriers is optimized to reduce similar data points. Two participants were recruited to capture data points including curbs with assigned height and crosswalk connections, stairs with or without stroller ramps, inclinations whether they are natural or wheelchair ramps, and other unspecified barriers. The results revealed challenges in capturing and optimizing data for curbs and inclinations. However, the VGI approach showed promise in identifying the presence of stairs. Additionally, unspecified barriers related to weather effects were found, such as snow, underscored their impact on streets and pathways. Overall, this research sheds light on the limitations of the approach in this research project and its technical implementation. Furthermore, this research highlights difficulties in data acquisition, recommendations of visualization of physical barriers, and the need for increased initiatives and data collection efforts.

Keywords: Geography, GIS, VGI, Mobility Impairment, Wheelchair, Physical Barriers, App, Geolocation, Accessibility

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Acronyms

API: Application Programming Interface
BSD: Berkeley Software Distribution
CSS: Cascading Style Sheets
DBSCAN: Density-Based Spatial Clustering of Applications with Noise
GB: Gigabyte
GIS: Geographic Information System
GPL: GNU General Public License
GPS: Global Positioning System
HTML: HyperText Markup Language
iOS: iPhone Operating System
ISC: Internet Systems Consortium

JS: JavaScript
JSON: JavaScript Object Notation
JSX: JavaScript XML
MIT: Massachusetts Institute of Technology
NVBD: Nationella vägdatabasen
OSM: OpenStreetMap
QR code: Quick Response code
UI : User interface
VGI: Volunteered Geographic Information

1. Introduction

Geographical Information Systems (GIS) is a tool to capture spatial entities that pose the question "where?". For someone with a limited mobility, they might wonder whether there are any physical barriers that may affect their routing when going from A to B in an unfamiliar place. In several routing applications, the suggested route is not always the most sufficient due to the characteristics of the route that may mismatch the user's profile (Kasemsuppakorn et al., 2014). For example, a generated route from Google Maps may include inconsistencies on pathways or sidewalks which affects wheelchair users, such as high degree of slopes. Transitioning to the realm of routing and disability, we encounter challenges in building a personalized navigation system tailored to different needs. In general, when it comes to disabilities, different disabilities have their own limitations when it comes to optimized navigation (Gupta et al., 2020). Therefore, it is important to acknowledge that individuals' preferred characteristics of the route differs whether there is cognitive disability, visual impairment, or wheelchair dependency. Several routing applications have emerged which aim to address accessibility issues, to generate routes that are tailored around an individual's personal needs (Zipf et al., 2016).

The fusion of smartphone technology and *Volunteered Geographic Information* (VGI) presents an opportunity for addressing the challenges regarding accessibility on sidewalks and pathways. VGI, characterized by inclusive data collection, empowers individuals to contribute with open data through platforms like *OpenStreetMap* (OSM) (OpenStreetMap, 2022). Open data from OSM has been beneficial in developing routing applications tailored to the user's needs in terms of wheelchair users, one such example is *Openrouteservice* (OpenStreetMap, 2023). However, there are issues that have been imposed in VGI projects and initiatives built on crowdsourcing. Ensuring data quality, long time monitoring of projects, and low motivation are ongoing concerns (Antoniou & Skopeliti, 2015; Fritz et al., 2017). Although assistive technologies enhance functional mobility, street-level accessibility remains a pressing issue. To some extent, data to sustain a route direction service is insufficient, which is caused by various factors such as fragmented frameworks and the geographical or contextual scope of VGI approaches around the world.

With the empowerment of maps and localization of physical barriers, accessibility on sidewalks and pathways has been exposed. Innovative projects have emerged, with various VGI approaches such as gamification and machine learning techniques (Brovelli et al., 2016; Mobasheri et al., 2017a; Miyata et al., 2021). These projects enhance the development of accessibility applications and the potential in developing navigation services tailored to wheelchair routing. Thereby, data gathering methods of physical barriers and sidewalk to build the infrastructure of such application have improved significantly. However, the challenge remains of maintaining an open and updating framework based on VGI that links physical barriers with sidewalks and pathways.

1.1. Aim and Research Tasks.

This thesis aims to develop an open framework for anyone to contribute information about physical barriers that limit mobility for wheelchair users or potentially other movement impaired individuals. By acquiring information about the physical barriers on the sidewalks and pathways, their location and appended characteristics are displayed based on the participant's input. Due to the incompleteness of sidewalk data from VGI sources and accessibility-related attributes, the end goal is an application that updates information about physical barriers based on users' input until they are resolved or removed. These physical barriers consist of curbs at crossings or sidewalks and inaccessible pathways, such as stairs and inclinations.

The following research tasks were conducted:

1) *Design, implement and evaluate a technical framework for VGI barrier data collection.*
2) *Design, implement and evaluate a clustering algorithm for streamlining the physical barriers by grouping nearby data points into clusters and then enhance the visualization.*

1.2. Disposition

To address the research questions, this research paper defines VGI and the meaning of physical barriers and limited mobility, particularly focusing on limitations in wheelchair routing, in the chapter titled *Previous Research and Definition*. Additionally, the chapter reports on VGI projects, potential sources of physical barriers, and related research. Subsequently, in the chapter titled *Methodology*, the study area is described, the data that is acquired, and the VGI approach is set up with a description of the data acquisition application and its features. Furthermore, a clustering algorithm is explained, along with how the gathered data is processed. Lastly, the methodology chapter describes the tools utilized to display the barrier information. The following chapter, *Results*, presents the physical barriers that have been collected, their attributes, visualization of the barriers, potential errors, and participant feedback. The next chapter, *Discussion*, elaborates on and evaluates the results of this project. Here, the research project is compared with others and concludes with a discussion of its possible state in the future. Ultimately, in the sixth chapter, *Conclusion*, the research project's findings, implications, limitations, and suggestions for future development are summarized.

1.3. Limitations

This thesis has some limitations to address. When developing the application, the end goal is to provide open data which others can use in routing applications or by city planners. Potentially, the developed framework in this thesis may be transformed into a routing application. Moreover, the study area is limited to the neighborhood of Traneberg in Bromma in Stockholm. The target group of the framework is wheelchair users. The group was selected because potential limitations for wheelchair users were discovered in suggested routes from Google Maps, e.g. routes that include stairs. However, this does not mean that the final product is unsuitable for other move impairments, elderlies, or strollers. But primarily, the physical barriers in this project are targeted around wheelchair mobility. Ultimately, VGI is used as the source data mainly because one of the aims is to build an architecture for participants to update and access open data. Therefore, a potential obstacle in the beginning is to motivate users to participate in this project, especially if the weather conditions do not apply to the project's circumstances.

2. Previous Research and Definitions

The definition of limited mobility among individuals is defined differently in various works, but in the context of disabled individuals and geography, a limited mobility can be determined by the environmental conditions and the individual capability (Kocaman and Ozdemic, 2020). Physical barriers and other forms of inaccessible infrastructure are environmental factors that can impede an individual's mobility within the physical environment. The first section in this chapter reports on the context of wheelchair users' limitations when navigating in the physical environment and the physical barriers that cause these limitations. Afterwards, comes a section that describes sources where physical barriers can be retrieved and lastly a section that describes the complications in utilizing physical barriers in navigation services.

2.1. Navigation for Individuals with a Physical Disability

Physical disability and its relation to physical barriers is a widespread topic. Disability refers to a condition characterized by impairment in the human body, which can manifest as limitations in individuals' physical or mental functioning. These limitations may result from various biological or medical factors, and they often impact an individual's daily activities and routines (Hedlund, 2000). Disability encompasses a wide range of conditions, including visual and hearing impairments, as well as mobility challenges. Individuals with disabilities often encounter barriers, whether physical or societal, that significantly affect their daily lives (World Health Organization, 2011). Assistive technologies have significantly improved functional mobility for individuals with disabilities. For instance, a well-designed wheelchair can empower users to live fulfilling lives, potentially making them forget their limited mobility. However, the accessibility of routes from point A to point B remains a critical issue. Several streets contain physical barriers that are unsuitable for wheelchair use.

Navigational services offer individuals suitable routes when navigating unfamiliar places. However, navigational software for wheelchair users encounters challenges due to the limited availability of detailed environmental data in various cities and countries (Cruz & Campelo, 2019). Often, existing databases lack crucial information, such as the presence of obstacles like trees, poles, holes, and uneven surfaces. These elements can significantly impact the mobility and safety of individuals with special needs. To address these issues, utilizing VGI and crowdsourcing methods has potential for developing navigational software tailored to the user's preferences. These methods involve the voluntary contribution of data from the public, offering a cost-effective and considerate solution for enhancing navigation services for people with limited mobility. Thereby, the physical barriers must be identified.

The World Health Organization (2011) has reported on physical barriers and wheelchair use, among these, curbed ramps on sidewalks were emphasized, since these properties affect the accessibility of vehicle entrances on the streets (World Health Organization, 2011). Moreover, to make streets accessible and friendly for people with limited mobility, entities that contribute to accessibility in physical constructions contains:

1. Curb cuts and ramps, ***2.*** Safe crosswalks and ***3.*** Accessible routes to travel.

Figure 2.1 displays cut curbs with a crosswalk and traffic signals. Meanwhile, *Figure 2.2* displays cut curbs with a crosswalk and no traffic signal. Additional examples can be elaborated from other research that has defined physical barriers on the streets.

Figure 2.1. Crosswalk with cut curbs and traffic signals (Wigen, 2023).

Figure 2.2. Crosswalk with curb cuts (Wigen, 2023).

Saha et al (2019) identified four types of barriers on the street based on American authoritative standards and previous research projects:

1. Existing curb ramps on streets, ***2.*** Physical obstacles in the path, ***3.*** Surface problems and ***4.*** Missing sidewalks.

Figure 2.3 displays an example of a missing curb cut and missing crosswalk. Meanwhile, *Figure 2.4* shows a potential obstacle on the sidewalk.

Figure 2.3. No curb cut and crosswalk (Wigen, 2023).

Figure 2.4. Potential obstacle (Wigen, 2023).

Similarly, Brovelli et al (2016) identified the following barriers:

1. Stairs, ***2.*** Ramps and ***3.*** Pathways, but they never specified the context of the pathways.

Meanwhile, Biagi et al (2020) reported on the OSM tagging schema for accessibility which included:

1. Presence of sidewalks, ***2.*** Crossings with curbs on each side that are either: a) *Raised* - the steps are more than 3 cm, b) *lowered* – the step is approximately 3 cm or less and c) *flushed* – there is no significant step, ***3.*** The type of surface on the streets: a) *Paved*, b) *Asphalt*, c) *Paving stones* and d) *Natural stones*, ***4.*** The amount of slope or inclination regarding both sidewalks and existing ramps, and ***5.*** Barriers on the streets such as any type of pole, manholes and trees.

Figure 2.5 displays an example of a surface problem and *Figure 2.6* shows an inclination next to a staircase.

Figure 2.5. Surface problem (Wigen, 2023).

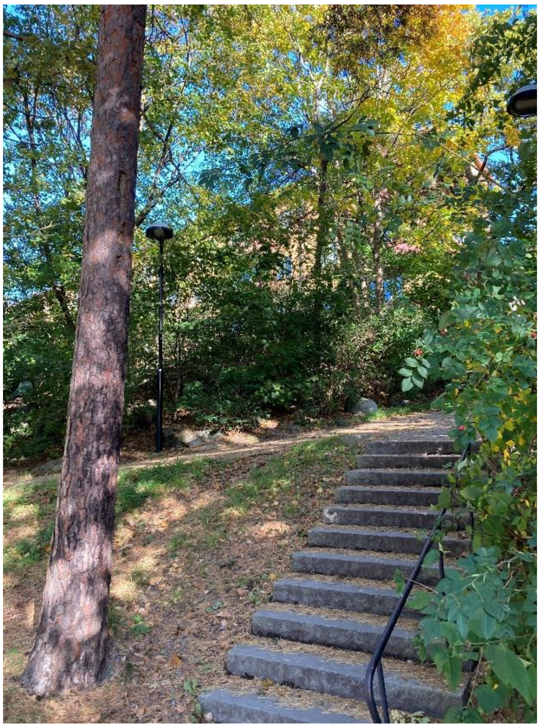


Figure 2.6. Natural incline and staircase (Wigen, 2023).

It is important to mention that physical barriers can be seen as temporal features on sidewalks and pathways. One example is weather phenomena such as snow which makes the surface difficult to travel and its coverage of curbs (Gharebaghi et al., 2018). Thereby, maintaining the cut curbs snow free is an important factor to enhance accessibility. The width of the curbs is also an issue that may be temporary, as recognizing them can advocate for policy changes aiming to increase the widths of curb cuts. In conclusion, there are several definitions and observed obstacles that limit mobility on sidewalks and pathways. Primarily, this thesis focuses on curbs, which gives access to cross the streets depending on their height. Additionally, any sort of physical barrier that makes a place on the pathway inaccessible such as stairs, inclinations, and potentially other obstacles. The following two sections, *Geospatial*

Databases as Sources of Physical Barriers and *VGI and Geo-crowdsourcing as Sources of Physical Barriers*, are highlighting potential sources of where to find information regarding physical barriers.

2.2. Geospatial Databases as Sources of Physical Barriers

There are existing databases that contain information regarding physical barriers and inaccessible places, but they are to some extent troublesome to utilize. Due to the geographical context of this study, databases available in Sweden are evaluated for their data on physical barriers. One potential source is The National Road Database (*Figure 2.7*), *Den nationella vägdatabasen* (NVDB), which is a collaboration between several national agencies and organization such as The Swedish Transport Administration, The Forestry Industry, The Swedish Mapping Cadastral and Land Registration Authority, The Swedish Transport Agency, administrational regions, and municipalities (Trafikverket, 2023b).

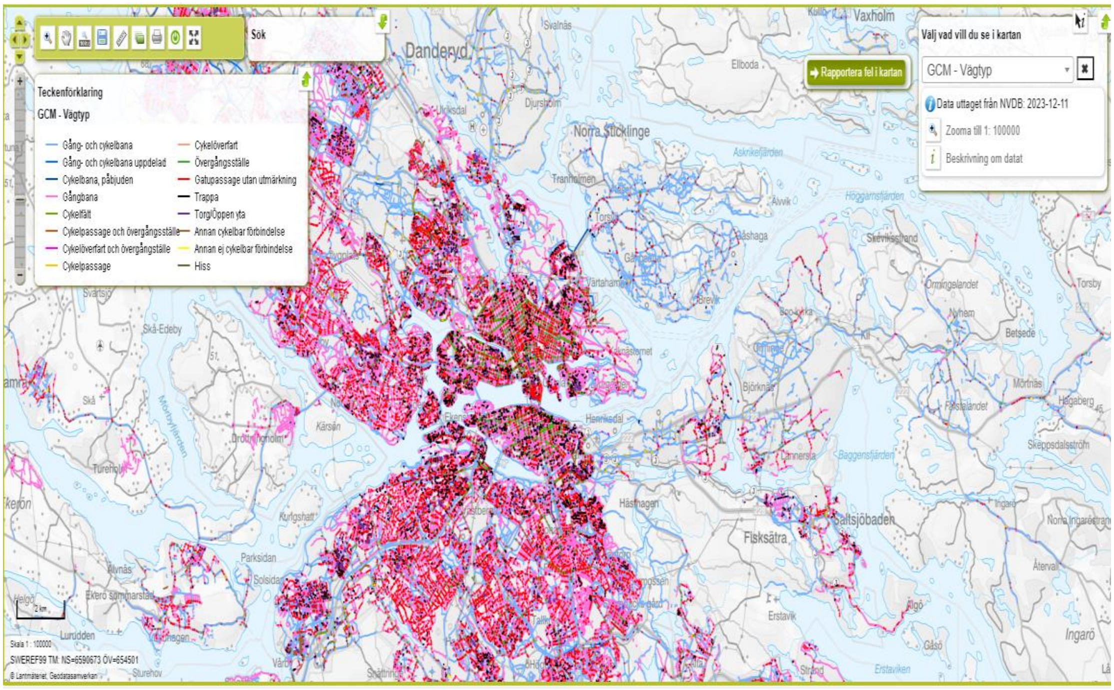


Figure 2.7. NVDB on the web (Trafikverket, 2023).

Together, they deliver data and maintain a database containing features of roads, streets, bike lanes and pathways that cover Sweden. While their data provides detailed information on the locations of stairs and crosswalks, essential accessibility attributes are lacking (Trafikverket, 2023a). For example, the data on stairs lacks relevant information about the presence of ramps for strollers, while information on crosswalks does not include details about the height of the curbs. Despite this limitation, NVDB is frequently updated, and there is potential for it to be augmented with accessible data collected from volunteer projects like this one, or even integrated into navigation services.

The Accessibility Database (*Figure 2.8*), known in Swedish as *Tillgänglighetsdatabsen*, is a project specializing in accessibility data for individuals with disabilities, which was initiated in 2013 (Sveriges Kommuner och Landsting, 2013).

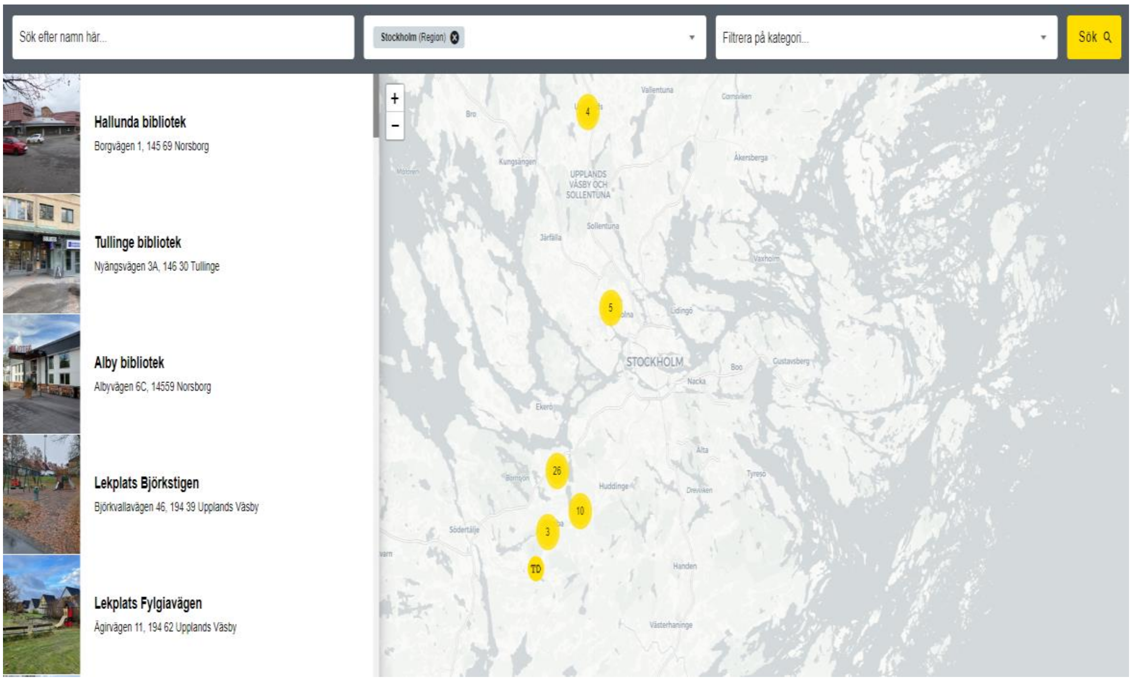


Figure 2.8. The Accessibility Database (Västra Götalandsregionen, n.d.).

Approximately 70 municipalities, along with several administrative regions and organizations, participate in the project, contributing data on accessibility to various facilities. The data is customized to assist individuals with special needs in accessing various facilities such as hospitals, libraries, and daycare centers. The accessibility parameters may include details about the presence of handicap parking and elevators, providing benefits not only to individuals with limited mobility but also to those with strollers. However, it's worth noting that these accessibility points only encompass buildings, and since its inception, only around 8,000 features have been reported. Additionally, due to limitations in participating municipalities, the majority of reports cover western Sweden, particularly the region of Västra Götaland.

While authoritative databases provide valuable information, their data is not always readily accessible for application development. Nonetheless, there is potential for collaboration between authorities and projects like this one in the future. The following section discusses VGI as an alternative source of information.

2.3. VGI and Geo-Crowdsourcing as Sources of Physical Barriers

There are several definitions in terms of collecting data through citizen science. The term VGI sets itself apart from traditional sample methods, as it welcomes participation from anyone motivated to provide data, rather than relying on selective sampling techniques (Lakshmi Steinberg & Steinberg, 2015). While the inclusivity of VGI allows for contributions from diverse individuals, it may also introduce variability in expertise and knowledge among participants. However, projects utilizing community-gathered data have demonstrated, to some extent, acceptable data quality. One example is OSM, which is described as a free, editable map of the world, where volunteers contribute map data that is used in various projects under an open-content license (OpenStreetMap, 2022).

Regardless of VGI's underlying definitions, it is commonly considered synonymous with *geo-crowdsourcing* (Brovelli et al., 2016). Geo-crowdsourcing is defined as the collection of geospatial information by an undefined network of people. Globally, access to smart phones has increased, and with people acting as mobile sensors, everyone can contribute to sharing and acquiring geospatial data (Lakshmi Steinberg & Steinberg, 2015). With smart devices connected to *Global Positioning Systems* (GPS), standardized frameworks, and open-source applications, individuals can contribute to projects that help others' everyday life. Another term worth mentioning is called *Public Participation Geographical Information Systems*, which focuses on involving citizens' and non-governmental organizations in urban planning and local decision-making processes (Bakowska-Waldmann & Kaczmarek, 2021). Throughout this thesis, the terms VGI and geo-crowdsourcing are used interchangeably since this thesis is not directed towards planning activities but may contribute to such actions.

It is important to acknowledge weaknesses associated with VGI approaches. The lack of data quality is a common issue, necessitating the development of a framework to monitor quality (Antoniou & Skopeliti, 2015). This includes a pressing need for universal standards to evaluate data quality. Also, it is crucial to acknowledge that data derived from VGI sources may be unreliable, given that it is collected using a range of tools, technologies, and varying levels of expertise (Mobasheri et al., 2017b). Furthermore, in some projects, VGI data collected by anonymous participants, which can introduce authenticity and reliability concerns in the final product (Cruz & Campelo, 2019). Another important aspect is the nature of volunteers. Some have genuine interest in projects such as OSM, some are motivated by financial incentives, and some have a causal interest in mapping and contributing geospatial information (Fritz et al., 2017). Therefore, it is fundamental to motivate participants to contribute. Various approaches can be employed, including simplifying the VGI application, using *gamification* to trigger the reward system in the participants, implementing tools that allow users to provide feedback or correct errors collected data, and involving a target audience to work towards a common cause. Consequently, three key issues should be considered:

1. Methods employed in the recruitment of volunteers, ***2.*** *S*trategies to motivate volunteers to contribute, and ***3.*** Tactics for sustaining long-term participation.

In conclusion, VGI and geo-crowdsourcing have emerged as valuable tools for collecting geospatial data with the active participation of individuals. While they offer numerous benefits, including rapid data acquisition and low cost, it is essential to address the associated challenges, such as data quality and participant motivation. As we transition to the next section, *Related Projects in Physical Barriers and Wheelchair Navigation*, we will explore how these innovative approaches can be harnessed to address specific challenges related to accessibility for wheelchair users.

2.4. Related Projects in Physical Barriers and Wheelchair Navigation

There are several projects which have focused on combining accessibility for wheelchair users with features of VGI, GIS, smartphone technology, GPS, standardized frameworks, open-source applications, and machine learning. Brovelli et al (2016) highlights the importance of VGI in smart phones, where humans are described as mobile sensors to detect spatial entities. Their project explained the utilization of VGI, and an Android application named *ODK Collect*, which is designed to create surveys for collecting geographic data. The participants registered mobility barriers and the positions of the barriers were displayed in a web map. Brovelli et al (2016) called for future projects to test the current state of smart devices' capability of recording geographical positions but also simplified applications for people who are not heavily technical oriented.

Another VGI project named *Wheelmap* (*Figure 2.9*), was developed to contribute to OSM and open data (Mobasheri et al., 2017a).

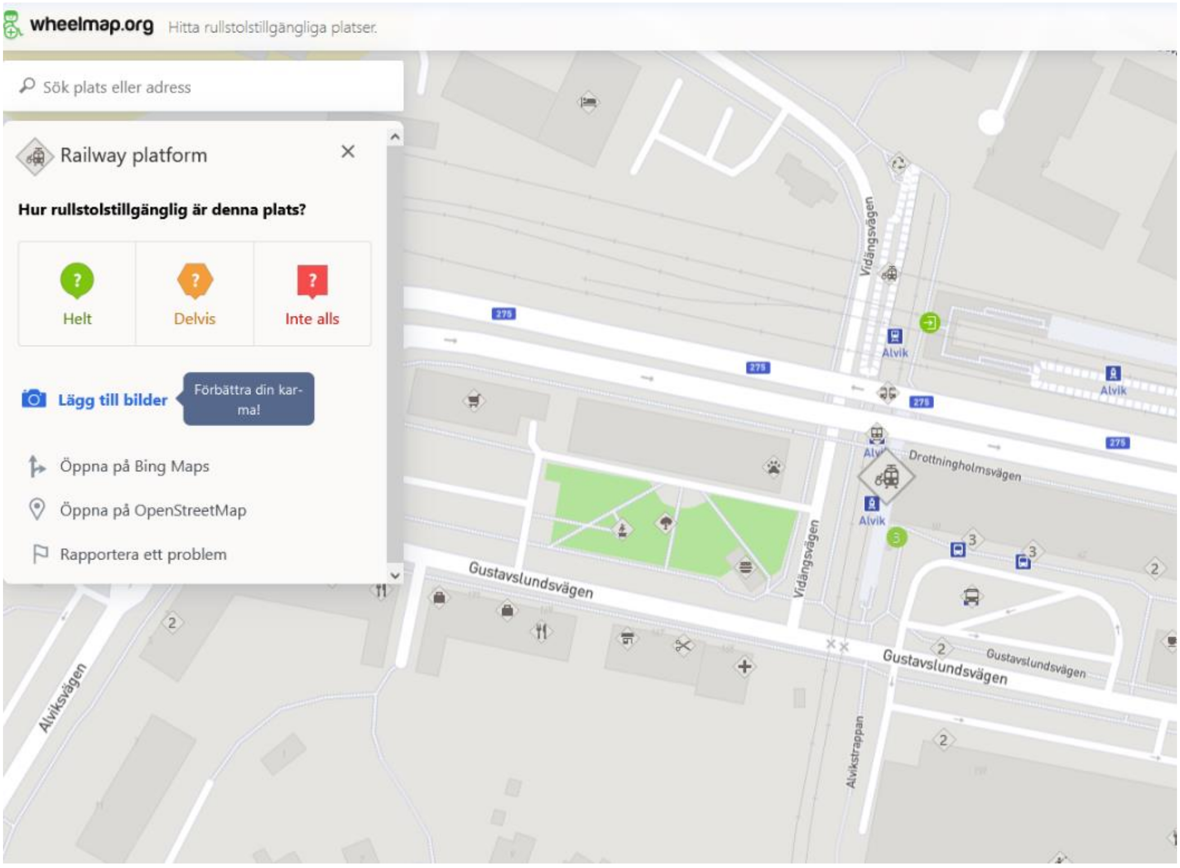


Figure 2.9. Screenshot of Wheelmap (Sozialhelden e.V, n.d.).

Wheelmap is based on geo-crowdsourcing to pinpoint places, e.g. buildings, and their access suitability for wheelchair users. This is accomplished by participants who update metadata and attributes related to these locations. Similarly, another initiative developed a social platform where users pinpointed places that represented barriers and their accessibility level were visualized with color codes based on the participant's subjective judgment (Miura et al., 2013). The barriers were rendered in a web map and contained information which type of barrier they represented.

In terms of navigation and wheelchair accessibility, *Openrouteservice*, developed by Heidelberg Institute for Geoinformation Technology (*Figure 2.10*), implements routing based on OSM data. Like other routing services, Openrouteservice offers navigation options for cars, bicycles, and pedestrians. Importantly, Openrouteservice includes a mode specifically designed for wheelchair users, which is based on road- and street-segments sourced from OSM (OpenStreetMap, 2023). This mode considers OSM-tagged barriers when generating accessible routes.

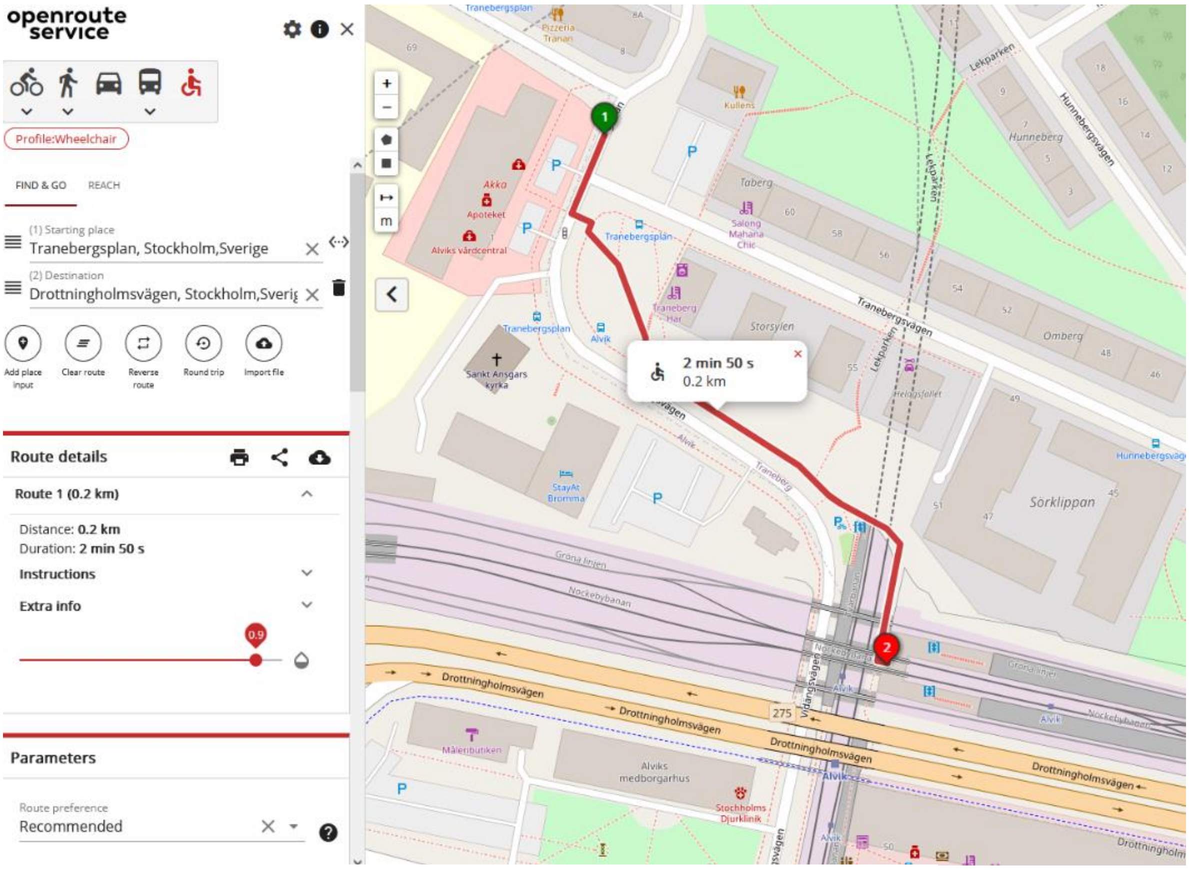


Figure 2.10. Screenshot of Openrouteservice (HeiGIT gGmbH, n.d.).

Wheelmap and other solutions that have been collected through geo-crowdsourcing have limitations due to inconsistency in the tagging and the unreliability in VGI methods (Saha et al., 2019). For instance, the optimization of online methods with gamification gimmicks or paid participation have been introduced. With these methods, participants navigate on roads using Google Street View, and label obstacles on the street. Nevertheless, Saha et al (2019) address certain limitations associated with relying on the latest Google Street View images and online sourcing. Firstly, there is a risk that the images may not be up-to-date. Secondly, crowd-workers lack physical presence or direct knowledge of the assessed streets, relying solely on the images and information provided by Google Street View, without experiencing the sidewalks first-hand. Additionally, another research project has criticized complete volunteered geo-crowdsourced services, even though they have proved sufficient, the methodology of relying on free will and motivation is not enough (Miyata et al., 2021). Instead, they introduced a platform with a hybrid form of complete volunteered mode and a gamification mode. The user takes photos of barriers and with artificial intelligence, the photo generates a monster that is collected. The different barriers are displayed on a map with the corresponding photo of the object.

Unfortunately, there is unreliability of using VGI datasets. Especially in routing based on OSM data, since the quality of the OSM sidewalk data is varying and should be with reference data, e.g. authoritative data, before implemented in navigation (Mobasheri et al., 2017b). This unreliability is based on several factors, foremost missing sidewalk data that has not been collected, identified as line segments on each edge of the street, which instead is replaced with a single line segment. Additionally, there is concern that the sidewalk or road data are missing significant attributes in its tags regarding accessibility, such as width and inclines. Furthermore, crossings, which are fundamental in navigation based on sidewalk data, should contain accessibility attributes, e.g. the accessibility levels of the curbs (Biagi et al., 2023). Another study regarding completeness of OSM data has reported inconsistency in tags regarding OSM sidewalk data, which has called for more accuracy regarding width, texture, and surface types of the sidewalks (Hosseini et al., 2023b). Moreover, there has been research which has reported that wheelchair routing solutions such as Openrouteservice. are not more time saving than using Google Maps (Tannert et al., 2019). Google Maps has the potential to be updated more frequently and barriers data that are collected through VGI are heavily dependent on the volunteer and the current time the barrier was reported. This poses the risk of either generating a route that avoids imaginary barriers or a route that is inaccessible because no barriers have been captured in that area.

Issues in VGI present challenges in developing open-source navigation systems, tailored by the sidewalk datasets. Mobasheri et al (2017b) have advocated for further research in acquiring sidewalk data, enabling the capture of specific positional data that is accurate to capture the true geometries of the sidewalks. Consequently, a study was established to retrieve data regarding sidewalks, employing data mining techniques on GPS traces to construct precise sidewalks (Mobasheri et al., 2018). The authors have called for research projects in generating such sidewalk datasets from smartphone location data. Therefore, it is suggested to find new methods and tools to extract information regarding a route and implement these in current navigation systems. An example of such solution is *Tile2Net*, an opensource tool in Python, which extracts the street properties in aerial images and draw the geometries of crosswalks and sidewalks which potentially can be used in navigation applications (Hosseini et al., 2023a). However, Tile2Net is currently only available in a few regions in the United States of America. Moreover, a research project developed a system called *WheelShare,* where they let sensors register the vibrations from the wheelchair rolling on the street (Edinger et al., 2019). The researchers collected data through geo-crowdsourcing which was used as reference data in a routing application. With machine learning techniques, their model learned code surfaces as accessible or inaccessible based on the vibration data. Thus, a route was generated based on the street surface properties.

Previous research highlights that there are initiatives that capture physical barriers and sidewalk data through various approaches, but the issue with unifying such data remains. Furthermore, previous research recognizes that there is unreliability in wheelchair routing due to incompleteness in sidewalk data and uncertainty in VGI approaches. This thesis aims to contribute to the data acquiring process of physical barriers where barriers are reported by the users in a mobile application and displayed on a web map. The following chapter *Methods* reports on the implementation of the methods to achieve the infrastructure of such application.

3. Methodology

3.1. Overall Structure

This chapter describes how VGI is applied for this project, and the process of acquiring physical barriers. A study area is selected, and the positions of the physical barriers are recorded through the GPS receivers on participants' mobile devices. The first section *3.2.* gives a brief introduction to the study area. The following section *3.3.* describes the barrier data that is going to be collected. Step 1 in *Figure 3.1* is then initiated where section *3.4* explains the data acquisition application and its architecture. Moreover, its sub-sections explain the scripting and libraries that are used to develop the application. Furthermore, step 2 is initiated, section *3.5.* briefly explains the recruitment of the participants and the contact formula is attached in the appendix. Henceforth, the participants collect the physical barriers in step 3. The end goal is to display the acquired barrier data on a web map where users can provide feedback on their reliability. Step 4 is initialized in Section *3.6*, which describes the methods to increase the readability of the barrier data through a clustering algorithm. Lastly in step 5, a framework is developed to visualize the processed barrier data in a web map and is covered in section *3.7.* The VGI approach and the final product may help identify physical barriers that are not discernible through satellite images or Google Street View.

Figure 3.1. From production to the end goal.

3.2. Study Area

The study area *Traneberg* located in Bromma, is a part of the Stockholm Municipality on the west side of the inner city. Traneberg is the chosen study area due to its various landscapes and the simplicity of concentrating the data gathering in a defined space. The area (*Figure 3.2* and *Figure 3.3*) is a mixture of hills, vegetation, and open spaces (AB Stockholmshem, 1998). Examples of characteristic spatial entities are the

Traneberg bridge which connects Bromma with the inner city, industrial bearing houses, the subway station of Alvik and seaside housing complexes.

Figure 3.3. Screenshot of the study area (Google Earth Pro, n.d.).

Figure 3.2. Extent of the study area (Esri et al., 2023).

The residential houses are built on the hills and connected with local roads and pedestrian paths through park areas. As seen in *Figure 3.4*, some of the pedestrian paths have stairs and no ramps to support wheelchairs or strollers. Additionally, there are several crossings that connect the sidewalks, but some sidewalks that are meant to be crossed do not have any zebra markings. In *Figure 3.5*, the pedestrian is intended to cross the sidewalk to the other side which is indicated by the lowered curb on the street.

Figure 3.4. Stairs in Traneberg (Wigen, 2023).

Figure 3.5. Sidewalks and street in Traneberg (Wigen, 2023).

Due to the various characteristics and hilly environment, there are environmental factors that may impact the navigation within the area. For someone with a limited mobility who is unfamiliar with the area, it may be troublesome to navigate.

3.3. Barrier Data

Point features, representing physical barriers are going to be acquired. The reason is that point features can be used as nodes and waypoints in network datasets. *Curbs* on the streets (*Table 3.1*) were included based on their frequency as recognized physical barriers, where cut curbs give access to cross the street. Also, curbs indicate whether a crosswalk is present and can form a polyline if two points on each sidewalk are registered. The first attribute captures the height of the curb, which is defined based on the research conducted by Biagi et al (2020) and OSM standards. Important to mention, is that the estimation of the height is subjective, where a flushed curb may be easier to estimate. The second attribute has Boolean true and false, where true indicates the presence of a crosswalk and false indicates the opposite. The second barrier, *Other barrier* in *Table 3.1*, is going to represent any other physical barriers that are present on the sidewalks or pathways. The first attribute of this data point is *User's Description*, where the participant specifies the type of barrier they encounter, e.g. if it is a lamp post or a manhole. The second attribute is a description where the user explains how the unspecified barrier causes blockade or inaccessibility.

Table 3.1. Types of physical barriers with two attributes to acquire.

Barrier	**Type**	**Attribute**
Curbed street	Height: *1.* 0 cm (*flushed*) *2.* 1≤3 cm (*lowered*) *3.* ≥3 cm (*raised*)	Crosswalk: *1.* True *2.* False
Other barrier	User's description of the object	Short description how the object affects accessibility

Stairs and inclinations (*Table* 3.2) are included because they are also fundamental when it comes to accessing places. Even though an inclination is long, it could be beneficial to display the location of these in case of electric wheelchair use. Also, whether there are inclinations that are specifically built for wheelchairs. In general, inclinations may be preferred over stairs. The *Stair barrier* has one attribute that indicates whether it has a stroller ramp or not. The presence of a stroller ramp has the Booleans true or false. Secondly, comes the *Inclination barrier*, which also has the Booleans true or false, where true indicates a wheelchair ramp and false indicates a natural inclination.

Table 3.2. Types of physical barriers with one attribute to acquire.

Barrier	**Attribute**
Stair	Ramp for strollers: *1.* True *2.* False
Inclination	Handicap ramp: *1.* True *2.* False

3.4. Data Acquisition Application

One of the main goals is to develop an application with a user-friendly interface. The purpose of the application is for the participants to acquire the physical barriers on pathways and sidewalks. The JavaScript (JS) library *React* developed by Meta or formally known as Facebook, is chosen as the scripting language for development due to its readability and simplicity. The extension of React, namely *React Native*, is a framework for user interface (UI) in smartphone application development. React Native allows the developer to write UI applications with JS code that interacts with the devices' application programming interface (API) (Meta Platforms Inc, 2023b). This provides access to native functionalities compatible on both Android and iOS, including features such as location services, pop-up screens, native UI design, and map packages.

3.4.1. Overview and Requirements of the Application

Firstly, custom components are created, serving as distinct pieces that collectively build the application's UI. Components in React are written using JSX, allowing developers to write HTML-like syntax in JS (Meta Platforms Inc, 2023a). In React Native, the components define the UI, fragmented into custom components that collectively compose the application's visual layout. Custom components can also be known as functional components, which encapsulate blocks of code and logic for the assigned component that is rendered on the screen. Additionally, custom components can pass or receive data and functions as properties to each other, similar to object-oriented programming principles.

Another crucial aspect in React is the concept of states, which enables the storage of data and facilitates rendering upon changes without refreshing the entire application (Meta Platforms Inc, 2023a). This proves powerful in React as it allows customization and modification of individual custom components without impacting one and another. States are frequently managed using React Hooks, allowing the rendering process to influence only the specific component being targeted, preventing unintended side effects on other components. Moreover, developers have the flexibility to create custom hooks, enabling the reuse of code logic across multiple components where the same functionality is needed. *Figure 3.6* presents several core components from React Native, methods from React, and React libraries that create functional components.

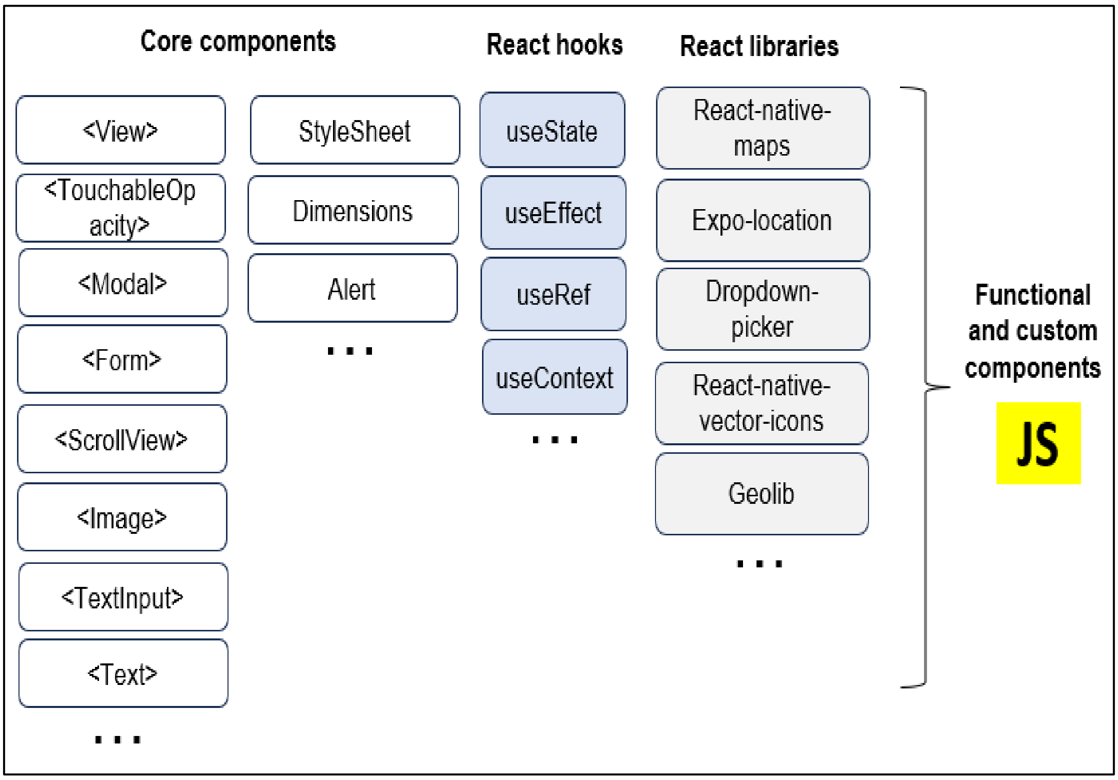


Figure 3.6. React Native components, React hooks and dependencies.

When the application is running, a loading screen appears prompting the user to allow location tracking through the *Expo-location* library (Expo, 2024). If the user accepts, a screen with a map appears and if the user declines an error screen will pop up. The main screen of the app renders several functional components, most importantly a background map and the position of the user through the *React-native-maps* library (React-native-maps, 2024). *Figure 3.7* and *Figure 3.8* display the initial UI of the application.

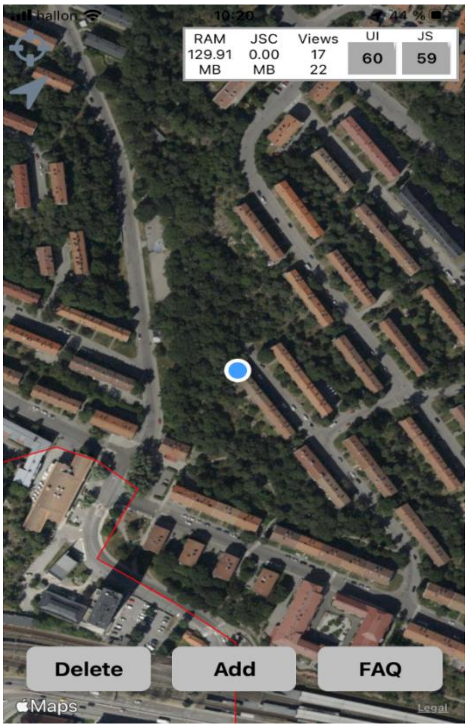


Figure 3.7. Application UI with satellite image background (Apple Inc, n.d.).

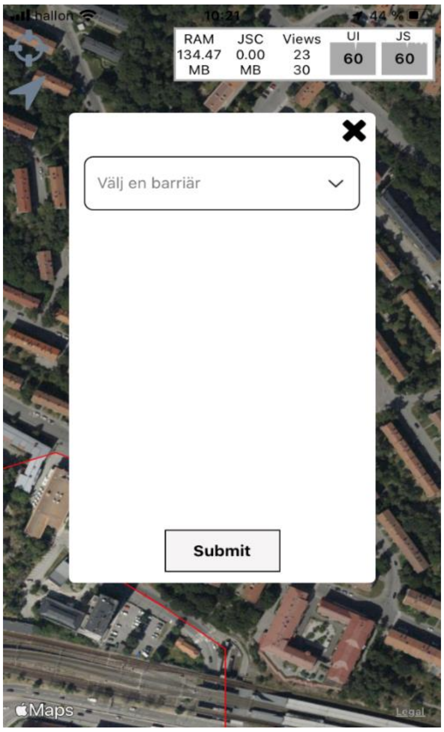


Figure 3.8. Application's barrier selection (Apple Inc, n.d.).

A basemap of satellite imagery is rendered in the background to give the user a sense of its surroundings. Additionally, a functional component of buttons built on the core component *Touchable Opacity*, containing buttons to add or delete barriers and open a how-to-use guide. These buttons have functionality attached, most importantly the add button's purpose to register the position of a physical barrier based on where the user is standing and then opens a *Modal* with a form where the user fills in the information regarding the physical barrier. A temporary dropdown list, the *Dropdown-picker* library from Zare (2023), is displayed when a user adds a position of a barrier. Within the list, the user fills which type of barrier they encounter and its attached attributes. Moreover, icons distributed through *React-native-icons* from Arvidsson (2023), are implemented for utilities to relocate the map view or permission to activate the tracking if a disconnection occurs. Lastly, the main screen with functional components is designed and positioned with the help of the React-native core components *View* and *StyleSheet*, which allows to position and style functional components with CSS-like properties. The functional components are rendered and modified with *React hooks*, which manage communication between the components and distribution of data. React hooks bind together and fetch data across multiple components, which allows the recorded location of the user and the filled form to be embedded and sent to the database.

Expo-location, as mentioned earlier, is utilized to read the user's geolocation, and display it on the map (Expo Technologies Inc, n.d., b). Expo-location has high importance in acquiring the position of physical barriers. The user stands on the spot of the physical barrier, presses the add button where the form pops up which disables all other functionalities. Moreover, an object is created containing the latitude and longitude of the user's current position as the add button is pressed. Thus, the user selects which barrier type they have encountered and the additional information regarding the barrier. If the user cancels the form the object is deleted and if the user changes barrier type, the object will change the barrier type to the corresponding attributes.

To summarize, the requirements of the mobile application consist of data acqusition where users record data of physical barriers that are located on their current position. However, there are limitations to these requirements where users cannot see what other users have recorded, the user is unable to put down points other than their current position and users are unable to edit data points they have added. These are limitations that may affect the outcome and are solutions that could improve data acquisition.

3.4.2. Selection of Programming Environment

The application is developed for smartphones. However, there is an issue regarding the distribution of the application. Anyone who wants to release an application on Google Play or App Store, is required to pay a fee for a developer account, which is considered expensive for this individual project. Fortunately, this issue has been resolved with a framework for mobile app development, there is an open-source solution where developers can test and run their application without further complications. *Expo-go* is a service where the developer can render and upload their project to test it directly in their smartphone (Expo Technologies Inc, n.d., a). Expo-go is not suitable to distribute applications to a wide audience, rather it is useful for testing and improving a project with a few numbers of participants. Expo-go is available in Google Play and App Store, where projects can be distributed through *quick response* (QR) codes. The project is accessible through a server hosted by Expo and can therefore be distributed to its participants. Thus, Visual Studio Code is selected as the integrated development environment, due to its user-friendliness and extensions that utilize text editing.

3.4.3. Selection of Database Environment

Firestore, developed by Google, is a NoSQL cloud database suitable for storing data from mobile applications and offers synchronization between users' devices and the database (Google for Developers, 2023). This project is utilizing Firestore where recorded data is sent to the database with assigned attributes regarding accessibility. Cloud-hosted databases can be rather complex to set up; thus, the scope of this project determines the choice of Firestore. Since the purpose of the database in this project is to store the acquired coordinates of physical barriers and their attributes, it provides a flexible and rapidly deployable solution tailored to the project's needs. Designed with an API to handle the communication between the device and the database. Firestore offers free storage up to 1 GB, where the stored data can be retrieved in JSON format.

3.4.4. System Architecture of the Application

The mobile application and Firestore are going to be complemented with a web map which displays the data that is collected. Thus, the user collects data with the data acquisition application, which is then stored in Firestore and is retrieved through a web map. Overall, *Figure 3.9* summarizes the architecture of the mobile application and the web map application.

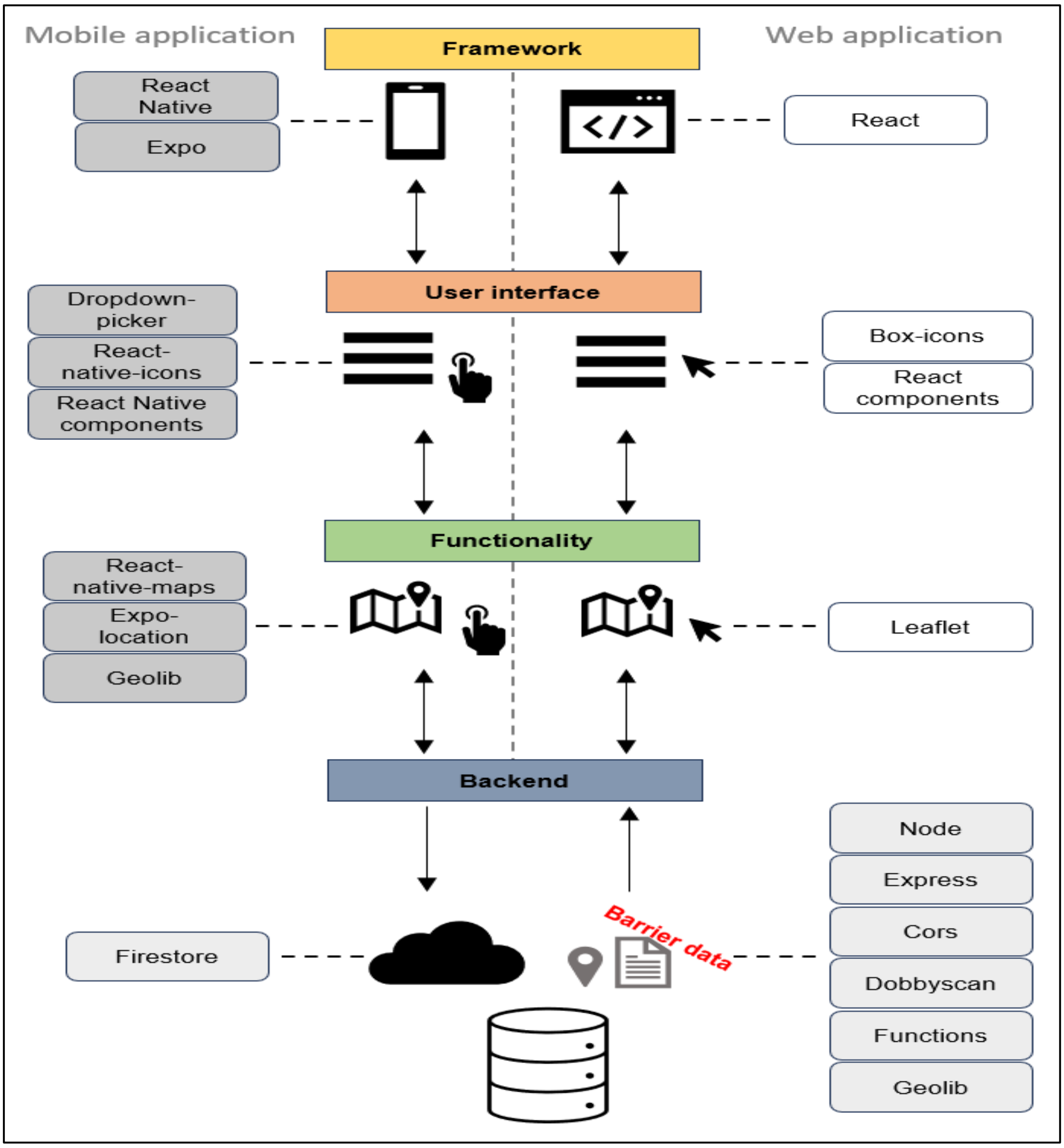


Figure 3.9. System architecture.

Foremost, React Native (Facebook, 2024) and Expo (Expo, 2024) are the main frameworks to develop the mobile application. Dropdown-picker (Zare, 2023) is used as a form to users to select options in the input-barrier form. React-native-icons (Arvidsson, 2023) provides icons as buttons along with additional React Native Components used for UI design or built-in functionality. The button functionality consists of accessing the GPS of the smartphone to track user location through Expo-location library or zoom in to the user location displayed on the map provided by React-Native-Maps (React-native-maps, 2024). Geolib (Bieh, 2023) ensures that the user is located inside the study area through point-in-polygon method, otherwise the acquisition of barrier data is disabled. When all fields have been filled in, which is a requirement, the user submits the barrier data to Firestore. The barrier data is displayed in a web map developed React (Meta, 2022). The web map also utilized UI design and buttons with functions, for example icons from Box icons (Atiaswd, n.d.). Moreover, the web map and its functionalities are provided with the Leaflet library (Leaflet, 2023). Barrier data in Firestore is accessed from the server through Node (Node.js, 2024) which handles scripts in the backend. Express (Expressjs, 2022) runs in Node to fetch data on the server-side and Cors (Goode, 2018) complements this procedure by ensuring that the data fetch on the server side is linked between the web client and Firestore. Lastly, Geolib and Dobbyscan (Mapbox, 2018) are utilized on the server-side to process the barrier data and improve its visualization.

The following section explains the recruitment of participants which are going to utilize the data acquisition application, followed by methods to process the collected barrier data, the visualization of the barrier data and lastly a section of distribution of the project.

3.5. Participants for Collecting Barrier Data Using the Data Acquisition Application

Participants are gathered from the neighborhood of Traneberg through advertisement on bulletin boards with a short description of the project and QR-code to apply, see *Figure A.1* in the appendix. Anticipated community involvement holds promise for enhancing neighborhood accessibility. The eventual project outcome is expected to yield advantages not only for individuals dependent on wheelchairs but also for parents utilizing strollers. Participants receive an email containing instructions on accessing Expo-go based on their smartphone device. This email includes QR codes, links, and instructions for accessing the project within the Expo-go application, all of which are referenced in the appendix.

3.6. Selection of Barrier Information to be Displayed

The participants have individually recorded different numbers of physical barriers. Suppose that an object of stair S_1 receives j number of reports and is located 2 meters away from another object of stair S_2, which receives k number of reports. This may cause issues; foremost visual issues in the map due to several reports of the objects representing stairs. Additionally, several stair-features may appear in the map than there are stairs at ground truth. Therefore, the reports must be reduced to one single point for S_1 and S_2 respectively.

3.6.1. Density-Based Spatial Clustering of Application with Noise

Given that data points representing the same object on the ground may be widely dispersed, a clustering algorithm can be employed to group these data points together. *Density-Based Spatial Clustering of Application with Noise* (DBSCAN) is a clustering technique commonly used in various fields, data mining, and machine learning to detect clusters in datasets with outliers (Khan et al., 2014). With the assumptions that the participants record the physical barriers standing on different positions nearby the object, DBSCAN can be applied to group the points that are spatially nearby, and each cluster results in a single point feature to represent the physical barrier.

DBSCAN has the following set comprehension from Khan et al (2014):

$$N_\varepsilon = \{q \in D: dist(p,q) \leq \varepsilon\}$$

$$N_\varepsilon(P) \geq MinPts$$

Where:

N_ε denotes the neighbourhood around the point p,

D is the dataset of points,

$dist(p,q)$ is the distance between the points p and q calculated with Euclidean distance:

$$|pq| = \sqrt{(x_q - x_p)^2 + (y_q - y_p)^2},$$

ε is the given radius around point p,

P is a core point if it contains the minimum number of q,

$MinPts$ is the minimum number of q to fulfill the criteria of a core point

The radius (ε), and *the minimum number of points* ($MinPts$) are the parameters which define *the neighbourhood* in N_ε (Ester et al., 1996). In the dataset of points, the algorithm iterates through each point (p) and searches for points (q) in the given radius. If the radius around the point p contains the minimum number of points q or more, it is considered as a core point. Thereby, a cluster has been defined and the algorithm continuously searches for nearby points that belong to this cluster. Data points that fulfil the proximity are registered as core points and any other point is considered as an outlier. Therefore, depending on the spatial distribution of the data, several clusters are created. *Figure 3.10* displays the concept of the algorithm where a cluster is defined by any point that is within the radius of a core point.

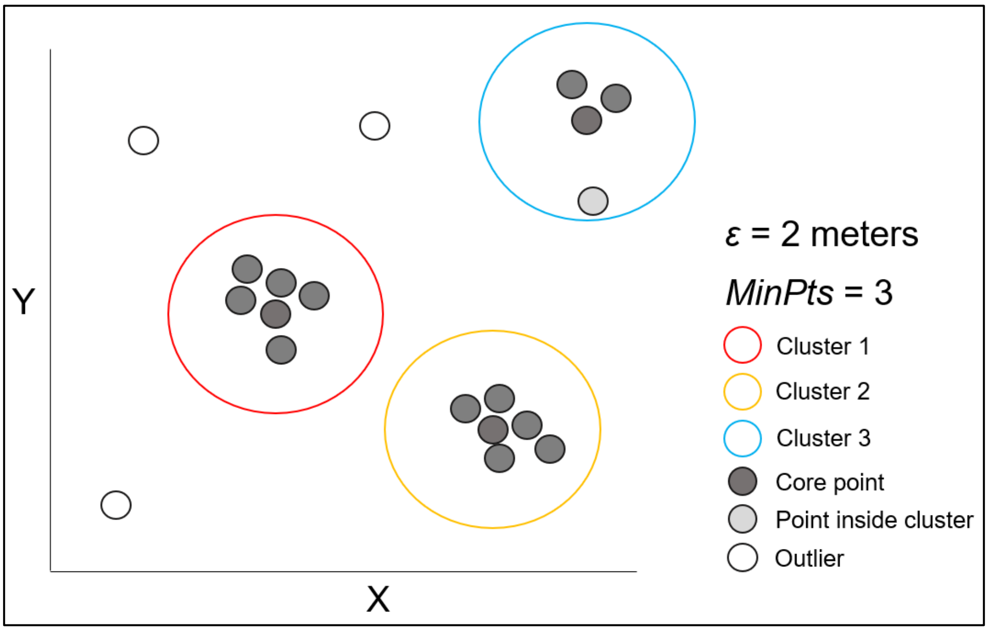


Figure 3.10. Theoretical concept of DBSCAN and points in the two-dimensional plane.

In this example, a core point is defined if it has a minimum of 3 points within its radius. The boundary points in a cluster, the point with a lighter shade of grey in Cluster 3, are not required to be classified as core points. They are included in the cluster when all clusters and core points have been defined if they are within the radius of one of the core points.

3.6.2. Study of Input Parameters

Clusters are generated for each barrier type separately. Since the barriers have geographical coordinates, the JS library Dobbyscan is utilized (Mapbox, 2018). Dobbyscan has a fast modification of the DBSCAN algorithm which handles distance between geographic coordinates, which is beneficial instead of converting the points to the two-dimensional plane. The epsilon's value differs depending on the characteristics of the barrier type. The epsilon thresholds 1, 5, 10, 15 and 20 meters are tested for the barrier types stair and inclination. The threshold is increased by 5 meters if the conditions are not satisfied. Due to the assumption that curb barriers are located nearby each other, the epsilon will start at 1 meter and increase with 1 meter in every iteration. When operating the dataset, the epsilon 5 meters was most sufficient to group nearby duplicates. As seen in *Figure 3.11*, the original curbs are displayed in the top left image where two flushed curbs with crossing and one mid curb with crossing are too close to each other.

Figure 3.11. Epsilon testing for the curb objects.

When captured by epsilon, the curbs are marked with a dot. Red dots indicate that they are not mergeable due to different height and crossing attributes. When a dot is green, it has found a match with at least two points of the same attributes within the epsilon threshold and merges them. The threshold ensures that duplicates are covered on the same side of the street without extending to a similar curb object that is located on the other side of the street. Increasing the threshold further implies diffidence whether the same object was merged or if two different objects are merged. As the epsilon increases, more curbs with different attributes were put in the same cluster.

When it comes to the stair type, *Figure 3.12* displays two location examples. Example 1, in the top images, shows several records of a stairs object with stroller ramp and one without stroller ramp. The top image shows that the objects are successfully merged at 15 meters, eliminating all identical features. At ground level, there are two stair objects on each side, one with a stroller ramp and one without a stroller ramp. The cluster in the bottom images has still not captured all the nearby stair data points.

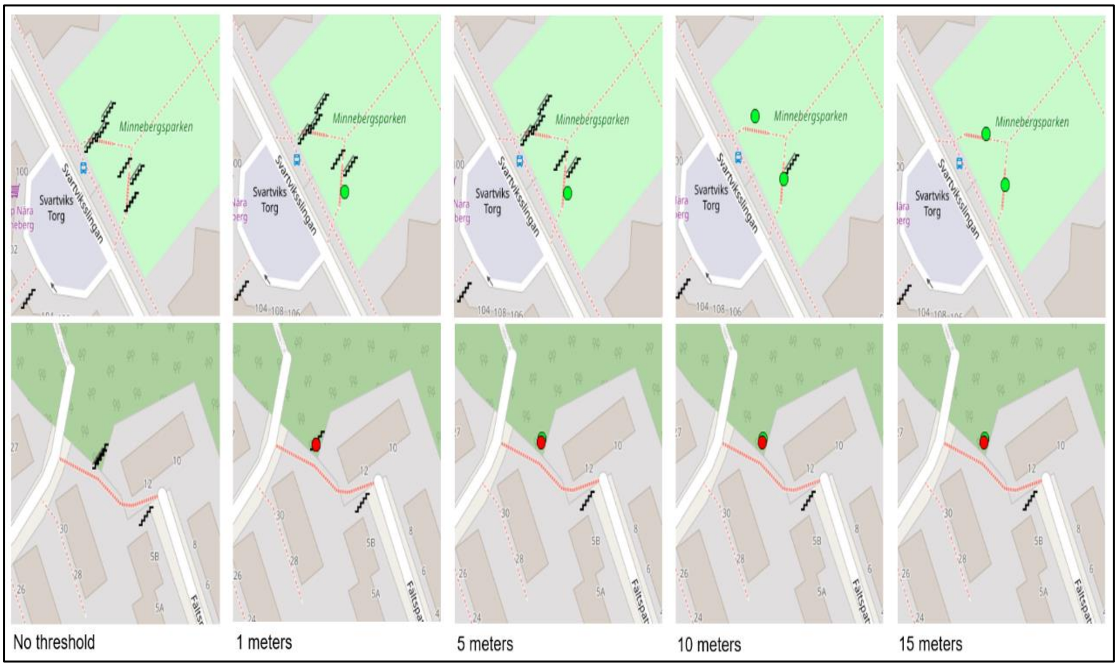


Figure 3.12. Epsilon testing for the stair objects.

Increasing each iteration by 5 meters revealed that a threshold of 25 meters offers the most optimal results. *Figure 3.13* shows that two stair objects are within the location, one with a stroller ramp and one without. The epsilon 25 meters covers and groups the different recorded points of the stairs sufficiently. Increasing the threshold size may affect nearby stair objects at other locations.

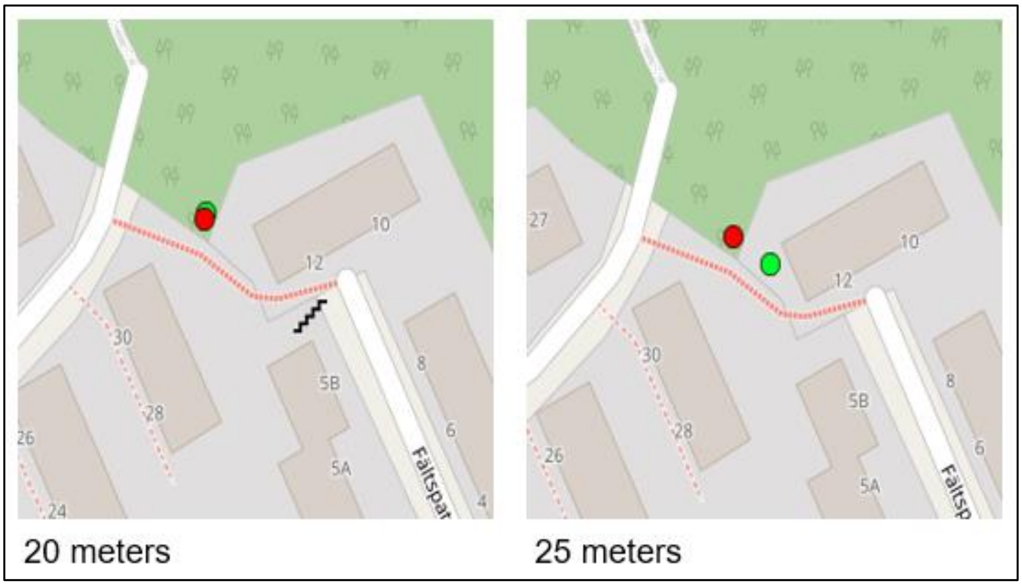


Figure 3.13. Epsilon testing for the stair objects.

Lastly, due to the variety length of the inclination barriers, the position for each identified inclination object differs widely in the locations of the upper and lower images in *Figure 3.14*. An increase of 5 meters has no impact on the data points until it reaches the threshold of 30 meters. The top images show 3 records of an inclination that are merged but the lower images with the second location needs a bigger threshold.

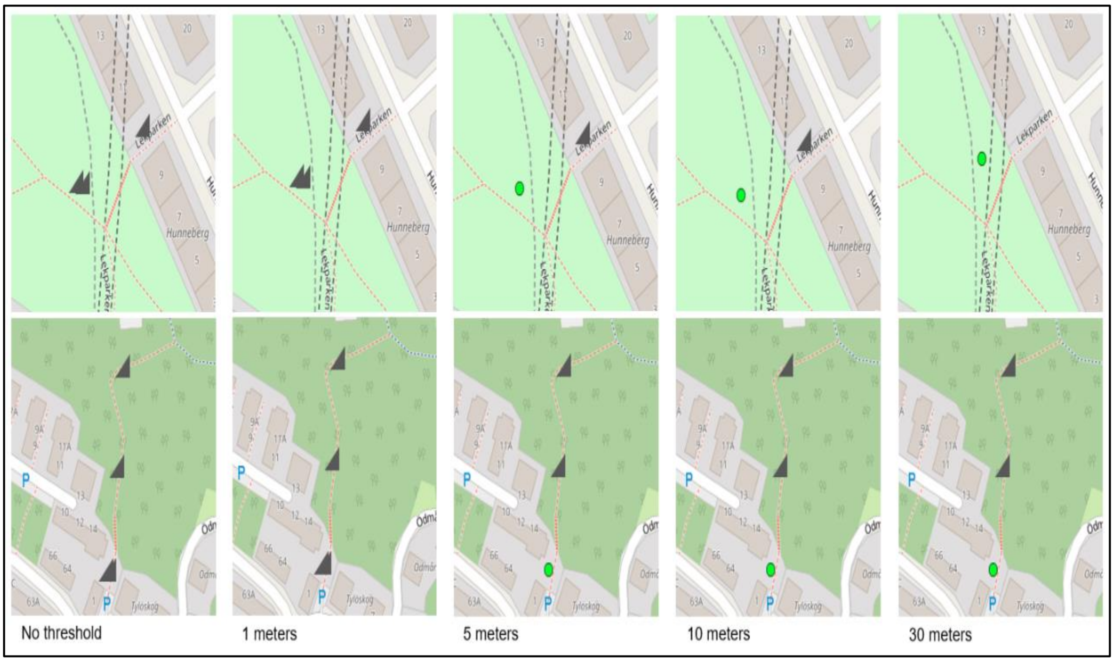


Figure 3.14. Epsilon testing for the inclination objects.

In *Figure 3*.15, the threshold of 55 meters is demonstrated to be the most suitable for the current dataset.

Figure 3.15. Epsilon testing for the stair objects.

3.6.3. Setting the Parameters

Barriers that are not eligible to be sorted into a cluster, the outliers, will be handled as standalone features, and are displayed without further computation. The barrier type other will be excluded from the computation since its attributes vary depending on the users' input. *Table 3.3* summarizes the input parameters for respective barrier type where a cluster is identified if at least one point is within the radius of the core point. To sort out the similar data points which share the same attributes within the cluster, the library Geolib is used to find the centroid of the geographical coordinates to group them (Bieh, 2023).

Table 3.3. DBSCAN parameters.

Barrier	**ε (kilometeres)**	**$MinPts$**
Curb	0.005	1
Stair	0.025	1
Inclination	0.055	1

The centroid of points $(Lat_1, Lon_1), \ldots, (Lat_n, Lon_n)$ in a cluster, is retrieved and represents the cluster as a single point. If a barrier does not share common attributes with its neighboring points within the cluster, it is displayed as a standalone feature.

3.7. Visualization

To visualize the computed physical barriers, a web map is developed and hosted on a server with processed data. This is achieved with JS frameworks and libraries.

3.7.1. Basemap

The background map is sourced from OSM, which operates under the *Open Data Commons Open Database License* (OpenStreetMap, n.d.). The basemap, named *OpenStreetMap Carto*, comprises tiles licensed under the *Open Database License,* while its visual style is covered by the *Creative Commons Zero license*, indicating no reserved copyright (OpenStreetMap, 2024). Consequently, the basemap is freely available for use and distribution, with attribution to OSM required. The OSM trademark is visible on the map, and the source code attributes the basemap to OSM as contributors. Utilizing a Pseudo-Mercator projection, the OSM basemap overlays barrier points across the Traneberg study area, with a pixel scale of 100:200, which translates to 200 meters per 100 pixels.

3.7.2. Symbols of the Barrier Data

Depending on the zoom level of the web map, the barriers' symbols will differ. Since the readability of the symbols are affected depending on the zoom-level, the symbols will change dynamically. The standard zoom level is set to 15 to capture the study area. The curbs are displayed with a symbol with an orange color on the map (*Figure 3.16*), the height is defined by the pixel gap for each category of the curb.

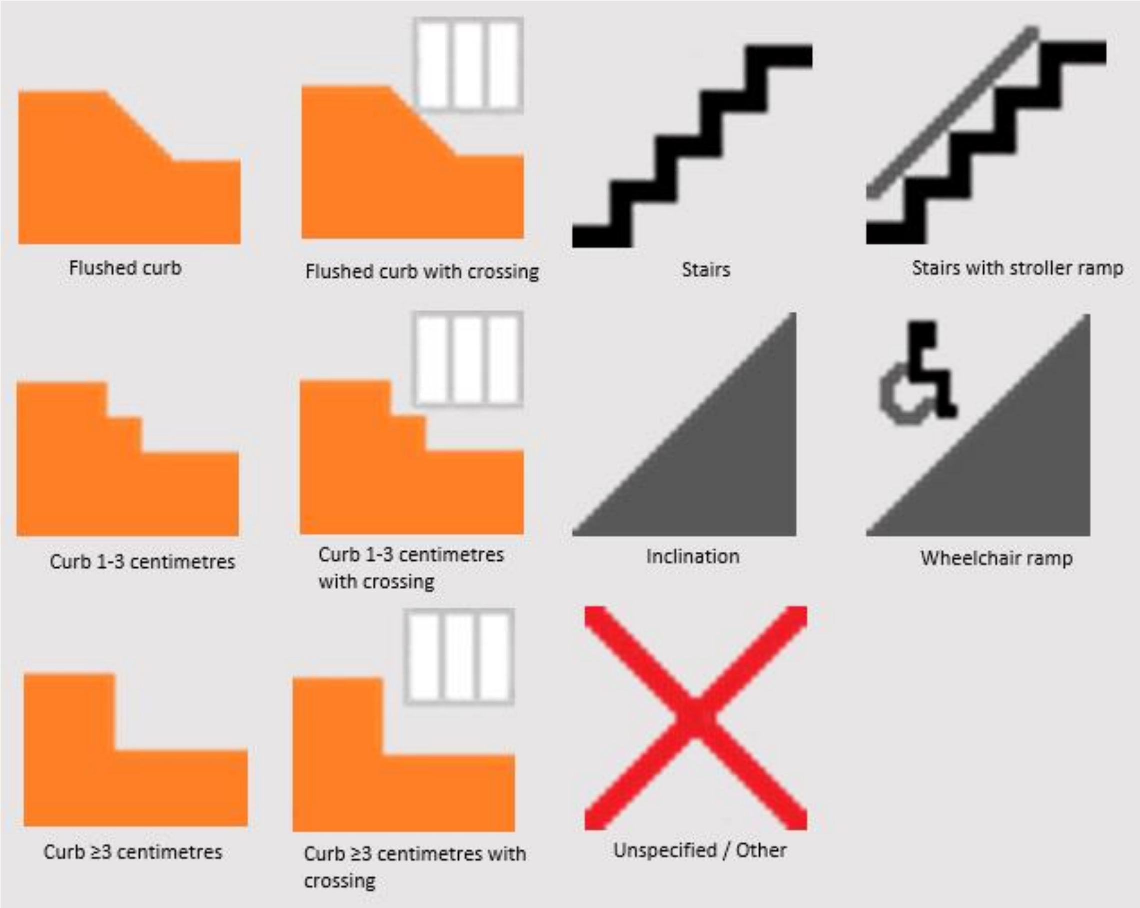


Figure 3.16. The symbols of the physical barriers (Wigen, 2024).

Depending on the curb's access to a crosswalk, if true the icon is accompanied by a crosswalk symbol in its right corner; otherwise, there is no crosswalk in the right corner. Secondly, the feature *Stair* is represented with a stair symbol. If the data point has a stroller ramp, it is represented by a stair symbol with a line drawn over it; otherwise, it has no stroller ramp, which results in a symbol of a simple staircase. Thirdly, the *Inclination* is represented by a symbol resembling a linear slope. If the data point is a wheelchair ramp, it is indicated by the linear slope accompanied by a wheelchair symbol; otherwise, it is a natural inclination. Lastly, the feature *Other barrier* is represented as a red cross. *Figure 3.17* presents the default view of the map set to the study area and the type symbols. The symbols are difficult to distinguish at the current zoom level 15.

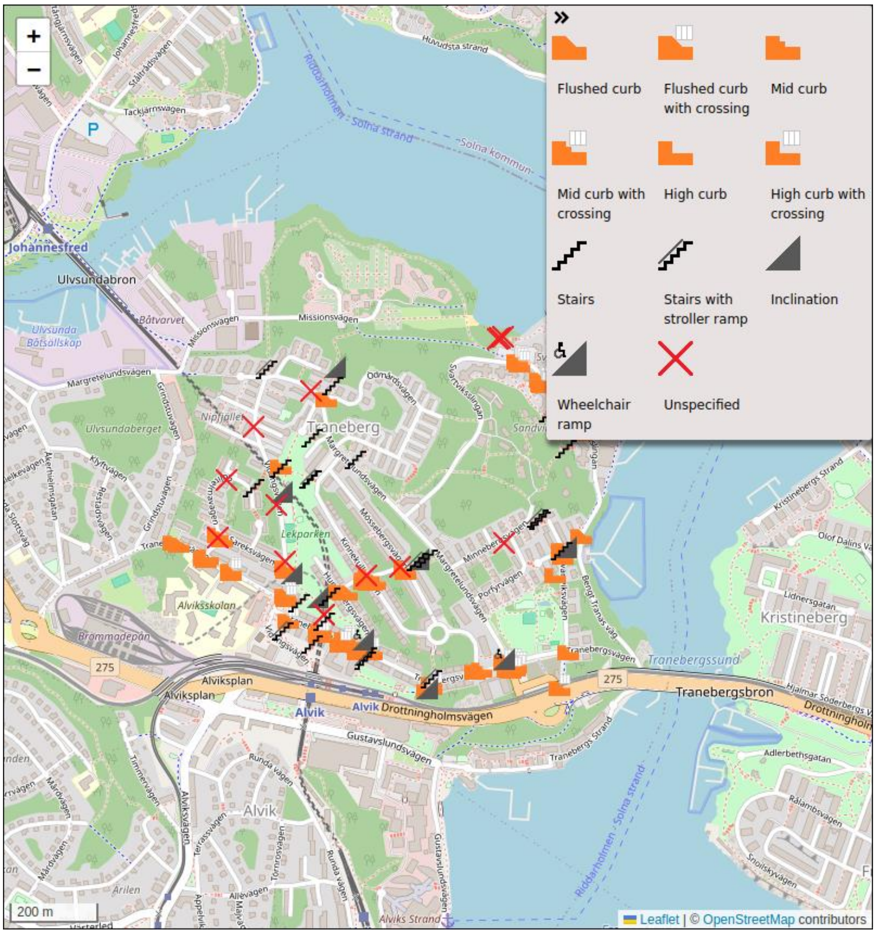


Figure 3.17. Default view with barrier type specific symbols on the web map.

Figure 3.18 presents the default view of the map set to the study area at zoom level 15, along with the default marker icon from Leaflet to represent the barrier data.

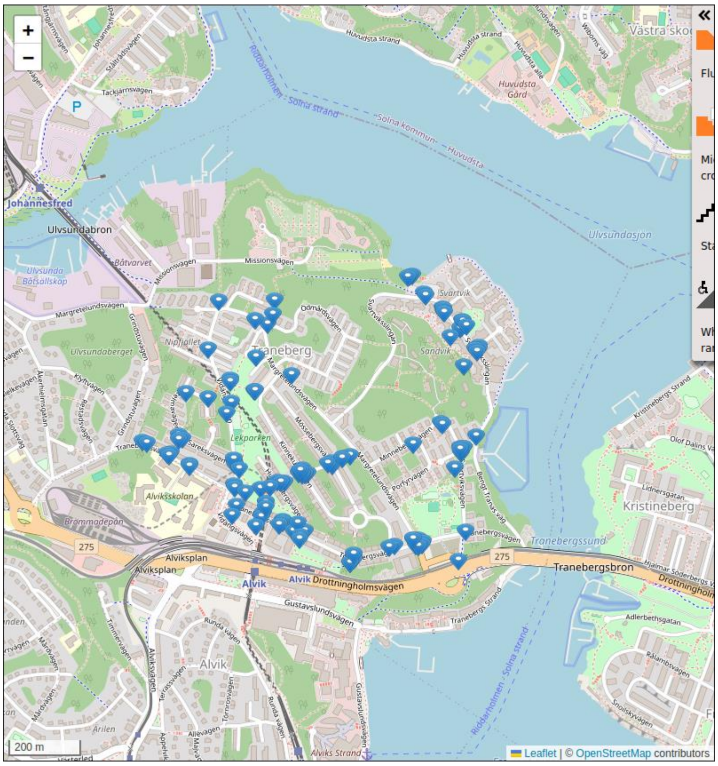


Figure 3.18. Default view with default Leaflet icon on the web map.

As seen in *Figure 3.19*, when the web map is zoomed in to level 17 or higher, the readability of the barriers improves, and the symbols of the various barrier types appear.

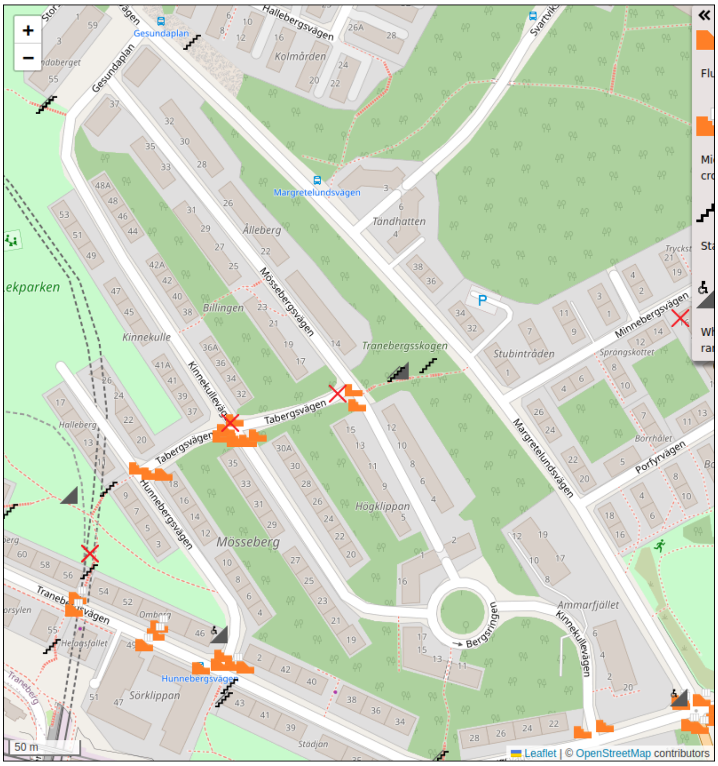


Figure 3.19. Zoomed in view with type specific symbols on the web map.

3.8. Program Libraries and Licenses

In total, 13 libraries are utilized for the data acquisition application, and the web map. Therefore, various licenses are attached to monitor the extent of publication in software where they are applied. *Table 3.4* presents the various libraries, their role in the research project, and the accompanying licenses. The most frequently one, MIT License, is used by 9 libraries which includes Cors (Goode, 2018), Box icons (Atiaswd, n.d.), Expo (Expo, 2024), Express.js (Expressjs, 2022), Geolib (Bieh, 2023), Node.js (Node.js, 2024), React.js (Meta, 2022), React Native (Facebook, 2024), React-native-dropdown-picker (Zare, 2023), React-native-maps (React-native-maps, 2024), and React-native-vector icons (Arvidsson, 2023). The MIT License allows free use, modification, and distribution of the software, subject to the inclusion of the copyright and permission notices in all copies or substantial portions. It comes without a warranty, and the authors are not liable for any claims or damages. The condition is that the copyright notices and the permissions notices of all these libraries are included in the software of this research project.

Table 3.4. Summarization of external libraries and licenses.

Library	Application	License
Cors	Web	MIT License
Box icons	Web	MIT License
Dobbyscan	Web	ISC License
Expo	Mobile	MIT License
Express.js	Web	MIT License
Firebase	Mobile and web	Apache 2.0 License
Geolib	Mobile and web	MIT License
Leaflet	Web	BSD 2-Clause “Simplified” License
Node.js	Web	MIT License
React.js	Web	MIT License
React Native	Mobile	MIT License
React-native-dropdown-picker	Mobile	MIT License
React-native-maps	Mobile	MIT License
React-native-vector-icons	Mobile	MIT License

The library Dobbyscan is licensed under the ISC License (Mapbox, 2018). The ISC License is a permissive open-source software license that allows users to freely use, modify, and distribute licensed software.

Firebase's Apache 2.0 license allows you to freely use, modify, and distribute the software globally (Firebase, 2023). You have copyright and patent permissions, can create derivative works, and must include the source library’s license when distributing. Contributors grant these rights, but trademarks need separate permission. There are no warranties, and contributors are not liable for damages, except as required by law. When redistributing, you can offer additional support or warranty for a fee and apply for any license that suits your program.

Lastly, Leaflet’s license is the BSD 2-Clause “Simplified” License which is permissive (Leaflet, 2023). You are free to use, modify, and distribute the software, but you must retain the original copyright notice and disclaimer when redistributing it. Additionally, the software is provided without any warranty, and the copyright holders or contributors cannot be held liable for any damages.

3.8.1. Selection of License and Implementation of the Final Product

Based on the licenses of the libraries and their compatibility, the distribution of code and license of the website does not have many shortcomings. The project has excluded libraries that limit the choice of license for this project, such as GNU General Public Licenses (GPL) which requires inheritance the same version of GPL or later version. React-leaflet was also excluded, since it utilizes a Hippocratic License, an ethical license, which may pose compatibility challenges with other licenses (Le Cam, 2023). Thus, citing the Apache License 2.0 for the web map of the project, fosters open collaboration and innovation. It provides clear legal guidelines, encourages community participation, and allows for commercial use. With patent grants included, it promotes transparency and supports the project’s commitment to openness and progress in this project.

4. Results

4.1. Barriers Collected

In total, two participants were gathered to collect the barrier features that are displayed. The participants recorded 167 barriers, where the barrier type *curb* scored *83* records, followed by *stair* with 53 records, then *inclination* with 17 records, and lastly the unspecified barrier type *other* with 14 records. As *Table 4.1* displays, 93 data points were placed within clusters by DBSCAN, whereas 76 data points in the clusters were mergeable due to identical attributes and reduced to 28 data points. Moreover, a total of 17 data points were unique in their clusters and therefore not merged. A total of 74 data points were not recognized as belonging to any cluster, comprising 48 curb features, 5 stair features, 7 inclination features, and 14 other features. The records in each cluster were merged if the nearby data point had similar attributes, otherwise displayed as standalone features.

When it comes to the curb features, 24 records belonged to mergeable clusters which were reduced to 11 records. Meanwhile, 11 records were unique within their cluster and therefore displayed without further computation. Secondly, the stair features had 42 mergeable data points and were reduced to 14 data points. Additionally, 6 records were unique within their cluster and displayed without further computation. Lastly, the 10 inclination features that were located within a cluster were grouped into 3 points whereby 0 data points were unique. This resulted in a total of 119 barrier points, comprising 70 curb features, 25 stair features, 10 inclination features and 14 other features.

The unspecified barrier types named other, had 14 records in total where the categories were mostly weather related. In total, 11 records report on large snow piles blocking the streets, icy streets and sidewalks, snow or ice that made the streets uneven and slushy snow. Out of the remaining 3 records, 2 records describe reconstruction work and 1 record describes a tree that is blocking the sidewalk.

Table 4.1. Summarization of records.

Barrier	Records	Records in clusters	Mergeable records, before merge	Mergeable records, after merge	Unmergeable records	Records outside clusters	Records after merge
Curb	83	35	24	11	11	48	70
Stair	53	48	42	14	6	5	25
Inclination	17	10	10	3	0	7	10
Other	14	0	0	0	0	14	14
	167	*93*	*76*	*28*	*17*	*74*	*119*

Table 4.2 presents descriptive statistics of the physical barriers within clusters. The barrier "curb" comprises 35 records sorted into 15 clusters. The mean value is 2.33 records per cluster, with a variance of 0.36 records per cluster. The maximum number of data points within a curb cluster is 4 points, and the minimum is 2 points.

The "stair" features consist of 48 records sorted into 15 clusters. The mean is 3.20 records per cluster, with a variance of 2.43 points per cluster. The maximum number of data points within a stair cluster is 7 points, and the minimum is 2 points.

Finally, the "inclination" feature comprises 10 data points sorted into 3 clusters. The mean is 3.33 points per cluster, with a variance of 0.89 points per cluster. The maximum number of data points within an inclination cluster is 4 points, and the minimum is 2 points.

Table 4.2. Descriptive statistics of barriers inside clusters.

Barrier	Clusters	Records in clusters	Mean	σ	Max	Min
Curb	15	35	2.33	0.36	4	2
Stair	15	48	3.20	2.43	7	2
Inclination	3	10	3.33	0.89	4	2

In *Table 4.3*, a total of 70 curbs were extracted from the DBSCAN computation. These curbs are categorized based on their height and accessibility to crosswalks. The term “point concentration” provides a measure of the data points that were merged due to identical attributes within the clusters, indicating the agreement of attributes among the data points within the unique cluster locations. Firstly, the category of flushed curbs, which have no significant height, comprises 33 records. Among these, 22 records indicate access to a crosswalk with a relative low point concentration rate of 27.27%, while the remaining 11 records indicate no access to a crosswalk and a low point concentration of 0%. For curbs with a height between 1 to 3 centimeters, classified as lowered curbs, there are 27 records. Out of these, 12 records indicate access to a crosswalk with a slightly higher point concentration rate of 41.66%, while 15 records indicate no access to a crosswalk and point concentration of 0%. In contrast, curbs with a height above 3 centimeters, categorized as raised curbs, consist of 10 records. All 10 records in this category indicate no access to a crosswalk and have a point concentration rate of 0%. The overall point concentration scored 15.71% which is relatively low.

Table 4.3. Statistics of computed curbed street barriers.

Curb type	Records	Records merged	Point concentration (%)
Flushed curb with crosswalk	22	6	27.27
Flushed curb without crosswalk	11	0	00.00
Lowered curb with crosswalk	12	5	41.66
Lowered curb without crosswalk	15	0	00.00
Raised curb with crosswalk	0	0	00.00
Raised curb without crosswalk	10	0	00.00
	70	*11*	*15.71*

The results of the computed stair features are presented in *Table 4.4*. In total, 25 stair data points were computed from DBSCAN, where 8 of the records have access to stroller ramps with a relative high point concentration of 37.50%, and 17 records do not have a stroller ramp with a high point concentration rate of 64.70%. The overall point concentration scored 56%, which is relatively high.

Table 4.4. Statistics of computed stair features.

Stair type	Records	Records merged	Point concentration (%)
Stair with stroller ramp	8	3	37.50
Stair without stroller ramp	17	11	64.70
	25	*14*	*56.00*

In *Table 4.5*, DBSCAN generated 10 inclination features in total, where 8 of the inclination points are specified as natural inclinations with a relative high point concentration of 37.50%, whereas a minority of 2 records are labeled as wheelchair ramps with a low point concentration of 0%. Overall, the point concentration scored 30%, which is relatively low.

Table 4.5. Statistics of computed inclination features.

Inclination type	Records	Records merged	Point concentration (%)
Inclination with wheelchair ramp	8	3	37.50
Inclination without wheelchair ramp	2	0	00.00
	10	*3*	*30.00*

4.2.1. Web Map

This section presents screenshots of the client, the web map, functionalities, content, and potential errors in the data. In *Figure 4.1*, an overview of the client is presented with the web map containing the standard OSM basemap in the background overlaid with the physical barriers.

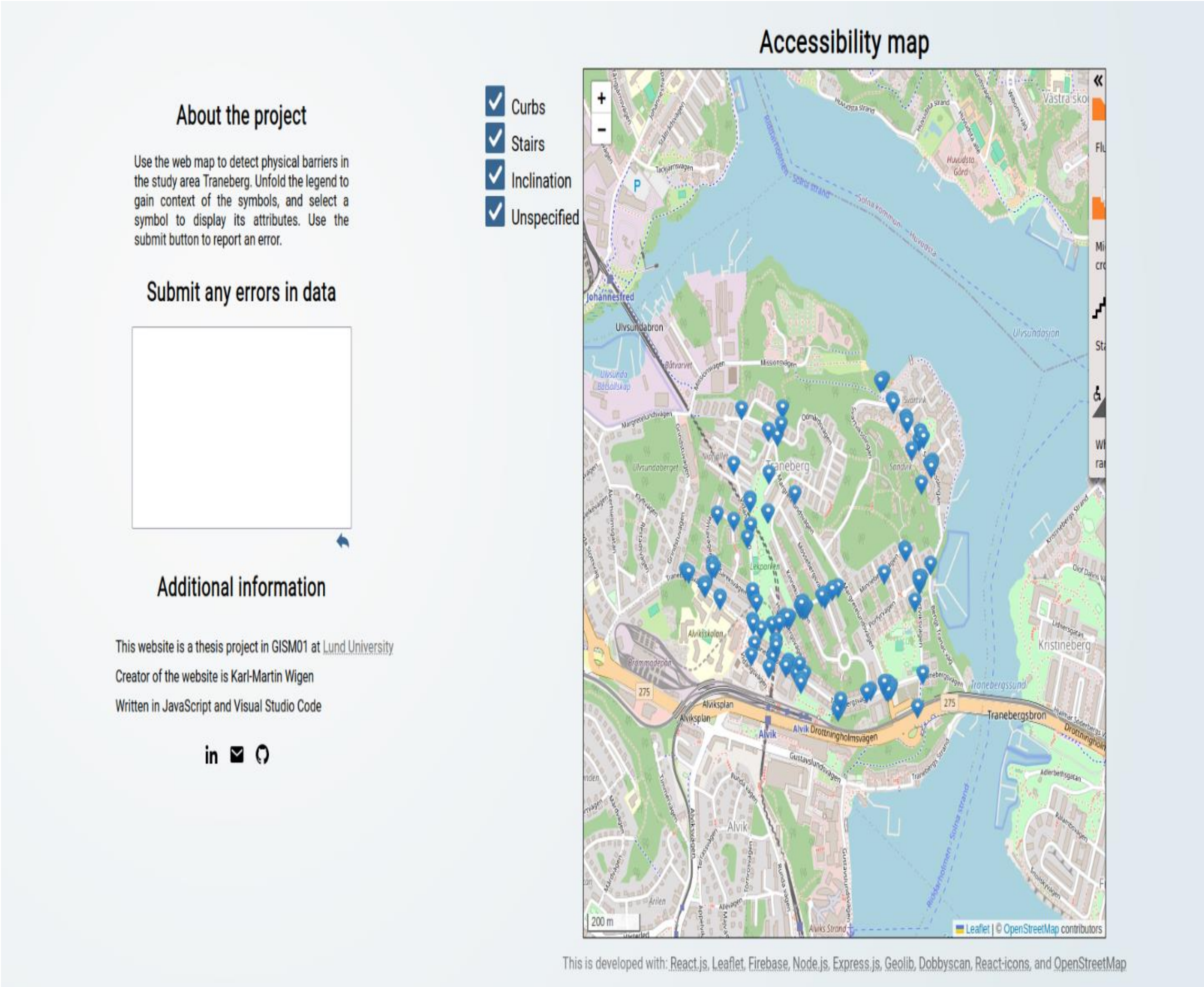


Figure 4.1. Overview of the web client.

The extent of the view is set to the study area of Traneberg when the page is loaded. The zoom buttons are in the top left corner, and the scale is positioned at the bottom left corner. On the top right corner of the map is a foldable legend. The web map can be panned, and by utilizing the zoom buttons the user can see exactly where the physical barriers are located. Moreover, the left section contains the box “Submit any errors in data”, if the user finds any data with errors. Lastly, in the left section of the client, there is some additional information about the project.

Figure 4.2 and *Figure 4.3* show the content of the map on a smaller scale.

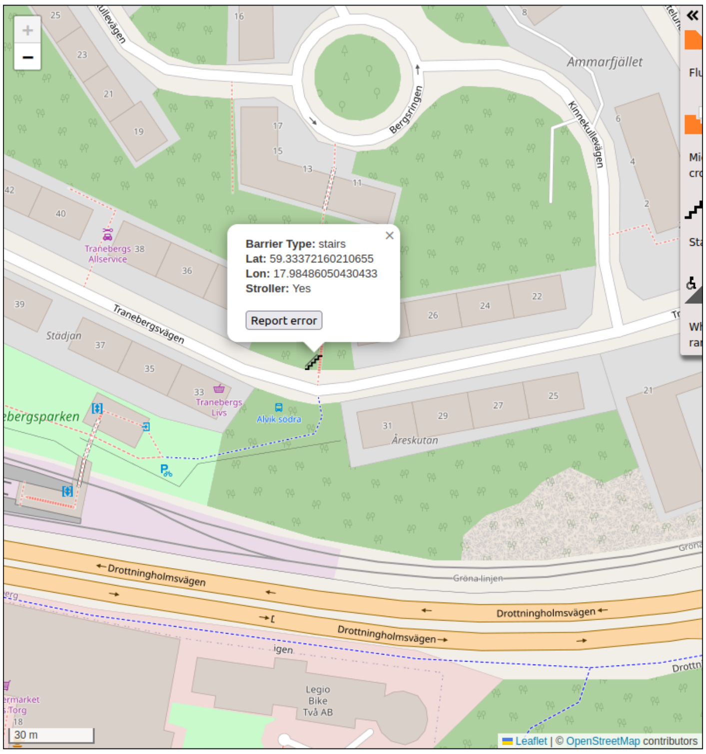


Figure 4.2. Highlighting a stair feature with stroller ramp.

Figure 4.3. Highlighting an unspecified feature.

When selecting a data point, the user can read its position, attributes, and issue a report if there is any error with the data. The information regarding the position and unique identifier of the barrier will be extracted to the submit-error box on the left side of the client, where the user can write text to describe the error and submit.

4.2.2. Errors in Data Acquired with VGI

When it comes to the placement of barriers, some potential errors were detected. Commonly, some barriers are stacked on each other or misplaced. This decreases the readability of the web map and its content. *Figure 4.4* displays a curb feature that is located on top of an inclination feature. In *Figure 4.5*, a curb object is located where a stair object is located, and its location is covered by greenery. Moreover, based on the OSM basemap, there is indeed a line representing a staircase in that location.

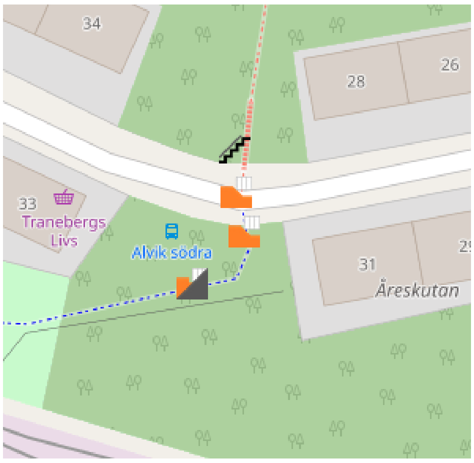


Figure 4.4. Inclination and curb stacked.

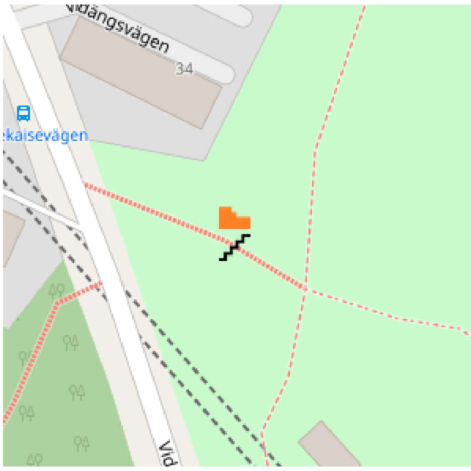


Figure 4.5. Stair and curb nearby each other.

Figure 4.6 displays three objects that are stacked on the same side of the sidewalk, where two of the objects are curbs of different height categories, and the third object is a wheelchair ramp.

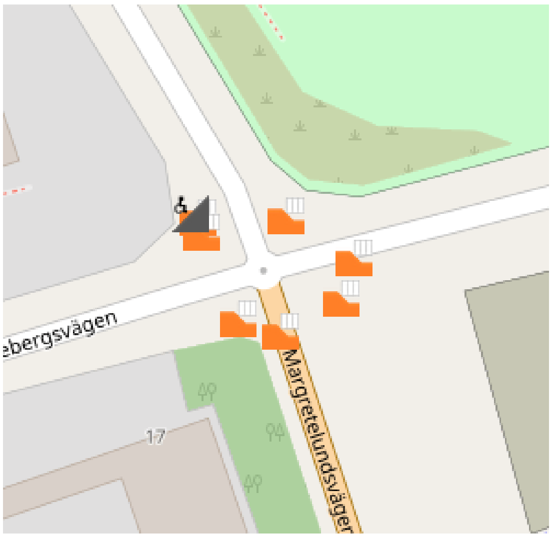


Figure 4.6. Wheelchair ramp, flushed curb, and medium curb stacked.

4.3. User Feedback

For user feedback of the data acquisition, five questions were phrased and sent out to the two participants regarding this research subject and the data acquisition application. *Participant 1* and *Participant 2* had the following answers to the questions that follow in this section.

What difficulties, if any, did you encounter in the data acquisition of this project?

Participant 1

- It was difficult to estimate where to stand, in relation to the physical barriers. Especially when gathering curbs since cars expected me to cross the road. The winter made it difficult to detect curbs and their height.

Participant 2

- I did not experience any difficulty with gathering and pinpointing data during this project. The application was not complicated to use, and I got the idea of how to use it quickly.

What technical difficulties, if any, did you encounter in the application?

Participant 1

- Sometimes it felt like the positions I was recording were placed somewhere else than I was standing. Also, the survey popup window was sometimes slow, and it could take a half minute or so before it popped up on the screen.

Participant 2

- I did not encounter any technical difficulties when I used the application. The update of data went smooth, and the pinpointing of the data seemed accurate. Also, I could smoothly remove a physical barrier that I regretted.

What are the shortcomings with a volunteer approach, in a project such as this one?

Participant 1

- I imagine it is difficult to motivate people to participate in a project like this voluntarily. I think some individuals expect a reward for hard work.

Participant 2

- I do not think of any shortcomings in a project like this one. Data gathering can be done on one's owns terms, for example on the way to the metro. The only shortcoming that I can mention is that bad weather or long winters can make it unattractive to people.

What barrier types would you implement in this project, that were not specified beforehand?

Participant 1

- Maybe cracks or uneven surfaces on the sidewalks. Also, an option of placing objects that may be temporarily, such as snow piles.

Participant 2

- During the winter: Unplowed pathways/sidewalks and icy or slippery pathways/sidewalks. Sidewalks and pathways could have physical barriers such as construction work since they block off the path. Also, scaffolds, garbage containers with additional waste that decrease the space of the sidewalks. Building materials in big plastic bags that block the sidewalks before they are picked up. Elevators that give entry to the metro, sometimes they do not work or disabled. A barrier that indicates another path or an elevator.

How could the application and this project be improved in the future?

Participant 1

- A more detailed guide on how one should position themselves in relation to the barriers. Also, a feature to edit a placed barrier in case of input error or a recorded position that is false. Markers that show barriers that have been placed out by others.

Participant 2

- Do not mix Swedish and English in the application. There are barriers that are permanent, e.g. stairs without stroller ramps, these are rarely changed. Moreover, there are barriers that are mentioned in question 4, which are not permanent but could still cause struggles for people with movement impairments. They could be marked with a warning sign. Also, these could include a feature with the date the barrier was recorded, to acknowledge how long it has been there. If possible, a list with the barriers one has added and a feature to edit the barriers one has placed.

5. Discussion

5.1. VGI Barrier Data Collection

The findings of this study shed light on the utilization of VGI as a data gathering method for physical barriers that may impact wheelchair users and potentially other movement-impaired groups. A total of 167 barrier data points were gathered. By grouping nearby data points with identical attributes using the DBSCAN algorithm and the centroid of the clusters, the records were reduced to 119 points, whereby 70 curb features, 25 stair features, 10 inclination features, and 14 other features which were identified from the computation.

Most of the records consist of curb features, although, as one participant noted, weather conditions made the acquisition of the curbs problematic, which implies that the gathering of curb features may have been affected. Furthermore, grouping the curb was difficult due to their proximity and the possibility that some curbs were recorded inaccurately. This could be explained by either technical difficulties, GPS errors or input errors. This aligns with the findings of Antoniou and Skopeliti (2015) regarding the uncertainty associated with data collected through VGI. One of the participants expressed difficulty in recording the curbs due to their positioning in relation to the curbs, as cars expected them to cross the street. Additionally, the same participant experienced that some of their records were placed further away than their actual standing position. Lastly, when examining the statistics of the curbs, out of the total, a majority comprised 33 flushed curbs. Among these, 22 curbs had crosswalk connections, and 11 lacked a crosswalk connection. There was a higher point concentration of the flushed curb with crosswalks at the unique cluster locations. The lowered curbs scored the second highest with 27 data points, where 12 had a crosswalk connection and a relatively low point concentration rate, while 15 data points had no crosswalk at all. Meanwhile, there were 10 raised curbs recorded, and all of them lacked a crosswalk connection.

When it comes to the stair data points, there were 8 stair features with an assigned stroller ramp and 17 stairs without one. Compared with the other barrier types, the stair type scored the highest point concentration rate for its data points within its clusters. With this knowledge, it could have been interesting to ask parents in Traneberg who are dependent on transporting their infants in a stroller. Due to the uneven distribution of stairs with stroller ramps and those without, what implications does this have on their routing? One of the participants mentioned that the state of the stairs rarely changes; therefore, such information could be useful for planning purposes. Furthermore, grouping the stairs with DBSCAN was easier because they are typically spaced further apart from each other, providing greater certainty when setting the threshold of epsilon compared to the curbs. In hindsight, despite the lack of essential attributes in Trafikverket's (2023a) dataset, their data could have been used as a reference, according to Mobasheri et al's (2017b) recommendation, to test the VGI data against an authoritative dataset.

For the inclination data points, there were a total of 10 records after the computation. Among these, 8 were regular inclinations with a relatively high point concentration at unique locations, whereas 2 were labeled as wheelchair ramps and were uncommon. The inclinations were challenging to group due to their length, suggesting that a line drawn between their start and end points could have been more appropriate. Additionally, the slope of the inclinations is not displayed, which limits the ability to integrate digital elevation models to show the degree of slope. Steep inclinations may pose difficulties for non-electric wheelchairs but could potentially serve as accessible paths for electric wheelchairs.

The barrier type “other” yielded 14 computed records with various objects specified by the users, mostly related to weather conditions such as ice or snow piles. Both participants mentioned that some barriers are only temporary, with winter-related conditions being cited as examples that disappear over time. There is room for improvement; for example, implementing a date stamp or considering whether weather-related barriers should be included at all. The same applies to construction sites and other objects that temporarily block the path. On the other hand, Gharebaghi et al (2018) expressed in their article that weather phenomena such as snow indeed obstruct accessibility on sidewalks for wheelchair users.

This project aims to utilize data that diverges from existing services. The data in this project is collected through volunteer work, contrasting with authoritative databases that contain accessibility data gathered by professionals. Furthermore, the data in this project differs from services utilizing volunteer-based data, such as OSM. The primary distinction from OSM lies in the project's focus on displaying barrier data with corresponding symbols, whereas OSM primarily focuses on various spatial data from streets. For instance, Openrouteservice, which offers search options for places and navigation services, relies on data gathered from the OSM community and may thus lack information regarding curb levels (Biagi et al., 2023). Consequently, Openrouteservice may fail to provide context about the curbs along the recommended paths, despite such context being deemed necessary by the World Health Organization (2011) and being highly recommended by Biagi et al (2020). This project aims to address this limitation by meticulously recording data on curb levels.

5.2. Number of Participants

In total, two participants signed up for the project through advertisement notes posted on billboards in Traneberg. This limited number of participants may have potentially influenced the number of data points collected and the comments on the usage of the service. There were difficulties in gathering participants, which could be explained by the lack of a robust reward structure in the project, as suggested by approaches such as gamification (Saha et al., 2019; Miyata et al., 2021). Moreover, the participants were anonymous and their engagement in participation may have varied. This aligns with findings from Cruz and Campelo (2019) and research by Mobasheri et al (2017b) regarding issues with authenticity in the final product, as evidenced by some barriers that were falsely recorded. Nonetheless, the participants were engaged and provided suggestions for improvements in the application. The number of errors may have been reduced through enhancements in the technical aspects of the application and by providing clearer instructions from the author.

5.3. Visualization

When visualizing the barriers on the web map, the default icons from Leaflet are set to appear on zoom level 16 and below. As users zoom in to level 17 and above, icons representing various barriers become visible. The symbols are designed to reflect the type of barriers and their attributes, providing users with context about their nature. For curbs, an orange color is used to make them stand out on the basemap. The symbols are designed with pixels to indicate their height. However, determining the height of the curb symbols with just a glance can be challenging for users. Various color ramps were tested to clearly indicate height, but the information was still difficult to distinguish. Additionally, if the curb is connected to a crosswalk, white stripes are visible on the top right corner of the symbol. The stair symbol is simple, featuring a black color that mimics a staircase and indicates the increment of steps. If a stroller ramp is present, a straight line is added along the elevated steps. The two types of stairs are easily distinguishable from each other. However, one downside is their size, which means they can be easily obscured by symbols with more pixels. The inclination symbol has a right triangle shape, indicating an incline, and features a man in a wheelchair on the left side if the inclination is a wheelchair ramp. Like the stair symbol, the two states of the inclination symbol are distinguishable and work well for display purposes.

When comparing the visualization with Wheelmap, a platform built on the OSM dataset that implements an accessibility degree for wheelchair users at various locations, contributed by volunteers (Mobasheri et al., 2017a), notable differences are observed. Wheelmap allocates points on the map for places such as subway stations, hotels, and stores, displaying their accessibility status for wheelchair users. This accessibility is highlighted with a color scheme that corresponds to the symbols of places, blending well with the basemap. In contrast, this project attempted to use a similar color scheme on the curb symbols to distinguish height, but it resulted in a cluttered appearance on the screen. Wheelmap also uses a different background map from OSM with less cartographic background information, which may make their design of interest points more desirable. On the other hand, Openrouteservice from OpenStreetMap (2023) utilizes the same basemap but with additional cartographic information added to the background. This approach works well, as the starting point is highlighted in red, with a red line drawn to the green-colored destination point. The simplicity of this color scheme ensures that the colors blend with the background map or with each other, resulting in a clear and easily interpretable visualization.

Overall, this research project enhances accessibility by visually representing barriers on the map with symbols, pinpointing locations of features that may impact accessibility on sidewalks and pathways. Users can select the types of barriers they want to display, thereby enhancing the map's readability. However, there are areas of improvement, such as redesigning curb symbols, refining the symbol point hierarchy, and introducing a search feature for specific barriers based on areas or addresses to streamline the displayed information.

5.4. Direction of the Project

For the continuation of this project, several improvements are needed. Firstly, motivating individuals interested in contributing to an application that displays physical barriers affecting mobility is crucial. Addressing people affected by sidewalk and pathway structures could effectively encourage participation. Collaborating with municipalities or physical disability associations could facilitate this effort. Launching a small-scale initiative in Stockholm, where substantial data is needed, would enable enhancements to the clustering algorithm and the identification of inaccurately recorded data. Furthermore, integrating accurate sidewalk datasets from public sources like NVDB would significantly enhance the navigation service within the application.

The development of both a mobile app and a web page has been insufficient. Consolidating these platforms into one unified platform is essential for improving user experience and efficiency. However, financial resources are necessary to release an application on platforms like the App Store or Google Play, as they incur costs. Therefore, securing funding or exploring alternative revenue streams is crucial for the project's sustainability and success.

It is preferable to implement everything in a single mobile application. As Lakshmi Steinberg and Steinberg (2015) describe how humans act as mobile sensors, relying on their smartphones with GPS, which demonstrates humans' trust in navigation applications while navigating the streets. Therefore, the goal is to develop a routing feature in the application while also incorporating the acquisition of physical barriers. This unified approach would streamline the user experience and make the application more accessible and practical.

5.5. Technical and Functional Improvement

With some final remarks on functionality and technical aspects that could be improved, the participants provided useful recommendations. Both participants recommended addressing temporary barriers, such as snow obstacles, by marking them with a date and displaying them with a warning symbol. One suggested solution to winter-related effects is to use a symbol to indicate that the barrier has been resolved, possibly based on seasonal periods. Both participants also advocated for a feature to edit or remove barriers that have been placed. One participant suggested allowing users to view barriers recorded by others and providing a more detailed guide for data capture. With this information in mind, the other barrier type could be categorized as follows: *1)* winter or weather-related barrier, where the symbol changes depending on the season; *2)* obstacles blocking the path, with a selection list containing trees, scaffolds, garbage bins, or user's input; *3)* a barrier that specifies construction sites. Additionally, to address the uncertainty in some of the recorded curb barriers, the feature should be updated to require the user to insert two points that define the crossing of the sidewalks. Implementing this feature from the beginning could have reduced the number of questionable curb locations, thereby enhancing the user-friendly experience in the application, as recommended by Brovelli et al. (2016) in their article.

Given the potential benefits of a larger dataset, adjusting clustering parameters like $MinPts$ and ε for scalability is crucial. To handle validation and refinement with a larger dataset, automated approaches can be explored. This may include scripting for result validation against ground truth data, employing machine learning for error detection, or using cross-validation techniques. Additionally, iterative refinement processes and integration of user feedback mechanisms could enhance the overall data quality assurance.

6. Conclusion

This thesis aims to develop a framework open for anyone to contribute information about physical barriers that limit mobility for wheelchair users or potentially other movement impaired individuals. By acquiring information about the physical barriers on the sidewalks and pathways, their location and appended characteristics are displayed based on the participant's input. Due to the uncertainty with VGI-sourced data, the end goal is an application that updates information about physical barriers based on users' input until they are resolved or removed. These physical barriers are curbs on sidewalks, stairs, inclination, or other unspecified obstacles. The physical barriers visualize accessibility, primarily with wheelchair users as target group, on sidewalks and pathways.

The first research task was: *Design, implement and evaluate a technical framework for VGI barrier data collection.*

A data acquisition application was developed with the React Native framework which utilized Expo-go to distribute the application to participants. Since these frameworks target both Android and iOS, they were implemented to fulfill a cross-platform approach. Expo-go was a beneficial solution to distribute and test the application. The gathered data points were based on the participants' current position which were recorded through the participants' GPS on their smartphone and were stored in Firestore with real-time data storage. Furthermore, a web map was developed with React, Node and Leaflet to display the captured data. Based on the review of the participants on the data acquisition, they highlighted that there were lacking guidelines, the application could appear slow and that there could be discrepancies between recorded barrier location and the participants' actual position. Moreover, they provided feedback on implementing an editable feature of the barriers, view data points that others have placed, language consistency and an option for temporary barriers.

The second research task was: *Design, implement and evaluate a clustering algorithm for streamlining the physical barriers by grouping nearby data points into clusters and then enhance the visualization.*

In total, the two participants captured 167 data points in the study area of Traneberg. In the original dataset, there were 83 curb features, 53 stair features, 17 inclination features and 14 other features. With the DBSCAN algorithm, the barrier data points were reduced to 70 curb features, 25 stair features and 10 inclination features. There were several limitations of the VGI-based data collection approach that varied between the different barrier types. While 11 unique locations of the curb data points resulted from a merger, several data points were outside the clusters, with some possibly excluded due to false recordings or a lack of data points acquired. The gathering of stair features was more successful in covering a range of data points within the same locations, with 14 out of 25 data points resulting from a merger. Furthermore, a few inclination data points were gathered compared with curbs and stairs, especially wheelchair ramps. Due to the varying levels of agreement among the identified features at several locations, more data points would have been required to enhance accuracy. Also, this resulted in mismatches in barrier locations, where some standalone barriers were stacked on top of each other. This could be explained by errors made by the participants during data input or technical issues with the data acquisition application. Overall, the clustering algorithm implemented in the data collection process contributed to improving the quality of information regarding physical barriers, although its effectiveness varied across different barrier types. The overall outcome of using DBSCAN to enhance visualization had limitations due to the methodology's constraints. Consequently, it appears that the VGI-based data collection for this project was more successful for stair features.

Despite challenges such as weather conditions affecting curb data collection and technical difficulties in accurately recording physical barriers, the project highlighted the potential of VGI approaches in mapping accessibility barriers. Recommendations for improvement include enhancing the clustering algorithm with more data points, integrating accurate sidewalk datasets, defining more types of barriers with various geometries, implement the aspect of temporary barriers, add editable tool for placed barriers and utilizing a reward system that motivates participants. For the framework of this thesis, these considerations will be considered when moving towards a unified mobile application for barrier identification and navigation. By addressing these challenges and the incorporated user feedback, the project has hopefully provided with insight for future projects to develop comprehensive and user-friendly software for mapping and navigating physical barriers, ultimately enhancing accessibility for wheelchair users and potentially other movement-impaired individuals in urban environments.

References

AB Stockholmshem. (1998). *Traneberg.* BOOM-gruppen, KTH Arkitektur & AB Stockholmshem.

Antoniou, V., & Skopeliti, A. (2015). Measures and Indicators of VGI Quality: An Overview. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-3/W5*, 345-351. DOI: https://doi.org/10.5194/isprsannals-II-3-W5-345-2015

Arvidsson, J. (2023, December 14). *React-native-vector-icons*. GitHub. https://github.com/oblador/react-native-vector-icons

Atiaswd. (n.d.). Boxicons. GitHub. Retrieved 2024 January February 5, 2024, from https://github.com/atisawd/boxicons

Bakowska-Waldmann, E., & Kaczmarek, T. (2021). The Use of PPGIS: Towards Reaching a Meaningful Public Participation in Spatial Planning. *ISPRS Int. J. Geo-Inf.* 2021, *10*(9), 581. DOI: https://doi.org/10.3390/ijgi10090581

Biagi, L., Brovelli, M. A., & Stucchi, L. (2020). Mapping the Accessibility in OpenStreetMap: A Comparison of Different Techniques. *The International Archives of the Photogrammetry, Remove Sensing and Spatial Information Sciences*, *XLIII-B4-2020*, 229-236. DOI: https://doi.org/10.5194/isprs-archives-XLIII-B4-2020-229-2020

Bieh, M. (2023, June 1). *Geolib*. Npm. https://www.npmjs.com/package/geolib

Brovelli, M. A., Minghini, M., & Zamboni, G. (2016). Public participation in GIS via mobile applications. *ISPRS Journals of Photogrammetry and Remote Sensing*, *114*, 306-315. DOI: https://doi.org/10.1016/j.isprsjprs.2015.04.002

Cruz, I., & Campelo, C. E. C. (2019). Improving Accessibility Through VGI and Crowdsourcing. *Social Entrepreneurship: Concepts, Methodologies, Tools and Applications*, 571-589. DOI: https://doi.org/10.4018/978-1-5225-8182-6.ch029

Edinger, J., Hofmann, A., Wachner, A., Becker, C., Raychoudhury, V., & Krupitzer, C. (2019). WheelShare: Crowd-Sensed Surface Classification for Accessible Routing. *2019 IEEE International Conference on Pervasive Computing and Communications Workshops*, 584-589. DOI: https://doi.org/10.1109/PERCOMW.2019.8730849

Esri, Maxar, Earthstar Geographics, & the GIS User Community. (2023, November 2). "World Imagery" [1:59 200] [Basemap]. Retrieved September 7, 2023, from https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

Ester, M., K, H., Sander, J., & Xu, X. (1996). A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise. *Proceedings of the Second International Conference on Knowledge Discovery and Data Mining (KDD'96). AAAI Press*, 226-231. DOI: https://dl.acm.org/doi/10.5555/3001460.3001507

Expo. (2024). *Expo*. GitHub. https://github.com/expo/expo

Expo Technologies Inc. (n.d., a). *Expo Go*. Docs Expo Go. Retrieved September 12, 2023, from https://docs.expo.dev/get-started/expo-go/

Expo Technologies Inc. (n.d., b). *Expo Location.* Docs Expo Go. Retrieved September 12, 2023, from https://docs.expo.dev/versions/latest/sdk/location/

Expressjs. (2022, October 8). *Express*. GitHub. https://github.com/expressjs/express

Facebook. (2024, April 22). *React-native*. GitHub. https://github.com/facebook/react-native

Firebase. (2023, December 7). *Firebase-admin-node*. GitHub. https://github.com/firebase/firebase-admin-node

Fritz, S., See, L., & Brovelli, M. (2017). Motivating and Sustaining Participation in VGI. In G. Foody et al (Eds.), *Mapping and the Citizen Sensor* (pp. 93-118). London: Ubiquity Press. DOI: https://doi.org/10.5334/bbf.e

Gharebaghi, A., Mostafavi, M., Chavoshi, S. H., Edwards, G., & Fougeyrollas, P. (2018). The Role of Social Factors in the Accessibility of Urban Areas for People with Motor Disabilities. *ISPRS Int. J, Geo-Inf.* 2018, *7*(4), 131. DOI: https://doi.org/10.3390/ijgi7040131

Goode, T. (2018, November 4). *Cors*. Npm. https://www.npmjs.com/package/cors?activeTab=readme

Google Earth Pro V. 7.3.6. (n.d.). *Traneberg* [Screenshot]. Google Eart. Retrieved November 21, 2023, from http://www.google.com/earth/index.html

Google for Developers. (2023, September 12). *Firebase Realtime Database.* Firebase Google. https://firebase.google.com/docs/database

Gupta, M., Abdolrahmani, A., Edwards, E., Cortez, M., Tumang, A., Majali, Y., Lazaga, M., Tarra, S., Patil, P., Kuber, R., & Branham, S. M. (2020). Towards More Universal Wayfinding Technologies: Navigation Preferences Across Disabilities. *CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing* Systems, 1-13. DOI: https://doi.org/10.1145/3313831.3376581

Hedlund, M. (2000). Disability as a Phenomenon: A discourse of social and biological understanding. *Disability & Society*, *15*(5), 765-780. DOI: https://doi.org/10.1080/713662001

HeiGIT gGmbH. (n.d.). *Openrouteservice.* Retrieved December 19, 2023, from https://maps.openrouteservice.org/#/place/@17.981663346290592,59.333888491226446,6

Hosseini, M., Sevstuk, A., Miranda, F., Cesar Jr, R. M., & Silva, C. T. (2023, a). Mapping the walk: A scalable computer vision approach for generating sidewalk network datasets from aerial imagery. *Computers Environment and Urban Systems*, *101*. DOI: https://doi.org/10.1016/j.compenvurbsys.2023.101950

Hosseini, R., Tong, D., Lim, S., Sun, Chayn, Q., Sohn, G., Gidófalvi, G., Alimohammadi, A., & Seyedabrishami, S. (2023, b). A Novel Method for Extracting and Analyzing the Geometry Properties of the Shortest Pedestrian Paths Focusing on Open Geospatial Data. *ISPRS Int. J. Geo-Inf.* 2023, *12*, 288. https://doi.org/10.3390/ijgi12070288

Kasemsuppakorn, P., Karimi, H. A., Ding, D., & Ojeda, M. A. (2014). Understanding route choices for wheelchair navigation. *Disabil Rehabil Assist Technol. 2015*, *10*(3), 198-210. DOI: https://doi.org/10.3109/17483107.2014.898160

Khan, K., Rehman, S. U., Aziz, K., Fong, S., & Sarasvady, S. (2014). DBSCAN: Past, present and future. *The Fifth International Conference on the Applications of Digital*

Information and Web Technologies (ICADIWT 2014). DOI: https://doi.org/10.1109/ICADIWT.2014.6814687

Kocaman, S., & Ozdemir, N. (2020). Improvement of Disability Rights via Geographic Information Science. *Sustainability, 12*(14), 5807. DOI: https://doi.org/10.3390/su12145807

Lakshmi Steinberg, S., & Steinberg, S. J. (2015). *GIS Research Methods: Incorporating Spatial Perspective* (1st ed.). Esri Press, 380 New York Street, Redlands, CA.

Le Cam, P. (2023, March 1). *React-leaflet*. GitHub. https://github.com/PaulLeCam/react-leaflet?tab=readme-ov-file

Leaflet. (2023, May 18). *Leaflet*. GitHub. https://github.com/Leaflet/Leaflet

Mapbox. (2018, February 2). *Dobbyscan*. GitHub. https://github.com/mapbox/dobbyscan

Meta. (2022, June 22). *React.* GitHub. https://github.com/facebook/react

Meta Platforms Inc. (2023, December 8, a). *React Fundamentals*. React Native. https://reactnative.dev/docs/intro-react

Meta Platforms Inc. (2023, July 21, b). *Core Components and Native Components*. React Native. https://reactnative.dev/docs/intro-react-native-components

Miura, T., Yabu, K., Sakajiri, M., Ueda, M., Suzuki, J., Hiyama, A., Hirose, M., & Ifukube, T. (2013). Social platform for sharing accessibility information among people with disabilities: evaluation of a field assessment. *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*. DOI: https://doi.org/10.1145/2513383.2513391

Miyata, A., Okugawa, K., Yamato, Y., Maeda, T., Murayama, Y., Aibara, M., Furuichi, M., & Murayama, Y. (2021). A Crowdsourcing Platform for Constructing Accessiblity Maps Supporting Multiple Participation Modes. *Conference on Human Factors in Computing Systems – Proceedings*. DOI: https://doi.org/10.1145/3411763.3451688

Mobasheri, A., Deister, J., & Dieterich H. (2017a). Wheelmap: the wheelchair accessibility crowdsourcing platform. *Open Geospatial Data, Software and Standards, 2*(27), 1-7. DOI: https://doi.org/10.1186/s40965-017-0040-5

Mobasheri, A., Huang, H., Degrossi, Castro, L., & Zipf, A. (2018). Enrichment of OpenStreetMap Data Completeness with Sidewalk Geometries Using Data Mining Techniques. *Sensors, 18*. DOI: https://doi.org/10.3390/s18020509

Mobasheri, A., Sun, Y., Loos, L., & Ali, A. L. (2017b). Are Crowdsourced Datasets Suitable for Specialized Routing Services? Case Study of OpenStreetMap for Routing of People with Limited Mobility. *Sustainability 2017*, *9*, 997. https://doi.org/10.3390/su9060997

Node.js. (2014, January 22). *Node*. GitHub. https://github.com/nodejs/node

OpenStreetMap. (2022, April 13). *About OpenStreetMap.* Wiki OpenStreetMap. https://wiki.openstreetmap.org/wiki/About_OpenStreetMap

OpenStreetMap. (2023, July 19). *Openrouteservice.* Wiki OpenStreetMap. https://wiki.openstreetmap.org/wiki/Openrouteservice#General_Information

OpenStreetMap. (2024, January 9). *OpenStreetMap Carto.* Wiki OpenStreetMap. https://wiki.openstreetmap.org/wiki/OpenStreetMap_Carto

OpenStreetMap. (n.d.). *Copyright and License.* OpenStreetMap Copyright. Retrieved January 17, 2024, from https://www.openstreetmap.org/copyright/en

React-native-maps. (2024, February 18). *React-native-maps*. GitHub. https://github.com/react-native-maps/react-native-maps

Saha, M., Saugstad, M., Maddali, H. T., Zeng, A., Holland, R., Bower, S., Dash, A., Chen, S., Li, A., Hara, K., & Froehlich, J. (2019). Project Sidewalk: A Web-based Crowdsourcing Tool for Collecting Sidewalk Accessibility Data At Scale. *CHI 2019.* DOI: https://doi.org/10.1145/3290605.3300292

Sozialhelden e.V. (n.d.). *Wheelmap.* Retrieved December 19, 2023, from https://wheelmap.org/way/241944510

Sveriges Kommuner och Landsting. (2013). *Tillgänglighetsdatabasen (TD): Bra för alla, nödvändig för några* [The Accessibility Database: Good for everyone, essential for few] (Report 5313). https://skr.se/skr/tjanster/rapporterochskrifter/publikationer/tillganglighetsdatabasen.65632.html

Tannert, B., Kirkham, R., & Schöning, J. (2019). Analyzing Accessibility Barriers Using Cost-Benefit Analysis to Design Reliable Navigation Services for Wheelchair Users. In D. Lamas, F. Loizides, L. Nacke, H. Petrie, M. Winckler and P. Zaphiris (Eds.), *Human-Computer Interaction – INTERACT 2019* (*11746*), (pp. 202-223). Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-29381-9_13

Trafikverket. (2023, December 12). *NVDB på webb* [NVDB on the web] [Screenshot]. https://nvdb2012.trafikverket.se/SeTransportnatverket

Trafikverket. (2023a). *Förhållningssätt och regler vid leverans/registrering av företeelser* [Approach and rules for delivery/registration of events] (Version 1.0). https://www.nvdb.se/globalassets/upload/styrande-och-vagledande-dokument/forhallningssatt-och-regler-vid-leverans.pdf

Trafikverket. (2023b). *Introduktion till NVDBs vägnät och företeelser* [Introduction to NVDB's road network and events] (Version 2.0). https://bransch.trafikverket.se/contentassets/e0faf1739d244cb384aadf8c1f7a91dd/introduktion-till-nvdbs-vagnat-och-foreteelser2.pdf

Västra Götalandsregionen. (n.d.). *Tillgänglighetsdatabasen* [The Accessibility Database]. Retrieved December 13, 2023, from https://www.t-d.se/sv/search

World Health Organization. (2011). *World Report on Disability* (World report on disability 2011). https://www.who.int/teams/noncommunicable-diseases/sensory-functions-disability-and-rehabilitation/world-report-on-disability

Zare. H. (2023, May 10). *React-native-dropdown-picker*. GitHub. https://github.com/hossein-zare/react-native-dropdown-picker

Zipf, A., Mobasheri, A., Rousell A., & Hahmann, S. (2016). Crowdsourcing for individual needs – the case of routing and navigation for mobility-impaired persons. In C. Capineri, M. Haklay, H. Huang, V. Antoniou, J. Kettunen, F. Ostermann & R.

Purves (Eds.), *European Handbook of CrowsSourced Geographic Information* (pp. 325-337). Ubiquity Press London.

Appendix

FRIVILLIGA SÖKES TILL FORSKNINGSPROJEKT

Vill du bidra till forskning om tillgänglighet på trottoarer och gångstråk? Mitt namn är Kalle, jag är mastersstudent inom Geografisk informationsvetenskap på Lunds universitet och boende i Traneberg.

Jag skriver en uppsats om framkomlighet och fysiska barriärer, där jag vill fånga in hinder på trottoarer och gångstråk. Dessa hinder är främst specificerade för rullstolsburna men denna data kan även gynna andra grupper som föräldrar med barnvagn eller äldre individer. Exempel på hinder är avsaknaden av ramper eller övergångsställen vars trottoarkanter har höga kanter.

Denna forskning är viktig för att uppmärksamma hinder i den fysiska miljön och för att bidra med data till navigeringsapplikationer som beaktar individuella preferenser. Jag har själv lagt märke till att Google Maps inte genererar föreslagna rutter som är genomförbara för alla individer. Med data av fysiska barriärer kan vi belysa hur stadsplaneringen kan förbättra tillgängligheten i den fysiska miljön eller förstärka navigeringstjänster anpassade för rullstolsburna och andra individer med begränsad rörlighet.

Om du deltar i datainsamlingen får du tillgång till en applikation där du, vid tillfälle du rör dig utomhus i Traneberg, noterar fysiska barriärer genom att registrera koordinaterna och tillhörande information angående det fysiska hindret du stött på.

Är du intresserad? I sådana fall, anmäl ditt intresse via mejl genom att skanna QR-koden nedanför med mobilkameran, därefter får du instruktioner hur du kan delta.

Figure A.1. Project advertisement.

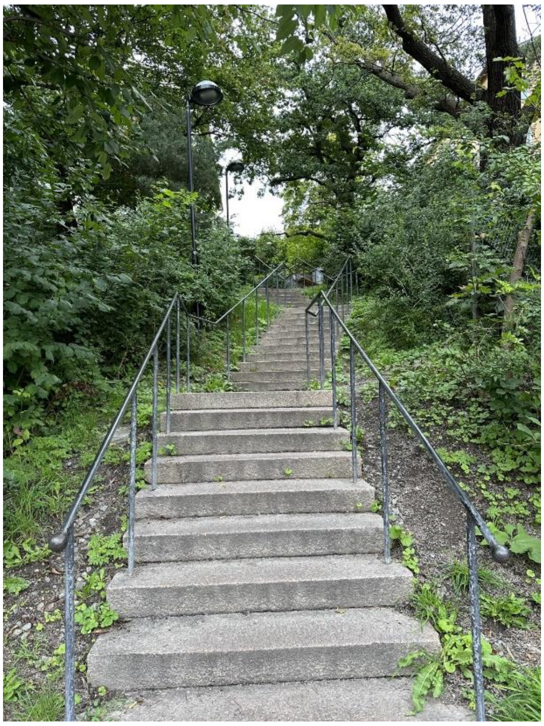
VGI instructions

1. Ladda ner **Expo go** från Appstore eller Google play
2. I Expo go, skanna QR-koden nedan för att få tillgång till projektet:

3. Du ska främst samla in tre typer av barriärer. Genom att ställa dig mitt på/exakt var barriärer är positionerad ska du registrera följande:

a) *Höjden av gatukanter*, se exempelbilder nedan. Det finns tre typer av höjder att välja mellan; ingen märkbar höjd (0 cm), mellan (1 till 3 cm) och hög (över 3 cm). Den som motsvarar 0 cm innebär att du gör en bedömning att det inte är någon märkbar höjd mellan gatukanten och vägen. Att skatta höjder med ögonen är självklart subjektivt, gör så gott det går. Jag ser gärna att du registrerar gatukanter som är ämnade att korsas från ena sidan till den andra. Exempelvis vid utmärkta övergångsställen eller slutet av vägar där övergångsställe saknas men behöver korsas. Använd bilderna nedan som referenser:

b) *Trappor*. Denna är ganska simpel. Du registrerar de trappor du stöter på. Här kan du fylla i om trappan har en ramp (e.g för barnvagn) eller utan. Bilden nedan visar en trappa som saknar ramp för barnvagnar:



c) *Sluttningar*. Sluttningar innebär stigande höjder som inte avser trappor. Dessa kan antingen vara ramper som är anpassade för rullstolar eller naturliga/vanliga stråk som sluttar. Exempel på dessa:

d) *Övrigt*. Här har du möjlighet att registrera hinder som inte avhandlats, men som kan orsaka svårigheter för framkomligheten. Dessa kan vara sprickor i marken, gallerbrunnar, stolpar som står i vägen, smala trottoarer/gångstråk, med mera. Du registrerar dessa på exakt samma sätt, genom att ställa dig mitt på barriären. Först fyller du i typ av objekt, exempelvis (spricka/spricka i marken), i nästa ruta skriver du mer beskrivande hur objektet försvårar framkomligheten. Exempel på övriga hinder:

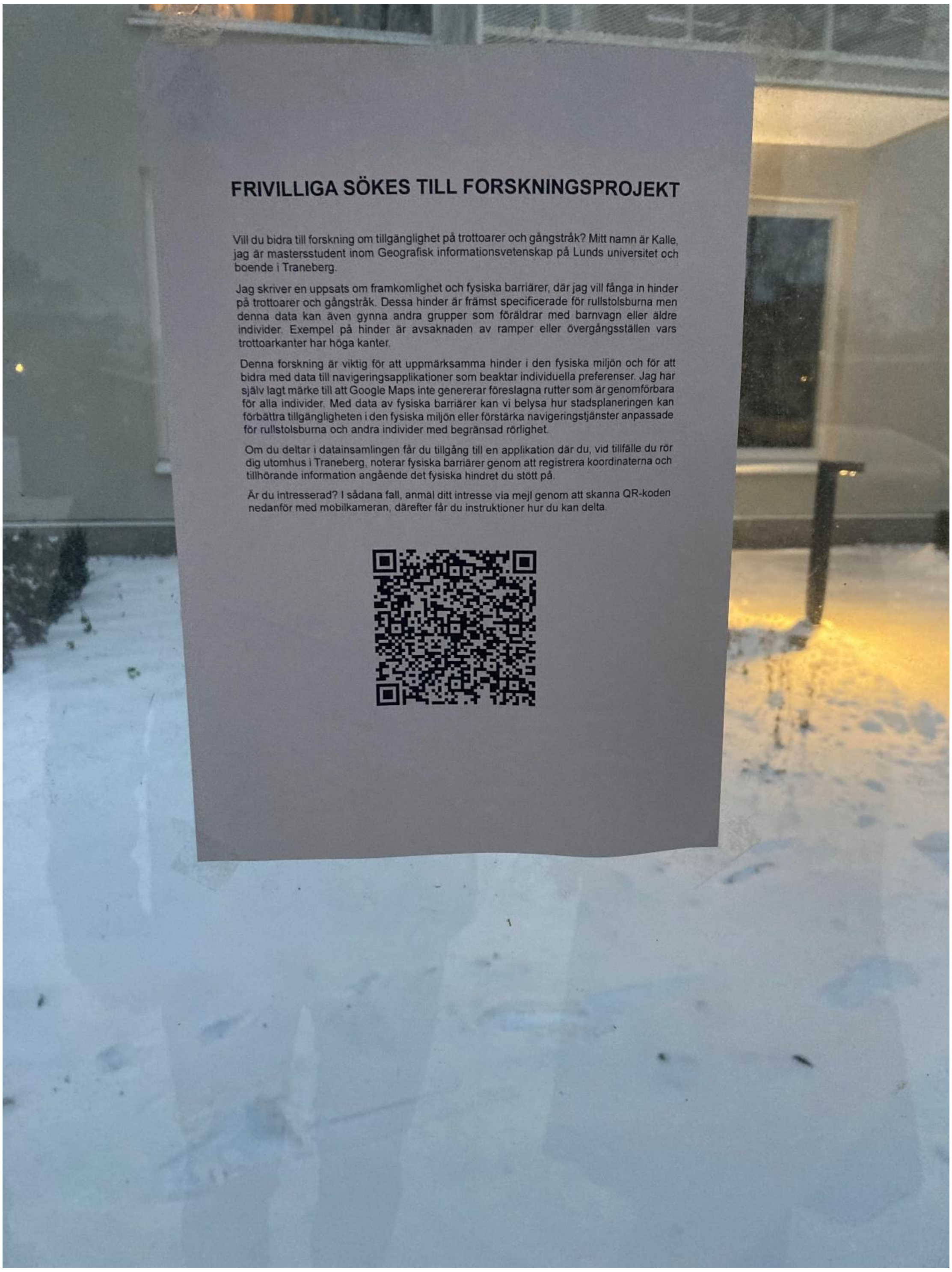


Figure A.2. Advertisement on bus stop.

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