Master Project

Making Maps Accessible to the Blinds and Visually Impaired

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Abstract

Mobility is one of the many challenges blind or visually impaired people face. This thesis started with the hypothesis that technologies such as LiDAR could replace white canes by providing a more effective obstacle detection tool. However, through literature review, SMEs, and ethnographic interviews with blind and visually impaired people, we refuted the hypothesis and quickly pivoted the project. The result is an application allowing users to explore simplified indoor or outdoor venues maps by moving their finger on the screen. Precise haptic feedback, sounds, and audio descriptions are given depending on the element under the finger. By doing so, users can understand any map even when having no vision, allowing them to gain autonomy and confidence in their everyday lives. Talks are taking place to open-source the project and transforming it as a framework for use in existing apps such as audio-GPS or even public transport apps to display maps of stations.

Keywords: Blind, Visual Impairment, Map, Haptics, Qualitative study, Human-Computer Interaction

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Chapter 1

Introduction

Low vision or blind people face many challenges in their everyday life. One of the biggest challenges, especially for the one with the complete loss of vision, is navigation. A blind or visually impaired person has difficulties detecting obstacles and often lacks orientation in unknown places. To reduce the risk of injuries, a white cane is often used.

1.1 About visual impairment

In 2019 alone, an estimated 377'000 people in Switzerland are visually impaired, blind, or deafblind, representing more than 4% of the country's population. Among those, an estimated 50'000 people are considered fully blind, 57'000 blind, and deaf and 270'000 are considered visually impaired (Figure 1.1). It is, however, essential to note that the concept of disability differs significantly between individuals and specialists. Also, the spectrum of impairments that people might experience is widely different among people. [1] [2]

There is a strong relationship between age and probability of experiencing any kind of visual impairment. As such, among the population of 80 years old or more, more than 20% experience a form of visual impairment (Figure 1.2). [2]

Based on this observation, the Swiss National Association of and for the Blind expects an

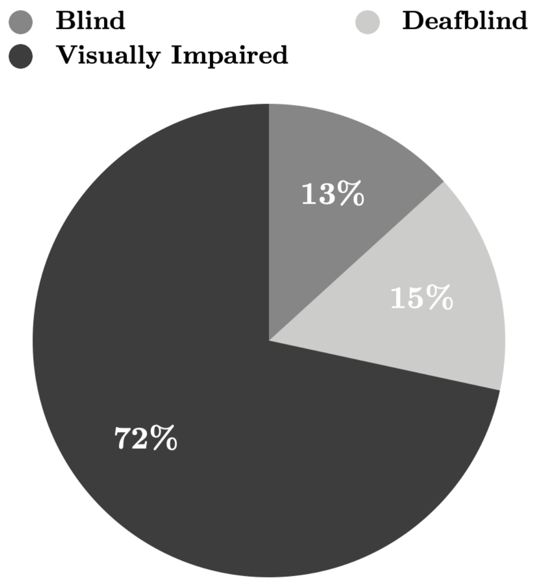


Figure 1.1: Proportion of blind, visually impaired and deafblind inside the community. [2]

increase of 59% of the number of Swiss people experiencing visual impairment until 2039, highlighting the importance of accessibility. [2]

1.2 About the White Cane

This classical object dates back to 1921, with James Biggs painting his walking stick in white color after an accident [3]. Many visually impaired and blind people use it to avoid obstacles and injuries. It is also used as a signaling tool to notify others of visual impairment, inviting them to be careful and more consilient. See figure 1.3 for an example.

Moreover, this tool gives blind and visually impaired people legal rights in many countries and regions. For example, in Switzerland, automobilists should stop and let pedestrians with a white cane cross the road. (article 6, alinéa 4 de l'Ordonnance sur la circulation routière OCR).

During ethnographic interviews, interviewees demonstrated the usage of their white cane, also called long cane. First, they swipe the cane in front of them; on the right when the left foot is ahead, and then on the left when the other foot is in front. Some people use it every time, and others, often those that are not entirely blind, use it punctually.

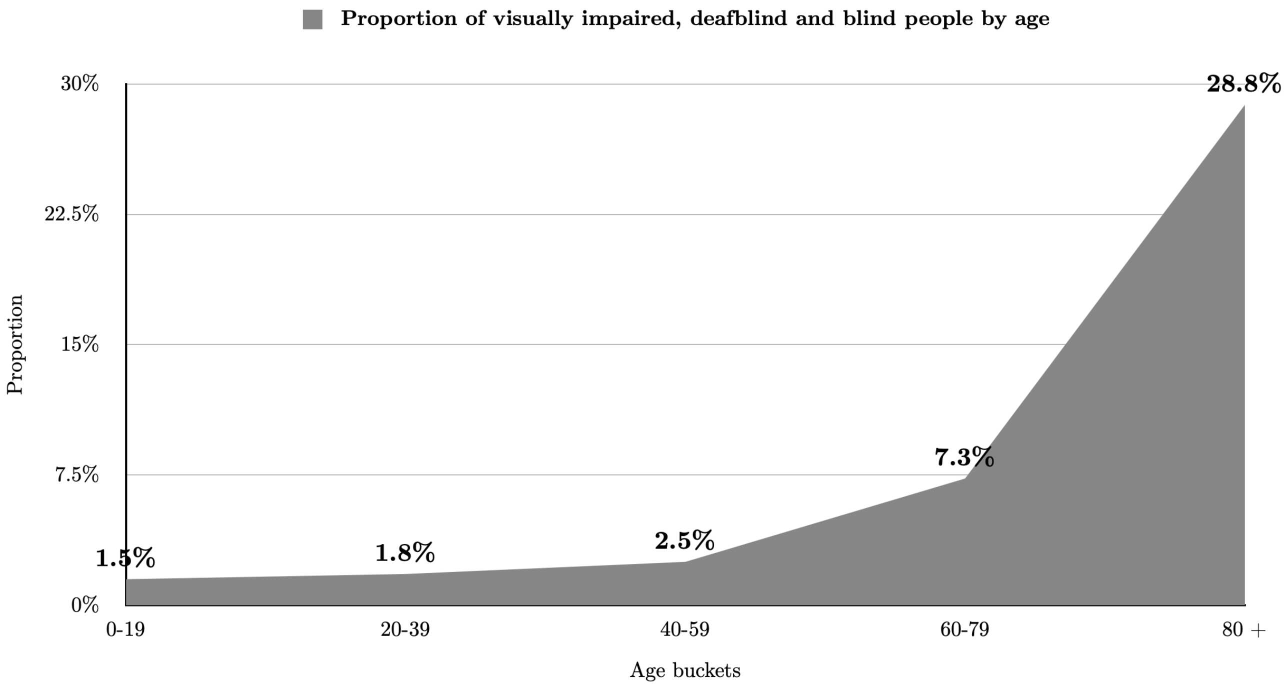


Figure 1.2: Proportion of blind, visually impaired and deafblind people by age. [2]

1.3 Initial Hypothesis

Our smartphones come with an increasing number of sensors, creating new opportunities to develop game-changing applications for our everyday lives. Light Detection and Ranging (LiDAR) is one of the latest novelties and allows developers to get a precise notion of the space around the user. This new scanner determines the distance between the user and any object by computing the time needed for a light beam to travel.

Blind people or people with vision disabilities rely on different tools and techniques to navigate, but the usefulness of such devices are often limited. Loss of orientation, increased risk of injuries; LiDAR technology and smartphones can solve many of those problems and potentially replace the famous white cane.

During the initial literature review and research phase, it was quickly discovered that such tools would not correspond to users' needs. Therefore, in order to learn more about blinds and low vision people's needs, we needed deeper research.

ELCA started the project from scratch. The project would act as an MVP for an application to help the visually impaired navigate in their daily lives. When developing products or services

Figure 1.3: Woman crossing the street using a white cane.

for a group target, one must always have a user-centered design approach to understand users' needs and goals. For this project, we chose the approach of goal-directed design consisting of field studies, semi-structured interviews with low vision people, subject matter experts' interviews, and literature review.

Chapter 2

Research

2.1 Scope

2.1.1 Objectives

This project aims to create an application that can help people suffering from visual impairment, using the hypothesis that we can replace the famous white cane with an application as a starting point. The resulting application must be a finished product and not a simple proof-of-concept.

This thesis would attempt to solve a century old-problem with a new approach, from user needs to robust and valuable technology.

Moreover, the underlying goal for the company is to foster innovation and gain knowledge about novel technologies and areas.

2.1.2 Timeline

The project duration is six months and will take place between August 1st, 2021, and January 28th, 2022. As a stakeholders request, the UX research phase duration will be about two months.

2.1.3 Financial Constraints

A small transportation budget is available for user and SMEs interviews. Moreover, there is the possibility to acquire devices such as smartphones, tablets, or computers if needed.

Lastly, the project is to be developed by one person. The team members are here to guide the project and provide support if needed, but no additional resources are attributed to helping conduct user interviews and observations or supporting development.

2.1.4 Process

This project tackles an ill-defined problem. As stakeholders do not have experience working for blind and visually impaired users, one has to validate the initial hypothesis before starting any software development.

To ensure maximum learning in the limited six months timeframe, we will follow the main structure defined by Alan Cooper's Goal Direct Design Process while also using other UX research techniques such as affinity walls throughout the project.

With the need to move and validate design ideas quickly, we will also take advantage of some aspects of Eric Ries Lean Startup approach, more specifically, the idea of quickly coming up with Minimum Viable Products to test hypotheses early on in the process and pivot if needed.

Here is the resulting project outline:

1. Research
    (a) Scoping
    (b) Audit
    (c) Stakeholder Interviews
    (d) SMEs and User Interviews & Observations
2. Modeling

3. Requirements Definition
4. Framework Definition
5. Implementation with Rolling Review

2.1.5 Internal expertise

The company's team following this project are essentially mobile and web software developers as well as project managers. Moreover, the team have great experience with in augmented and virtual realty on a technical point of view.

2.1.6 Milestones

- **Milestone 1:** Mid-fi design framework based user-centered research.
- **Milestone 2:** First app deliverable including the essential set of features.
- **Milestone 3:** Final app deliverable focused on improvements based on user feedback.

2.1.7 Kickoff meeting

The company's motivation behind this research project is primarily to explore the capabilities of LiDAR, a technology made famous on a smartphone with the iPhone 12, and now being deployed on other devices.

ELCA's mission is to offer state-of-the-art solutions to its clients, which implies closely monitoring new technologies available on the market and efficiently responding to clients' demands. Thus, this project aims to explore the opportunities offered by LiDAR, as well as its limitations.

For that reason, this research project needs to go further than simple experimentation with LiDAR. By creating a real-world example using this new scanner, ELCA can potentially launch new offerings.

2.2 Audit

2.2.1 Literature Review

Visual Impairment Classifications

According to World Health Organization International Classification of Diseases 11, Visual Impairment can be categorized into two groups; distance visual impairment and near vision impairment. The first group can be further dived into the terms listed in Table 2.2.1.

Visual Acuity	Definition
[6/18, 6/12[	Mild
[6/60, 6/18[	Moderate
[3/60, 6/60[	Severe
<3/60	Blindness

Table 2.1: Definitions according to visual acuity. [4]

As the WHO further describes:

> A person's experience of vision impairment varies depending upon many different factors. This includes, for example, the availability of prevention and treatment interventions, access to vision rehabilitation (including assistive products such as glasses or white canes), and whether the person experiences problems with inaccessible buildings, transport, and information. [4]

Assistive Technology Products

According to the Assistive Technology Industry Association, assistive technology can be described as

> Any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities. [5]

Those tools can significantly improve the lives of visually impaired people. However, lack of information and prohibitive costs often prevent people from adopting such devices [6] [7]. Moreover, according to US study [8], it is estimated that the abandonment rate of assistive technology products can be as high as 75% in some cases, mostly after only three months of usage. The study also highlights that the most abandoned device was the one that was the easiest to acquire.

Assistive Technology for Smartphones

While no official studies exist on the matter, it is commonly assumed that around 90% of devices used by visually impaired people are iPhones from Apple [9]. Later during this study, it is also what has been observed in the field.

Reasons for this might be the followings:

- iPhones came out in 2007 with accessibility features built-in, making it an accessible tool from the start and only improved going forward.
- Uniformity among devices. All Apple devices will work similarly, making it seamless to change devices.
- Developers have an incentive to include accessibility in their code, as automated UI testing of iOS relies entirely on accessibility features Apple doc contrary to Android. [10]

2.2.2 Competitive Audit

For this project's scope, the competitive audit is focused on any assistive technologies aimed at improving obstacles detection and navigation.

To cover a complete spectrum of such devices currently on the market, we have identified three main variables.

- Assistive device type: Pure hardware to pure software

- Assistive device goal: Pure obstacle detection to pure navigation
- Device price: Any price range

Smart Canes

Figure 2.1: Example of a smart cane. [11]

For decades, improving the classic white cane has been at the center of attention. The main idea behind those devices is to keep the feature of the standard white cane untouched while enhancing obstacles detections or navigation. That means that the user can always detect obstacles physically without using technology. Moreover, the devices can keep a 100% reliability rate in the device fails, since it still a white cane. This proved crucial for blind persons.

Classic white canes allow users to detect obstacles under waistline height, leaving obstacles above it undetected. Thus, tree branches, suspended signs, road works barriers, truck loading platforms might hurt blind people.

The goal of intelligent canes is to detect obstacles above the waistline and try to warn the user using haptic or sound feedback. More sophisticated devices can also guide the user around the obstacle or give different feedback depending on the type of obstacle.

Advantages:

- It reduces injuries from obstacles that would be undetected otherwise.
- It uses a form factor that is already well known to users.
- It requires only one hand.
- If the electronic device fails, the user can still use it as a standard white can.

Disadvantages:

- It can have reliability issues as the ultrasonic or infrared sensors might fail in certain circumstances, inducing false positives or negatives.
- It required training with a steep learning curve. The feedback given by the device is often complex to understand.
- It sometimes cannot detect transparent materials such as large windows or thin obstacles like wires.
- It induces a cognitive overload. Blind people have to be highly focused on their environment, such as sound people, and not lose orientation.
- It is expensive for most people.
- It needs to be recharged.

Examples: SmartCane, UltraCane, Tom Pouce.

Figure 2.2: Example of wearable device, the InnoMake Shoes. [12]

Wearable Devices

Wearable devices share the same goal as bright canes but are often more sophisticated and include more features. Such equipment can be glasses, belts, shoes, or helmets. The InnoMake shoes are a great example of those more advanced features by giving vibrations or acoustic signals when detecting obstacles up to 4 meters away. It can also scan the environment by moving the foot to find paths, and the next version might include AI for more precise and intelligent obstacles recognition.

Wearable devices often connect to bone conduction headphones and apps or smartwatches allowing for more sophisticated features.

Advantages:

- It can help the user feel safe.
- It can help the user navigate and understand the near environment better.
- It can include more sophisticated features with an app and headphones.

Disadvantages:

- It often needs to be connected to headphones, smartphones, or smartwatches, which implies more time needed to start using the device.
- It is often stigmatizing as those devices are often heavy and visible to others.
- It does not replace the white cane and thus represents an additional device to carry.

Examples: Be my Eyes, Aipoly Vision, Microsoft Seeing AI, Supersense.

Everyday-Life Assistance

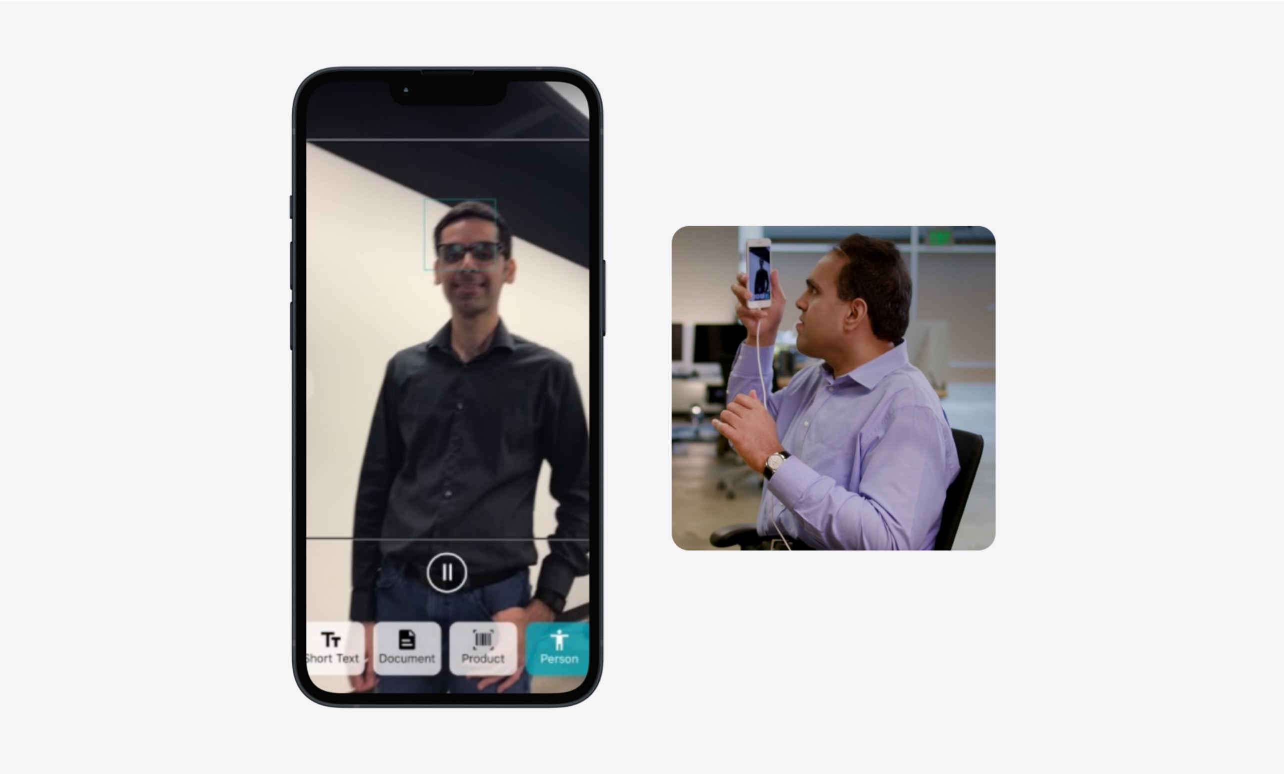


Figure 2.3: example of an app for blind people; Microsoft Seeing AI [13]

Countless smartphone apps exist aimed at helping users in their everyday life. Those applications often use machine learning and image recognition to help users read text, detect colors, read currencies, describe pictures, approximate people's age and emotions, and much more.

When the technology is not sufficient for specific tasks, apps exist to connect blind or visually impaired people to anyone in the world willing to help. Those volunteers have access to the impaired person camera and can help answer questions such as identifying objects or fonding buttons on a device, for example.

Advantages:

- Those apps can help the user gain autonomy for their everyday life.
- Those apps are often free or inexpensive.
- Contrary to many hardware devices, developers can easily update the apps with new features.

Disadvantages:

- Many apps exist with very different sets of features and interfaces. Thus, users have to constantly switch apps and learn to use every one of them.
- Only people who have and know how to use smartphones can use those systems.

Examples: Be my Eyes, Aipoly Vision, Microsoft Seeing AI, Supersense.

Distance Measurements Apps

A subset of apps is designed to compute distances between the user and objects to guide the user towards specific elements such as tables or doors. However, on the contrary, this principle can also help the user find areas of the environment with no obstacles, such as finding a corridor exit.

A notable example is the Swiss Federal Railways app, SBB Inclusive, winner of the "Canne Blanche 2020" distinction for accessible apps. While this feature is not yet available to the public, the approach detects train doors and guides the user to them by using vibrations and audio feedback. By doing so, blind and visually impaired persons can find the doors easily without asking for help, touching the train, or listening to other passengers. This app is exciting

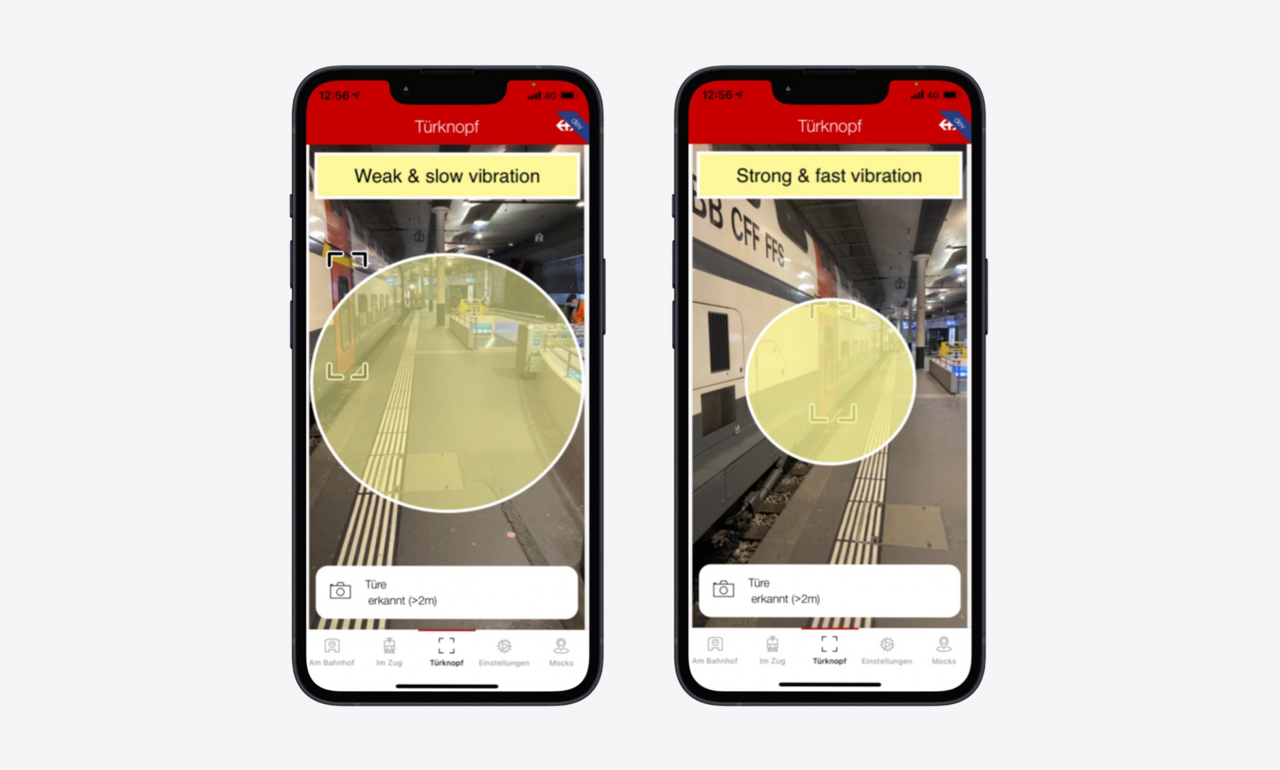


Figure 2.4: Screenshots of the SBB Inclusive application [14]

since it resembles the initial hypothesis of detecting items, computing distances, and guiding the user. We have arranged a meeting with the software developers and the UX designer behind this project. We gained many technical insights on the technology used to compute distance, performance issues, and battery life challenges. They are now testing the feature with users, and it is yet too early to conclude this study. However, preliminary findings seem positive.

Advantages:

- Such apps provide distances to users, which is not possible with white canes.
- It is possible to locate elements that would be otherwise hard to find.
- It does not require any additional hardware.

Disadvantages:

- Users complain that using such applications uses at least one hand, which is problematic is already using a white cane on the other hand and can be dangerous or impractical.

- Other techniques exist to locate such elements. People use the sound of crowds, spatial memory, or other techniques.
- The precise location of elements requires a LiDAR sensor which exists only on recent and premium smartphones.

Examples: SBB Inclusive, Super LiDAR

Audio GPS Apps

A wide range of audio GPS exists on app stores. The goal of those apps is often to help the guide the user along a path using voice.

Advantages:

- Such apps can help users find their way if they lose orientation.
- The most autonomous blind persons can use it to navigate places without learning the itinerary first.

Disadvantages:

- The GPS signal precision is insufficient for most situations. For people with vision, this does not represent a problem since they can look around and understand where they are compared to the GPS indications. However, for impaired people, this is a major issue. For example, if the GPS indicates to turn right, it does not mean that there is no wall, garage entry, or other obstacles to avoid. The pedestrian might have to walk a few meters ahead before making the turn.
- Using the device needs to use one hand, which, as for apps measuring distances, can prove unpractical or dangerous. During observations, people using such devices sometimes find tricks to place the smartphone horizontally in their pockets, which is a requirement for the embedded compass.

- Often uses sound or simple vibrations. However, hearing is of utmost importance for navigation as it can help orientation and avoid injuries.

Examples: MyWay Pro, Microsoft Soundscape.

Indoor Navigation Apps

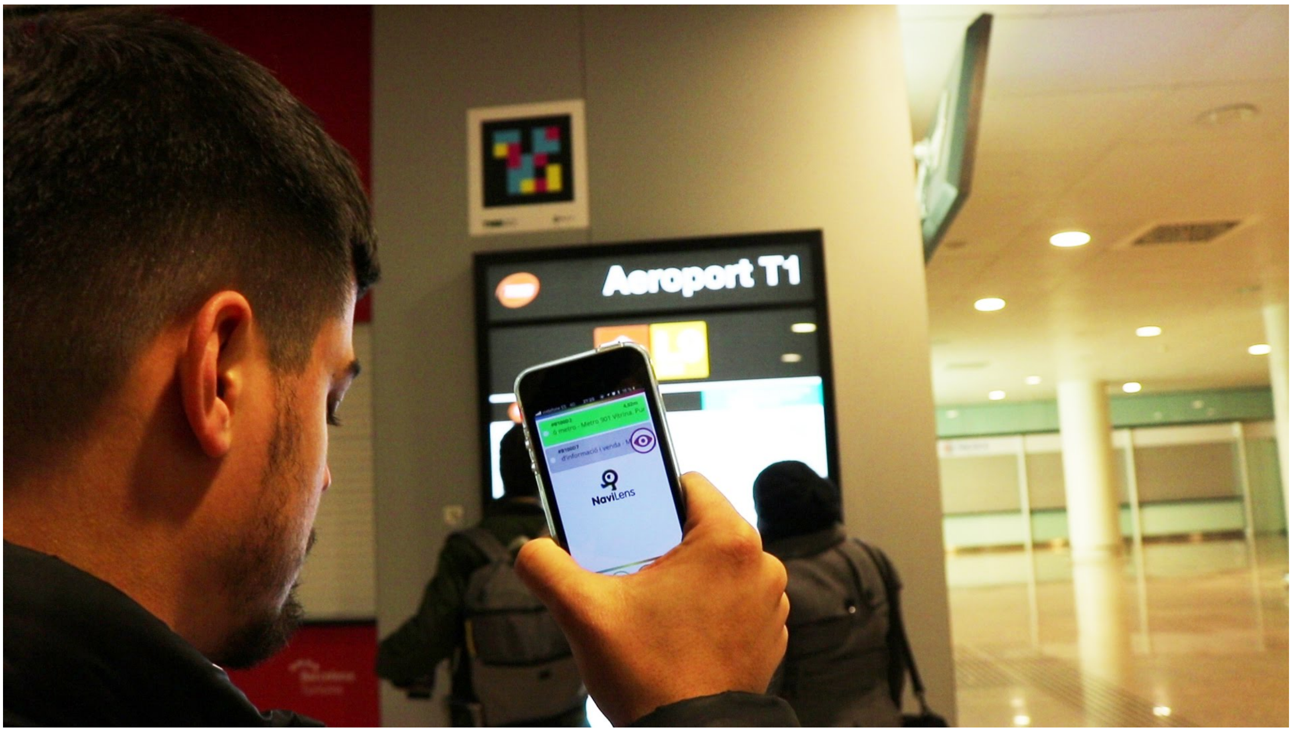


Figure 2.5: Example of indoor navigation app Navilens. The user has to point to the phone in the direction of the colored QR code on the wall. [15]

Indoor navigation apps work similarly to audio GPS. However, such tools rely on Bluetooth beacons or big QR codes.

Advantages:

- It can help blind or visually impaired persons navigate inside buildings autonomously by finding rooms, lifts, restrooms, and other places without external help. [16]

Disadvantages:

- As for other apps, the required use of one hand is problematic.

- It often requires installing hardware inside buildings which severely limits its availability and implies high costs.

Examples: Navilens, Evely, NavCog, ABAplans.

Insights

- Insufficient precision can significantly reduce the relevance of using assistive technologies. Poor accuracy can reduce user confidence in such a device for navigation and obstacle detection and pose safety risks.

- Reliability seems to be an essential characteristic of assistive devices. Today's technologies are unable to offer 100% reliability. Even being close to perfection will imply a loss of confidence and reinforce the abandonment rate.

- With insufficient precision and reliability issues, it is practically impossible to replace the classical white cane, meaning that when moving, the users have to use one hand. Many devices, especially apps, rely on the hypothesis that users are willing to use their second hand. However, field observations reveal a significant flaw of this system. Users try to find tricks to put the device in their pocket, further diminishing the accuracy and reliability. Moreover, using smartphones often requires holding the phone in one hand while interacting within on the other hand. Since the other hand is already used for the white cane, people must either stop or stop using the white for a few steps, causing safety issues.

- Many systems use sounds. While this does not bother users in a calm setting, it becomes a more significant issue if the device is intended for usage where many movements happen. Blind and visually impaired people rely on hearing for orientation danger detections and are highly concentrated. Some manufacturers recommend using bone conduction earphones to tackle these issues, but while this allows users to hear the environment better, it creates more overhead as they have to set up the device.

- Today's technologies can understand the environment like never before, especially with the rise of machine learning and artificial intelligence. However, we've observed that the bottleneck is now the transmission of the information from the device to the user. More precisely, audio descriptions, sounds, and vibrations quickly cause a cognitive saturation, causing stress or attention issues. The more signals the device transmits to the user, the more it requires training.

- Price represents a significant barrier to adopting assistive devices. Often, patients cannot acquire such devices, especially in cases where it is not reimbursed by insurance. Moreover, we have observed that some people are afraid to make such investments, as they fear that the devices will be too complicated to use or invasive.

- Training is also a major aspect of low device adoption. We have identified multiple reasons for that. Firstly, some people refuse to ask for help either because they have to accept their impairment, lack confidence, have little financial means, or do not want to disturb others. Secondly, some people prefer to use traditional analog techniques rather than go through training, requiring non-negotiable efforts.

[17] [18] [19] [20]

2.3 Stakeholders Interviews

Internally, the vision of this project is primarily to test the new LiDAR scanner on iPhone and iPad devices defined as:

> "[...] an instrument that detects the position or motion of objects and which operates similarly to a radar, but which uses laser radiation rather than microwaves." [21]

This sensor can be found on the back of the device, next to the camera lenses (Figure 2.6).

Figure 2.6: Example of LiDAR scanner on iPad. [22]

By combining images captured by the camera and the precise measurement of the LiDAR sensors, developers can create 3D mesh representations of the surrounding spaces, live, as the user moves the device. [23]

Today usages of the sensor are mainly for improving camera focus while the user is taking pictures of filming videos [25]. Other applications can include precise mapping of building floors [26], or measurements [27]. There is also a built-in accessibility feature made by Apple using the sensors, such as an app that indicates when blind users can move forward in a waiting line. This works by pointing the phone in front of the user and then using machine learning to detect the person and analyze if the person if the front moves forward or not. The initial goal of stakeholders is to find a new showcase of this technology and gain knowledge. This could then be used as an example for future clients.

However, company stakeholders are open to new ideas, and other project directions as internships are often used as innovation fostering.

The project has no goal to commercialize and bring additional revenues.

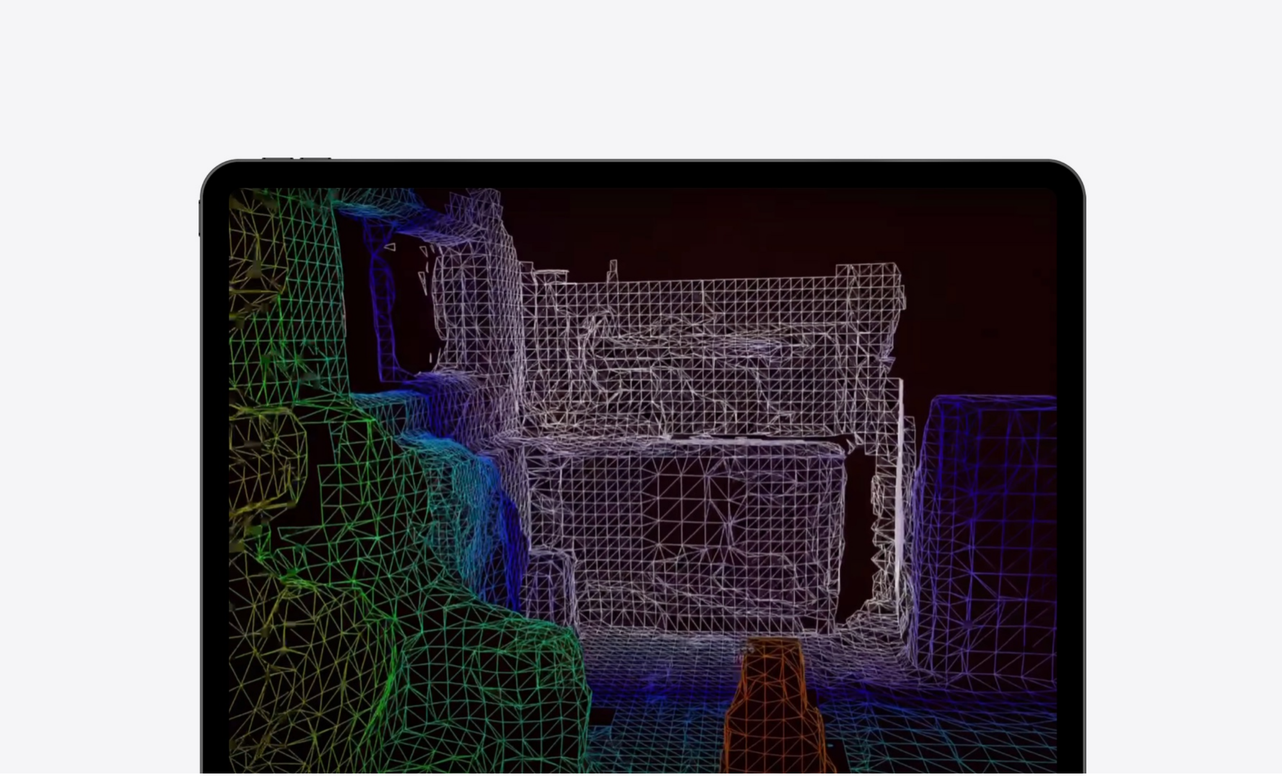


Figure 2.7: Example of a mesh created using ARKit and the LiDAR sensor. [24]

2.4 Ethnographic Interviews

2.4.1 Identifying Candidates

The world of visual impairment is a broad and complex domain. We have discovered that visual impairment comes in many different forms during the initial research phase. Different types of color blindness, absence of central or peripheral vision, no vision at all or only in certain conditions. It is exceptionally complicated to list all the possible disabilities. Moreover, it is essential to distinguish low vision from blind as their abilities vary greatly.

On top of that, people can be born with or without a handicap. We say that the handicap is either acquired or congenital in scientific terms. This affects the person's autonomy and acceptance of his handicap.

Blind and visually impaired people account for about 4% of the Swiss population, and most are past the age of retirement [2]. In addition to the difficulties of using complex user interfaces, people with such conditions are hard to recruit via publicly available contact sources such as

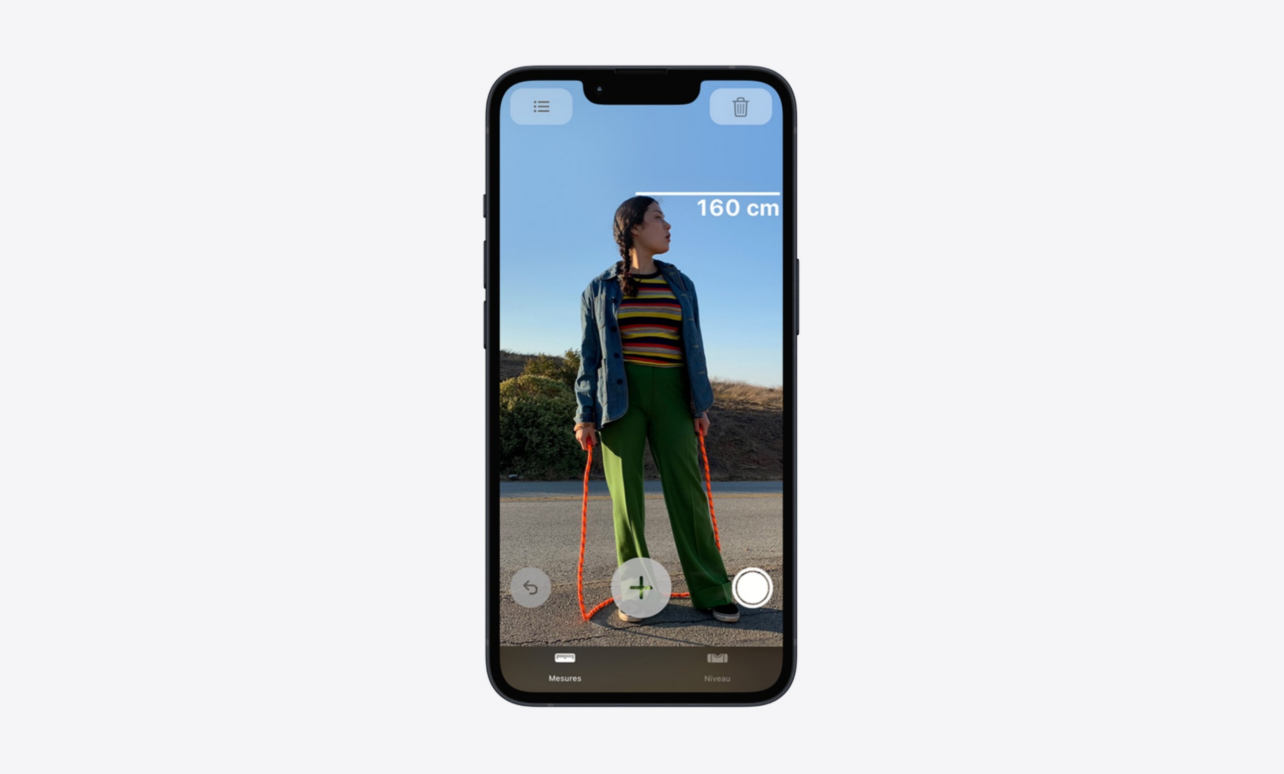


Figure 2.8: Example of measures made possible with LiDAR. [22]

social networks. Therefore, we chose to use SME as a proxy to recruit the first interviewees, which would serve as another proxy to recruit more. The downside of this approach is the time required to set up interviews, especially when the UX research phase is limited in time.

Cooper uses a persona hypothesis constructed from likely behavior patterns based on prior research, suggesting conducting approximately a dozen interviews per hypothesis. However, as a direct consequence of those constraints, we have decided to divert from the methodology outlined by Alan Cooper about Goal-Directed Design and use a large spectrum of the population at first to acquire as much knowledge as possible on time. To help with that, we have also continued to work with subject matter experts to understand better and target the different needs.

This will result in creating provisional personas to guide the design process further.

Subject Matter Experts

Subject Matters Experts Interviews can be valuable at the start of an ill-defined project such as this one. Knowledge can be quickly gathered, helping the designers better identify potential opportunities for the projects. In this context, those interviewees would also serve as a starting point for recruiting users for interviews later on in the process.

The chosen SMEs would be accessed throughout the project to:

- Gather initial general knowledge about blinds and the visually impaired.
- Used as a contact point for recruiting interviewees.
- Test hypothesis, insights, and ideas gathered during the interviewing and observation phase.
- Review and get feedback about the final product.

Often, SMEs would also act as potential users, as many of them might be blind or visually impaired themselves.

We have identified the following sectors:

Health

Lausanne, hosting the Jules-Gonin Hospital being one of the best expertise centers worldwide, attracts many talents and knowledge.

This Hospital offers eyes surgeries and consists of rehabilitation, training, and research divisions.

It has been decided to meet several specialists at this Hospital and proceed to semi-structured interviews of approximately one hour.

Figure 2.9: Photographs taken during observations at a specialised centre for blinds and visually impaired.

Associations

Lausanne is also a center for many associations and federations for the blinds. Both the Swiss National Association of and for the Blinds (UCBA) and the Swiss Federation of the Blind and Visually Impaired (FSA) have offices here. They represent the most extensive structures for this community in Switzerland, offer support training, and represent the interest of this community at the national level.

Public Sector and Transports

In Switzerland, laws exist to promote accessibility in many different areas. Public Transports are a great example of that, as they have the mandate to be accessible for a maximum of people, including blinds and the visually impaired. Train companies, for example, now have an obligation to make the stations and trains accessible to disabled persons.

Moreover, while this can certainly be improved, cities are also often sensitive to this problem.

As a result, urban planning often includes some notion of accessibility.

Schools

In addition, we have also decided to approach specialized schools and perform observations during classes. Lausanne is also an important center for the education of visually impaired children and teenagers. Hosting the *Educational center for the visually impaired* (CPHV), many children follow a personalized education, allowing many of them to join the university at the end of their curriculum. (Image 2.10)

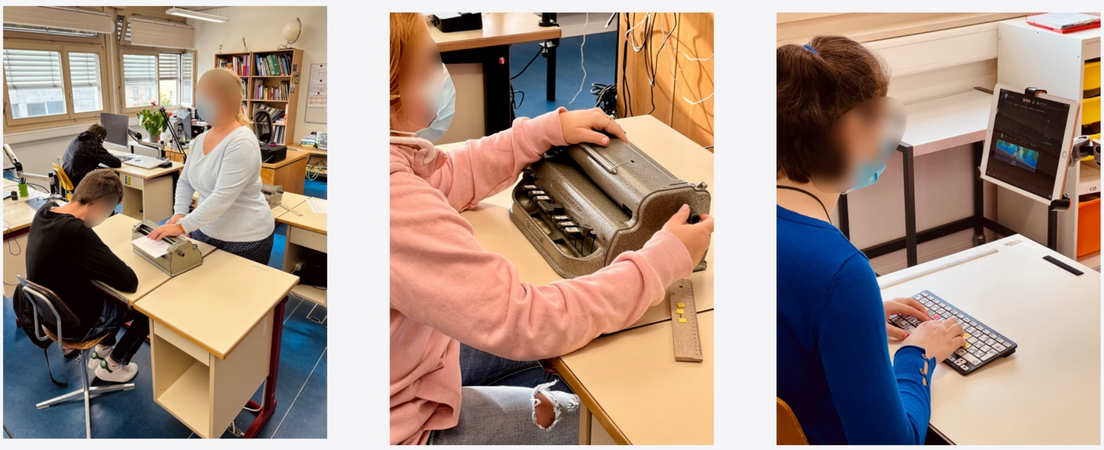


Figure 2.10: Photographs taken during observations at a specialised school.

2.4.2 Participants

In addition to ten subject matter interviews, we have held ten interviews with blind and visually impaired people. Most participants were adults (40-59, 60%), while some were young adults (20-29 years old, 20%) and nearly retired or retired (60+, 20%).

Half of the participants are fully blind, while the other half have significant visual impairments resulting in severe mobility implications, often requiring to learn itineraries by heart or needing assistance.

Among those two groups, 50% of the participants are born with the disease, while the 50% experienced it during their life (less than or 5 years ago, 40%) (more than 5 years ago, 60%).

All the interviewees use a smartphone and other technological devices such as computers or tablets. 4 were particularly expert users of such devices.

Every blind person uses a white cane, while for the visually impaired, participants use only occasionally (80%) and marginally not at all (20%).

All the interviews were held in french, as all of the participants are based in the french-speaking part of Switzerland.

No participants had other types of disease apart from vision.

2.4.3 Conducting Interviews

All semi-directed interviews took place in-person for an approximate duration of one hour in places familiar to the users; their home, work, or any places the user finds familiar.

Interviews were audio-recorded with the interviewees' consent, and written notes were taken during the discussions with particular attention to observations such as how people react to the questions, how they use their cane or other objects, how they used their smartphone and other insights.

Interviews were constructed as follows:

1. Initial easy warm-up questions followed by direct questions about their handicap.
2. First set of closed and open questions about mobility and learning itineraries.
3. Set of closed and open questions about the loss of objects.

4. Test of existing apps with observations followed by cold.
5. Asking for other contacts.
6. Conclusion.

A small presentation was given at the end of each interview.

Appendix B refers to the first version of the user interview guide.

Demos of existing application

We found it valuable to make the interviewee's test different existing applications. It often opened up more conversations and inspired the interviewees to more easily about related topics. Specifically, we have tested the following apps.

Super LiDAR This application relies entirely on LiDAR. The app calculates the distance between the smartphone and the nearest object at the center of the camera view. The app plays a sound becoming louder and more robust the closer the object is. When the nearest obstacle is far from the device, such as in figure 2.11, no sound is played.

Moreover, the app detects basic objects such as tables, chairs, or persons using image recognition and audio-describes them.

The goal of testing this app with blind, visually impaired and SME is to gather informations about the importance of describing distances and finding obstacle-free zones near the environement.

SBB Inclusive A detailed description of SBB inclusive can be found in section X. Testing this app with users assesses the importance of giving directions to an object. We can imagine a similar system to precisely locate and direct users to pedestrian crossings using the same concept.

AirTag AirTag is a small device no bigger than a coin. The device is designed to be attached to easily lost objects such as keys, wallets, or bags, for example. Using the app, the device

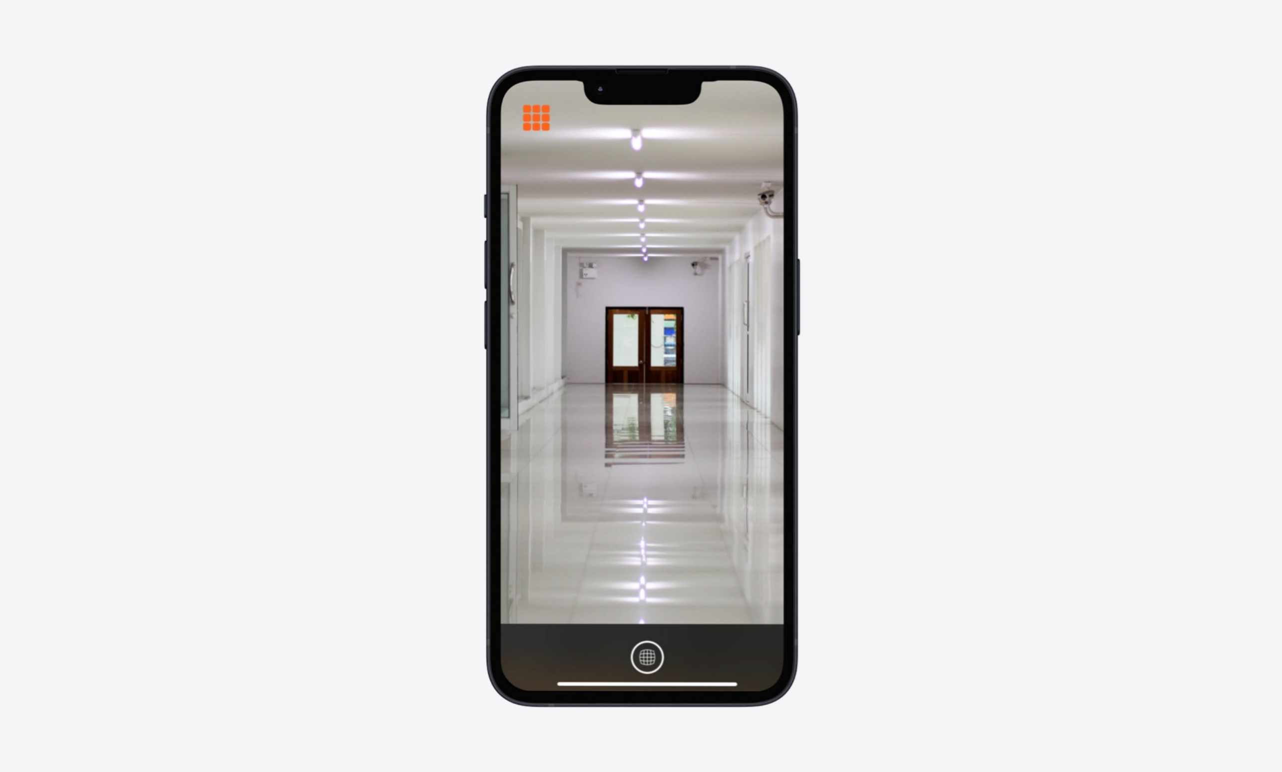


Figure 2.11: SuperLiDAR App. [28]

can precisely compute the distance and relative direction of the AirTag using Ultra-Wideband (UWB) connectivity.

The goal of testing this system is get similar insights as the SBB Inclusive app. However, since the latter can only be used near trains, AirTag proves to be a great remplacement for indoor interviews.

2.4.4 Data Analysis

After each interview, the audio recording was used to improve the notes taken during the interviews to avoid missing any details. Then, we have improved the interview guide for future meetings based on how people answered the questions to incrementally focus the interviews on the subjects that need the most attention.

Once the interviews were completed, it was decided to use the Affinity wall technique to extract data. [30].

Figure 2.12: Find My App [29]

Each participant has attributed a user code to ensure confidentiality. Codes starting with the letter U refers to bling or visually impaired interviewees, while those starting with S refer to SMEs. We have then analyzed each interview note and created concrete and concise affinities notes as:

- A participant quote
- An observation
- Questions
- Interpretations

The result is outlined by figure 2.13, representing the main structure of the resulting affinity wall.

2.4.5 Findings

Assistive technology are hard to adopt

SMEs blinds and visually impaired often expressed concerns about the use of assistive devices.

Acceptance Many interviewees expressed the difficulties of accepting the handicap, especially initially. It is more complicated for people that lost vision in life. Often, as S1, S2, S3, and S6 mentioned, the biggest problem in adopting a white cane is first to acknowledge that patients need one. U7 needed for years before accepting his disability and asking for help. U2 mentioned, "The hardest thing is the look of others. Not being like everyone else. It's not the disability". Despite the handicap acceptance, people are also worried about being unable to use the device properly; as U4 said, "You get judged if you can't use the technology". While a live test of SuperLiDAR, U1 said, "SuperLiDAR could be an approach for people having not accepted the cane, to help them through the acceptance process.".

Price As we have seen in the audit section of this report, the price has been mentioned by 60% of participants as being a problem for testing and adopting new assistive technologies. During subsequent questions, U2 mentioned having not tested a few applications multiple times because it costs around 2CHF each, highlighting that even a tiny amount can be an obstacle. Moreover, U4 seemed afraid of acquiring new hardware devices because he was unsure he would use them long after. U4 and U5 were enthusiasts about the LiDAR demonstration but immediately highlighted that such sensors were only available of higher-end devices, with a negative intonation.

Reliability The unanimity of the participants, including SMEs, highly criticized the reliability of assistive technologies, mentioning problems such as missed obstacle detection, precision issues, bug, or the fear of running out of battery. While testing SuperLiDAR with SMEs and impaired, most participants immediately tested edge cases such as detecting windows or thin items such as table stands. Figure 2.14 illustrates one of the participants testing a window detection.

Training Training is an essential part of the adoption of an assistive device. As U3 describes: "The advantage of the consultation is that people can safely test devices". Nevertheless, most participants also expressed that assistive devices often required much training, which can be time and energy consuming and expensive.

Regarding smartphones, two of our oldest interviewees mentioned that using such devices is not more complicated than using any other tool. U11 said, "If an app makes my life easier, I will certainly learn how to use it; it is not a problem for me". SMEe S2 and S3 also stressed the fact that it is a wrong popular belief that older people are uncomfortable with technology, especially among blind and low vision users.

Need to be concentrated

Sounds Indoor or outdoor sounds play an essential role for blind and visually impaired people, as they use it among other techniques to understand where people are moving (train station, for example), detect openings, and use recognizable sounds such as store music to understand where they are. Of course, sounds are also crucial to detect danger such as vehicles. For example, U11 explained that electric cars are problematic since they emit fewer sounds than internal combustion engines.

When asked about sounds emitted by assistive devices, most respondents answered that it was disturbing and reduced their attention. "Sound feedback influences concentration" (U3), "SuperLiDAR would be better with vibration" (U1). A subject matter expert was more nuanced and indicated, "Haptic feedback is better for people born blind, if not auditory perhaps better" (S6).

Need for one free hand Participants often mentioned that while using a white cane, it is important to have the second hand available, thus making smartphone use problematic. They often use the second hand to detect obstacles or touch surfaces to follow, such as tables and walls. Moreover, it is vital to use this hand in case of a fall. An illustration of this problem is the use of audio GPS. In our observations, U4 tried to set his smartphone inside his pocket horizontally while using the audio GPS. The app would function normally since the compass needs to be horizontal, and he would have a free hand. It is without saying that the phone sometimes moves around and thus becomes imprecise by doing so. Feedback from U7, U10, U11 regarding the SBB Inclusive application to find train doors goes in the same directing.

Notion of Space

The white cane is only helpful to discover the immediate environment People with vision use their sight to orient themselves and find their destinations. Naturally, this is something that is impossible for blind and some visually impaired people. The only tool they have at their disposal is their white cane to explore the immediate environment around them. The white can not only detect obstacles in front of them but, as U4, also taps the cane on the floor to get additional information using the sound reflected by surrounding objects. That way U4, like many others, can get a bit of extra information and understand how the environment is constructed a bit further. U8 also used it to test some surfaces, such as starts or lift openings. However, even with those techniques, those people often have a diminished notion of spaces, as S6 and S1 highlighted. Professionals will try to work those notions with the help of exercises.

Audio GPS are helpful About 30% of the interviewees use some guiding device using sound. The most popular one is MyWay Pro, an app developed by the Swiss Federation of Blinds. Such applications can be helpful to set waypoints and avoid being lost. Moreover, it can help people get oriented and on the right track if they lose orientation. However, it is infrequent for blind people to use it to navigate to unknown places, as only one of the interviewees would do it. "You won't see many of us doing that" (U4).

We have found that the central problem of using GPS in an unknown place is the lack of precision of such devices. GPS only allows for 10-20 meters of accuracy in the best condition, insufficient.

2.4.6 Unable to see Text and Objects

Loss of Objects We have explored the notion of object losses during the interview, having the hypothesis that losing objects would represent a significant challenge. We have discovered that while losing objects happens is not uncommon, it does seem to be a major problem and happens relatively infrequently. Blinds and in a smaller proportion visually impaired must be highly organized and always place objects at their intended place. It is the only way to avoid spending our searching for objects. Moreover, other people are advised not to move any objects if visiting a blind or visually impaired person. We have observed that children are trained to be highly organized during observations in a specialized school. For example, children must place them under the chair when removing their shoes. However, with young children, they might place them elsewhere by inadvertence. Nevertheless, instead of placing the shoes back at the correct place, workers let them where they are even if children might spend much time finding them. "They do it once or twice and will never do it again" (S4). Moreover, losing objects also highlights the importance of listening to surrounding sounds; as per U4 "When we make something fall, we listen where it falls with attention".

When asked about what objects they lose the most, many mentioned glasses, bottle caps, TV control. However, U4 and U5 gave many examples of tools helping find objects by making sounds (e.g. AirTag).

Desire of Independence Most participants expressed their desire to be independent and avoid relying on other people for help. It is especially the case for people who have lost vision recently. For example, "I will often avoid doing something if I think I will need the help of somebody" (U7). Or "I think I already ask too much to my family, and I will try to do everything I can to avoid asking for help, even if it takes three hours." (U2). We also noticed negative emotions while speaking about autonomy, mainly for people who have lost vision a few years ago. U2, U4, U7, U9 gave examples of especially humiliating situations where they would get judged by asking for help, further reducing their willingness to ask for assistance in the future.

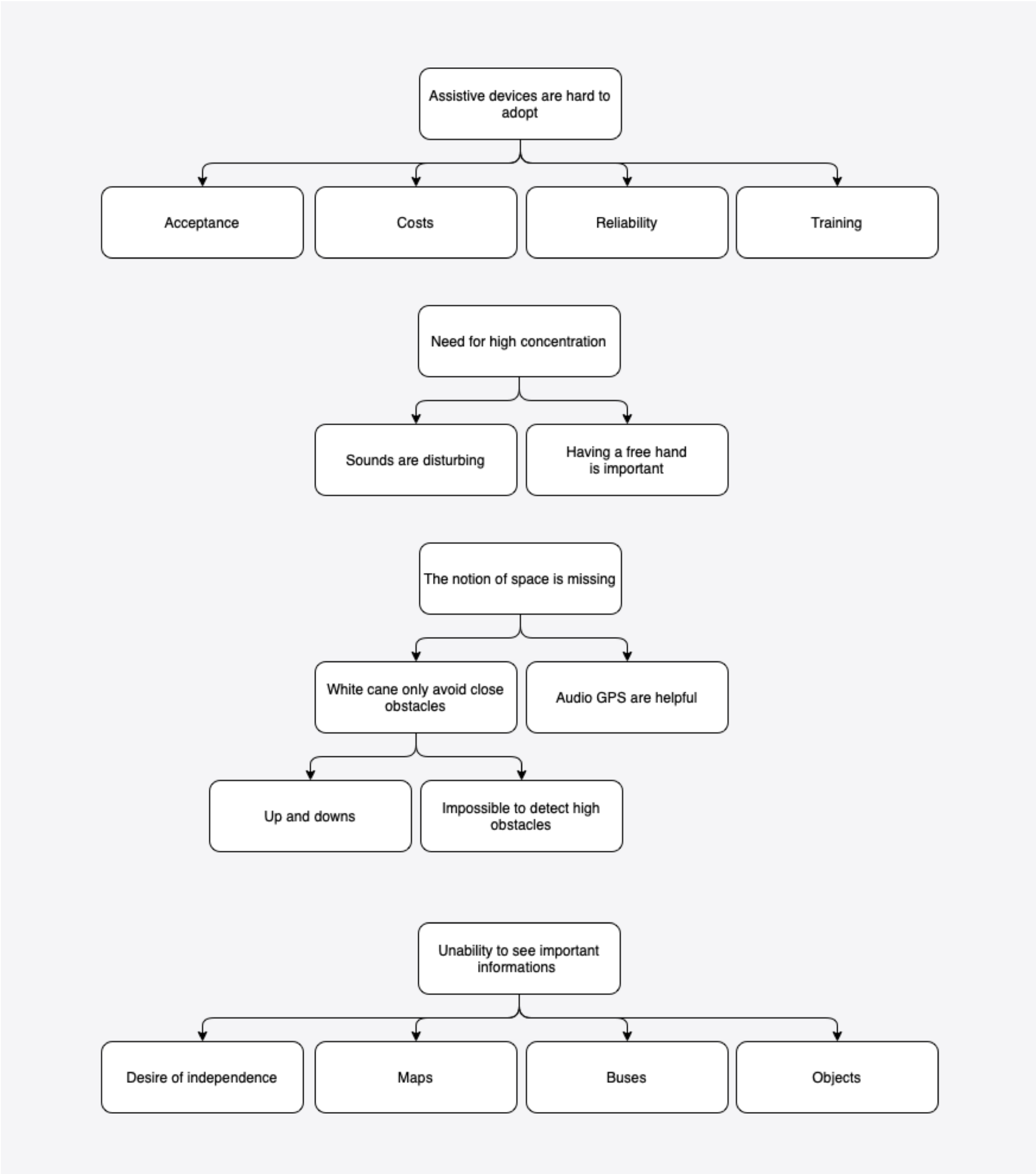


Figure 2.13: Main structure of the affinity wall.

Figure 2.14: Photography taken during observations at a specialised centre for blinds and visually impaired.

Chapter 3

Modeling

Due to the limited two-month time constraint, the limited human resources to conduct interviews, and the ill-defined nature of the initial problem, we would need to conduct more interviews to create state-of-art personas. However, based on the literature, competitive audits, SMEs, and users interviews, we can create provisional personas that will still be helpful in the process of designing the product.

3.1 Primary Provisional Persona

Philip (Figure 3.1), 32 years old, has always lived an active life. He enjoys traveling, meeting friends, and discovering new things. Unfortunately, he suddenly lost vision abruptly four years ago and has now completely lost vision. His employer was willing to support him through this life-changing event, and he was able to continue working part-time.

He had a hard time accepting his conditions and seeking help and support from professionals as he would consider not being able to do things by himself as being weak.

With time, he finally adopted a white cane to help him and learned three itineraries. From home to work, home to a supermarket, and home to the lake. Also, he learned to use smartphones and computers with a screen reader himself but learning braille is still a challenging task for

Figure 3.1: Collage representing our primary provisional persona

him.

However, Philip is reluctant to learn new itineraries, especially those he might only use a few times per year. He is not willing to ask for help and does not want to disturb his professionals. Moreover, he ended up forgetting what he learned if not regularly practicing in the past.

Philip thinks he has already asked a lot to his family and is reluctant to ask them for help. As a result, he lost confidence in those infrequent itineraries, would not ask for help, and has now decided to stay home most of the time, making him sad about his past active life.

3.2 Secondary Provisional Persona

Nadia (Figure 3.2), 30 years old, is a locomotion expert, passionate about helping her patients gain autonomy and confidence. She is a definite believer that the best care is personalized care, meaning that she will always look for the most appropriate training techniques to help blind and visually impaired people.

Figure 3.2: Collage representing our secondary provisional persona

Nadia goes on the field beforehand and documents the environment to coach her patients learning itineraries. Then, having constituted a report, she will make the first itinerary by guiding her patient along the way while helping him find markers and memorize them.

In specific cases, she will also use LEGO® or magnetic boards to represent roads and the surrounding environment of specific areas. During her session, she will work with her patients to build those maps and apprehend the space without going outside.

However, she also has to think about time and budget; naturally, her organization cannot spend an infinite amount of time for each patient. Thus, she is willing to try new things, as long as she will not increase her workload much.

Chapter 4

Requirements Definition

4.1 Problem and Vision Statement

Problem Statement Combining loss of vision and a white cane which only helps explore the immediate environment, blind and low vision people have a hard time apprehending the notion of space. For each new itinerary, one has to learn it by heart which, when not regularly trained, will result in loss of confidence to getting lost. Moreover, learning such itineraries requires external help and proves to be a barrier for some. Lastly, current assistive devices have a low adoption rate due to high price, reliability issues, training needs, and cognitive overload. As a result, many blind and low-vision people will become isolated and go out less often.

Vision Statement A new app, HapticMap, will allow gaining autonomy and confidence by helping blind and low vision people remember itineraries from the comfort of their home or as a supporting tool while outside.

4.2 Context Scenarios

4.2.1 Scenario One

Based on our provisional persona, Philip, and his retrieved motivations, needs, and goals, this scenario represents the most frequent use case.

1. Philip wants to learn a new itinerary from home to a new café that has just opened a few blocks away. He now has an appointment with Nadia, who will help him learn his itinerary.

2. Nadia uses a physical board to represent a complex intersection containing stairs, shops, roads, crosswalks, and a central pedestrian place. Philip then uses his hand to feel the place and understand the environment and collaborates with Nadia to improve his preferences.

3. Once the two of them are comfortable with the constructed map, Nadia quickly creates a digital version of the map on her computer.

4. The process is repeated for important aspects of the itinerary, resulting in a few digital maps being created. Nadia now sends to maps to Philips, and the consultation is over.

5. Philip comes home and opens HapticMap to return to the maps they have created. He spends long hours trying to memorize the place and become comfortable with it over the next few days.

6. After a few weeks and multiple consultations with Nadia, Philip has successfully learned this new itinerary and can now do it independently.

7. Since he only makes this itinerary a few times a year, Philip is confident he can remember it by using HapticMap a few times at home.

4.2.2 Scenario Two

1. Philip is on his way to the lake to enjoy the fresh air, an itinerary he has not done since last summer.

2. Everything is going well until he approaches road works on the sidewalk he normally used. Philip is a bit worried about getting lost as he does not remember well if the is a second sidewall on the other side of the road and how to cross.

3. Philip stops, opens HapticMap, and reads the map previously created by Nadia. He discovers that an opposite sidewalk effectively exists and locate the pedestrian crossing to get there safely.

4. Philip closes the app finds the pedestrian crossing and proceeds to his destination.

4.2.3 Scenario Three

1. Philip needs to go to the city hall to get some documents located along the train line he uses the most. However, he never went there and only knows that the train station is near it.

2. Since he does not want his family or friends to spend hours driving him there, he asks his wife to make a simple digital map of the place so he can understand how to get there.

3. His friends use a simple drawing tool to design the map and send it by message.

4. Philip opens the file from messages in HapticMap, spends a few minutes reading the map, and can now understand the surroundings of the train station and the location of the city hall just around the corner.

5. Philip goes to the station and opens HapticMap again to remember the map.

6. After closing the app and putting his phone inside his pocket, Philips goes in the correct direction and finds the city hall asking only one person at the destination.

4.2.4 Scenario Four

1. Philip has stored a map to get to the city hall from the train station, and one of his blind friends needs to go there.

2. Philips opens HapticMap and shares the map to his friends instantly.

3. His friends has now access to the map and will explore it at home.

4.2.5 Scenario Five

1. Philip finds that maps are too small on his smartphone and want to use his tablet.

2. Philips downloads HapticMap on the tablet, and all his itineraries are already synced.

3. He can now use both hands and understand the maps better and more comfortably.

4.3 Design Requirements

- Open a digital map directly from messaging applications
- Have a set of itineraries by name
- Each itinerary consists of several ordered maps
- Ability to read a map using other means than vision
- The app should give information about roads pedestrian crossings with or without lights highlight itineraries and destinations.
- Maps and itineraries should be shareable via messaging applications
- Maps and itineraries should be synced across devices
- Maps should be easily created by any person to remove any barriers to creating maps

Chapter 5

Design Framework

See Appendix C for all wireframes.

5.1 Key Path Scenarios

We have constructed a set of main key path scenarios using our initial context scenarios. Note that we describe interactions using the usual vocabulary such as *touch*, *scroll*, or *long-press* for clarity purposes. Philip, our primary persona, would use the interface using a screen reader, VoiceOver on iPhone, as further described in Chapter 6.1. The philosophy of VoiceOver is that the interface remains identical for both users with or without vision and thus allows us to use the same vocabulary.

5.1.1 Key Path Scenario 1

1. Philips receives a HapticMap file representing an itinerary containing a list of maps.

2. Touching the file opens the HapticMap application and saves the itinerary in his list of itineraries.

3. Touching the newly added itinerary opens the list of maps contained inside.

4. Maps are ordered by position in the itinerary.

5. Touching an itinerary opens the map in full screen.

6. Philip can move his finger on the screen and feel the map. The phone sends specific vibrations and sounds depending on the type of object under the finger.

Figure 5.1 illustrates this scenario.

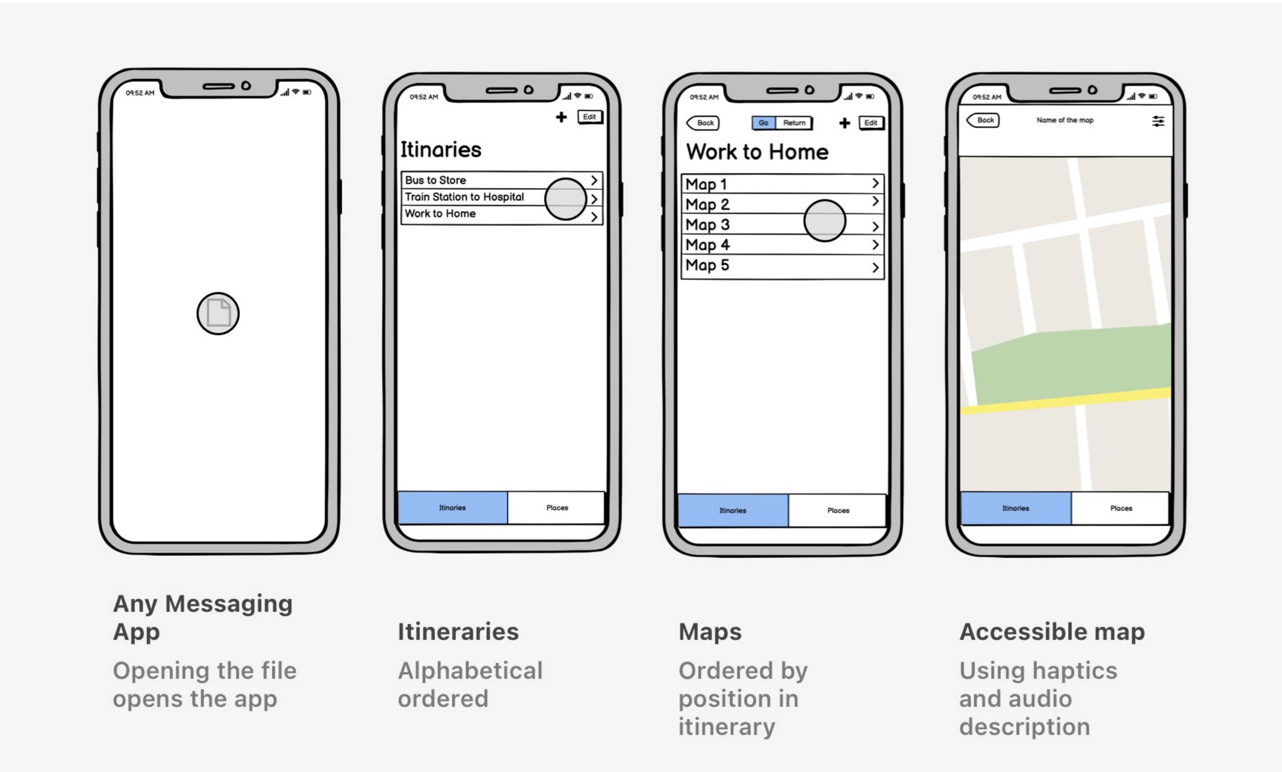


Figure 5.1: Storyboard for scenario 1

5.1.2 Key Path Scenario 2

1. Philips touch the add button to create a new map.

2. A modal sheets appear, inviting him to give a name to the itinerary. He can use the standard keyboard, voice recognition, or braille keyboard.

3. By touching *next*, he is invited to upload a map file. The file can be any image using standard extensions.

4. The name of the map is automatically deduced from the file's name, but he can override the name.

5. Touching *done* saves the map and opens back the list of itineraries.

Figure 5.2 illustrates this scenario.

Figure 5.2: Storyboard for scenario 2

5.1.3 Key Path Scenario 3

1. Philips wants to share the map with his friends. He uses a long-press gesture to open a contextual menu containing options on the itinerary. He could also use the *edit* button as it is a common pattern for many other apps he used.

2. Philips chooses to share the itinerary.

3. The default iOS share sheet opens, and Philip can send the map through any apps or AirDrop.

Figure 5.3 illustrates this scenario.

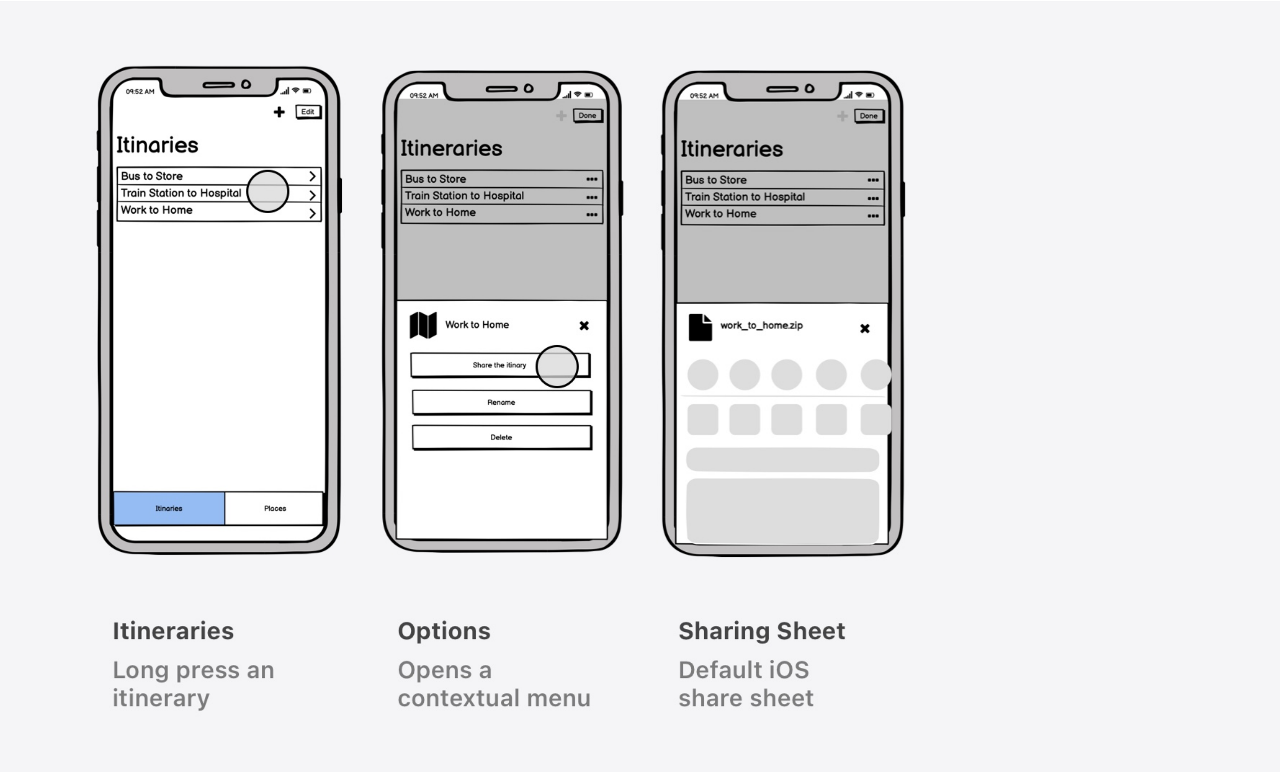


Figure 5.3: Storyboard for scenario 3

5.1.4 Key Path Scenario 4

1. Philips touches the *Edit* button or uses a long press on one of the itineraries.
2. A list of options appears and chooses *Delete*.
3. The app asks for confirmations; the itinerary is deleted on the device and synchronized with the cloud.

Figure 5.4 illustrates this scenario.

5.2 Interaction with Maps

The user interactions with maps are an essential part of the application. During the user observations, we were inspired by physical, 3D maps. Such maps are illustrated in figure 5.5

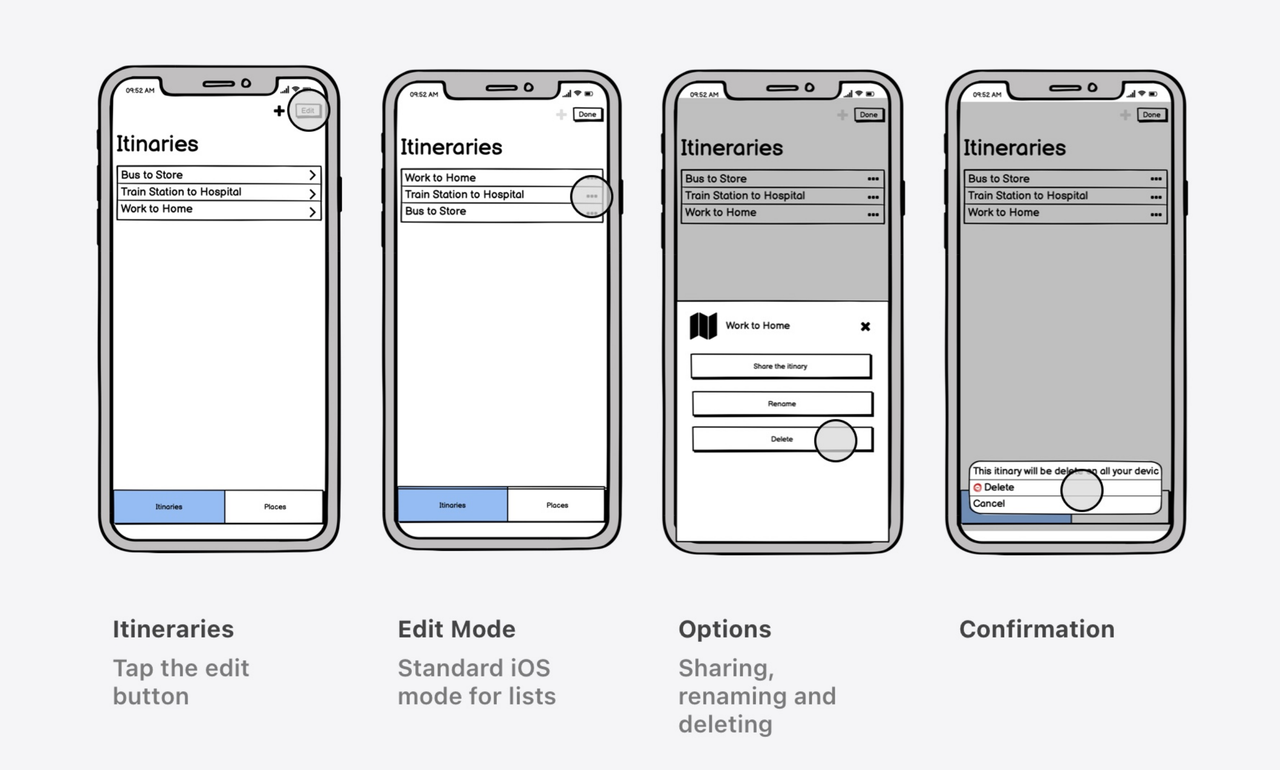


Figure 5.4: Storyboard for scenario

and 5.6. Such maps are expensive, big, and impossible to carry with while walking.

Moreover, we have observed a promising direction using haptic to display shapes on a screen. A study conducted with fourteen adults with low vision or blindness had the following hypothesis:

> Here, we reasoned that visually-impaired and blind participants can create mental representations of letters presented haptically in normal and mirror-reversed form without the use of any visual information, and mentally manipulate such representations. [31]

The results are promising, with the researchers stating:

> Our findings demonstrate, for the first time, the suitability of a digital haptic technology in the blind and visually impaired. Classic devices remain limited in their accessibility and in the flexibility of their applications. We show that mental representations can be generated and manipulated using digital haptic technology. This

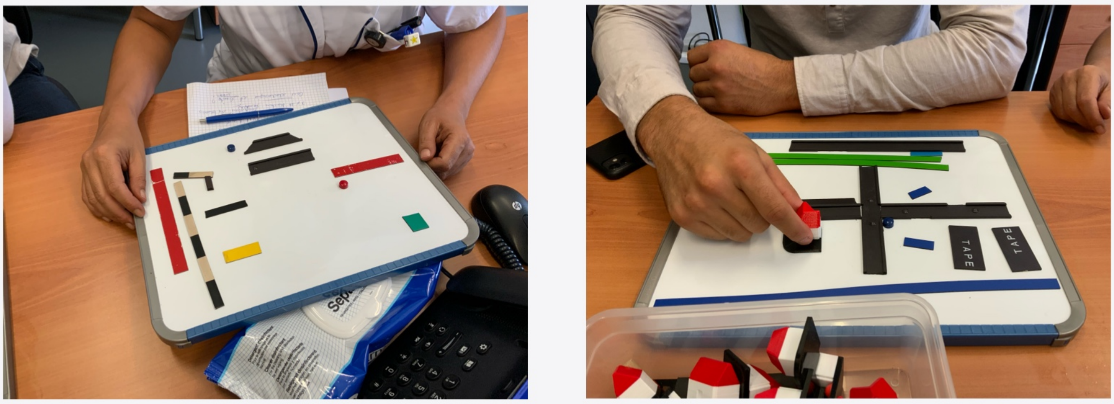


Figure 5.5: Photographs taken during interviews.

> technology may thus offer an innovative solution to the mitigation of impairments in the visually-impaired, and to the training of skills dependent on mental representations and their spatial manipulation. [31]

We decided to pursue this direction and experiment with haptic maps. Thus, the map interface (Figure 5.1) would entirely rely on vibrations. Depending on the type of element under the user's finger, we would create precise and distinctive vibrations using the iPhone Taptic Engine, illustrated in figure 5.7. Suing this hardware allows us to precisely set the sharpness of vibrations as well as the intensity. Moreover, we can also play patterns of vibrations, making them even more distinctive (Figure 5.8). Photo 5.9 illustrates a user interacting with a map, with one hand holding the device in order to feel the vibrations and the other exploring the map.

The interaction permits the use of the app without sounds. However, in order to accommodate new users, we will also add sounds and audio descriptions in addition to vibrations. Also, devices not equipped with Taptic Engines would feature an audio-only mode, playing different frequencies depending on the element under the finger.

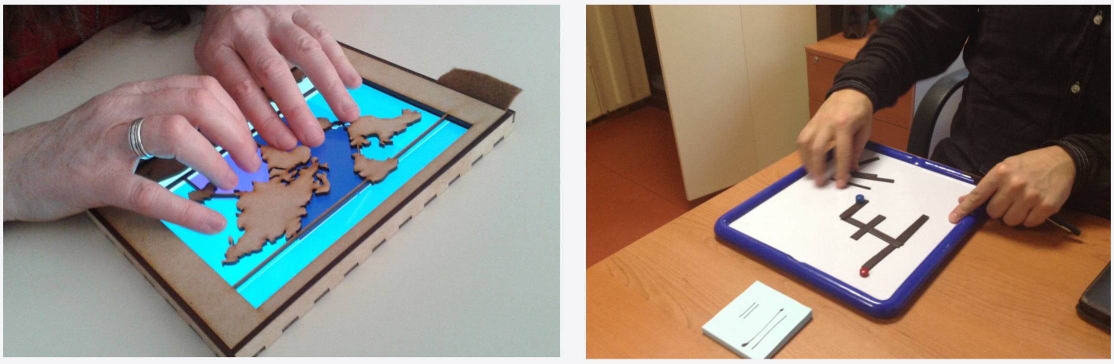


Figure 5.6: Inspirations from other projects [32]

As a direct consequence of our design requirements, users should be able to create maps easily and rapidly. We found a simple solution without the need to design and implement software specifically for maps creations. Maps would be static images, using shapes and specific colors to describe elements (Figure 5.10). By doing so, users can use any software they like to create those maps and send them as images. The app would then interpret the colors and give the appropriate feedback.

5.3 Final Design

The interface will mainly be used by people with disabilities, often having no vision. Therefore, we chose to implement the most familiar and straightforward interface to simplify the use integrated screen reader. Apple's SDK comes with a standard user interface for lists, buttons, and other basic controls. Those interface elements are already tailored for VoiceOver and other accessibility features described in the subsequent chapters. We decided to implement this interface directly and save time designing high-fidelity prototypes.

Figure 5.7: Apple Taptic Engine

Figure 5.8: Apple Taptic Engine Sharpness and Intensity

Figure 5.9: Example of Interaction with the App.

Figure 5.10: Colors Used to Representing Maps.

Chapter 6

Implementation

The resulting software should be extremely reliable as a direct consequence of the design implications. Visually impaired and blind users have a harder time recovering from errors or unexpected app behavior. Therefore, we defined the following goals before starting the coding part of the project:

- The code should be easily testable.
- The app should be translated in English and French while other languages should be easily integrable in the future.
- The app should be fully accessible with VoiceOver.
- The app should adapt to accessibility settings such as dynamic fonts, font types, contrast settings.
- The code should be unit and UI tested as long as it does not disproportionately slow the development. (Remember that the project was initially intended as a proof of concept, and stakeholders preferred features over tests.)

6.1 VoiceOver

VoiceOver is Apple own screen reader technology. As per their own definition:

> With VoiceOver—a gesture-based screen reader—you can use iPhone even if you can't see the screen. VoiceOver gives audible descriptions of what's on your screen—from battery level, to who's calling, to which app your finger is on. You can also adjust the speaking rate and pitch to suit your needs.
>
> When you touch the screen or drag your finger over it, VoiceOver speaks the name of the item your finger is on, including icons and text. To interact with the item, such as a button or link, or to navigate to another item, use VoiceOver gestures].
>
> When you go to a new screen, VoiceOver plays a sound, then selects and speaks the name of the first item on the screen (typically in the top-left corner). VoiceOver tells you when the display changes to landscape or portrait orientation, when the screen becomes dimmed or locked, and what's active on the Lock Screen when you wake iPhone. [33]

Figure 6.1 illustrates a few gestures available with VoiceOver.

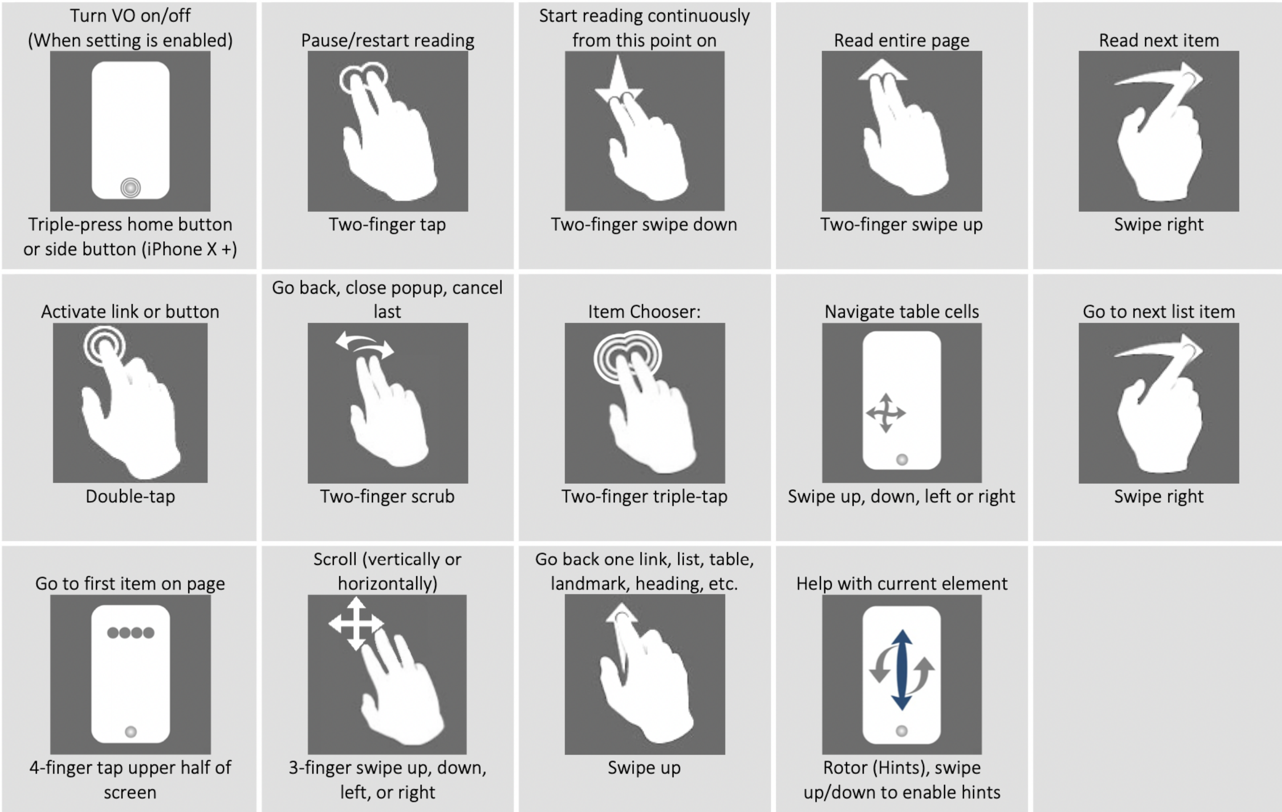


Figure 6.1: Examples of VoiceOver gestures [34]

Using this powerful tool, users who cannot see the screen can use most of the features of iPhones or iPads. However, a certain amount of work is required from developers in order to provide great accessibility. More specifically, VoiceOver works well when using native iOS elements such as native buttons, text fields, containers, or lists, but additional work is often required when designing complex interfaces. A great example of this is the illustration in figure 6.2.

Rating stars are a common interface among many apps but pose significant problems when using VoiceOver. As a result, VoiceOver might read "image - image - image - image - image" which is not helpful to the user. To fix this, the developer must indicate to VoiceOver that the five stars are a single control element and define actions that can be used on it, such as:

- Add a star
- Remove a star
- Read the value

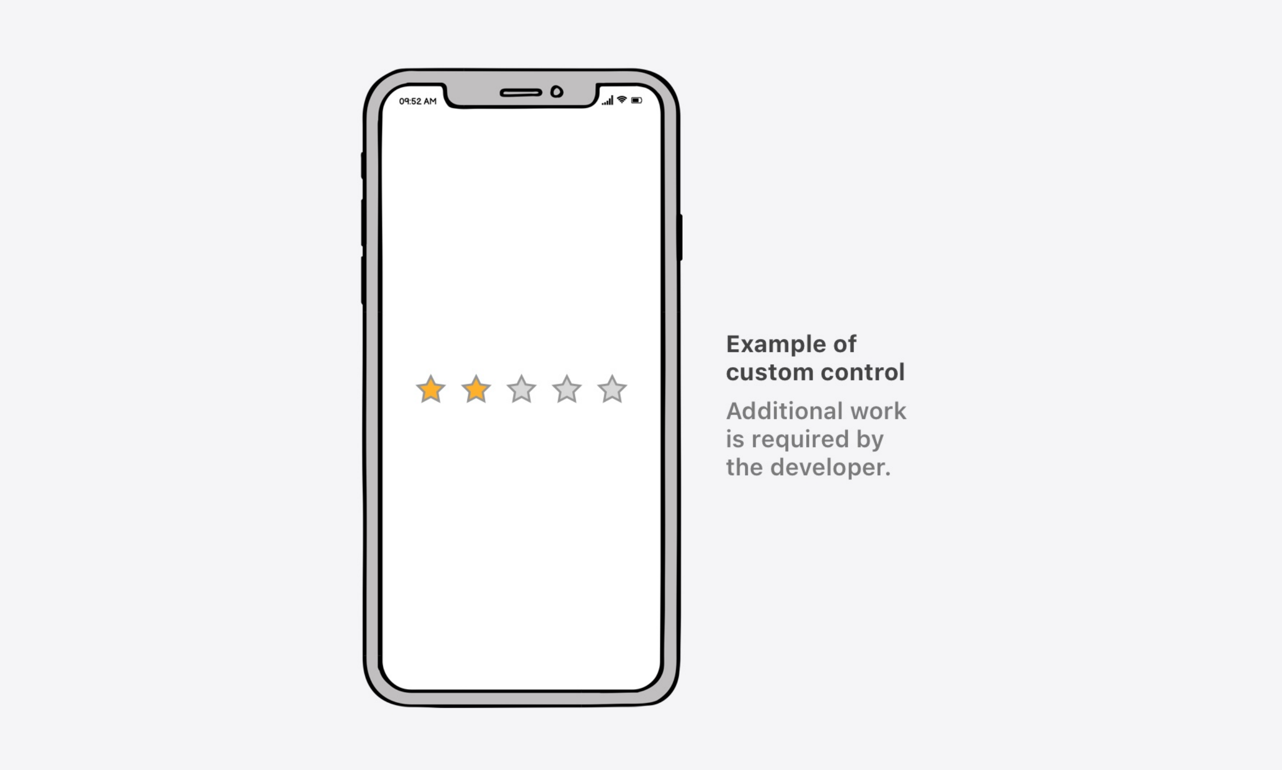


Figure 6.2: Example of a custom control found on many applications.

In code, this would translate as:

```
SomeView()
// Indicates that the stars represents a single control
.accessibilityElement(children: .ignore)
// Sets the title that should be read to the user
.accessibility(label: Text(title))
// Sets the current value that should be read to the user
.accessibility(value: Text(ratingString))
// Declares an adjustable actions to interact with the control
.accessibilityAdjustableAction() { direction in
        guard let rating = self.rating else {
                return
        }
        if direction == .increment {
                self.rating = min(rating + 1, 5)
```

```
        } else if direction == .decrement {
                self.rating = max(rating - 1, 0)
        }
}
```

As we can see, this required some code and particular attention and highlighted the importance of including accessibility from the start. Doing it later will prove practically infeasible in a business environment and often result in a mediocre result. Embracing accessibility from the start also improves the testability of the code with automated tests as it relies on accessibility features to function. Moreover, in UX terms, an interface that would be hard to use for a disabled user has great chances of being unclear to other users.

In the design requirements part of the project, we have tried to minimize the number of such custom controls and instead relied as much as possible on native controls.

6.2 Accessibility Features

Low vision or blind individuals rely on VoiceOver to use an iPhone. However, some low-vision users also use other instruments, such as extra-large texts or greater contrast. To satisfy such users, the developer has to, as with VoiceOver, include it from the start.

6.2.1 Dynamic Fonts

Fonts are one of the most crucial aspects of an accessible interface. Unfortunately, age is a synonym for having difficulties reading small font sizes. Apple's solution is called Dynamic Type and allows users to define their preferred font size for every app [35]. However, this requires the developer to use such special fonts, but many keep setting a fixed font size.

In the case of HapticMap, we have embraced Dynamic Types everywhere so that the operating system can take advantage of them. Figure 6.3 illustrates the result of using those.

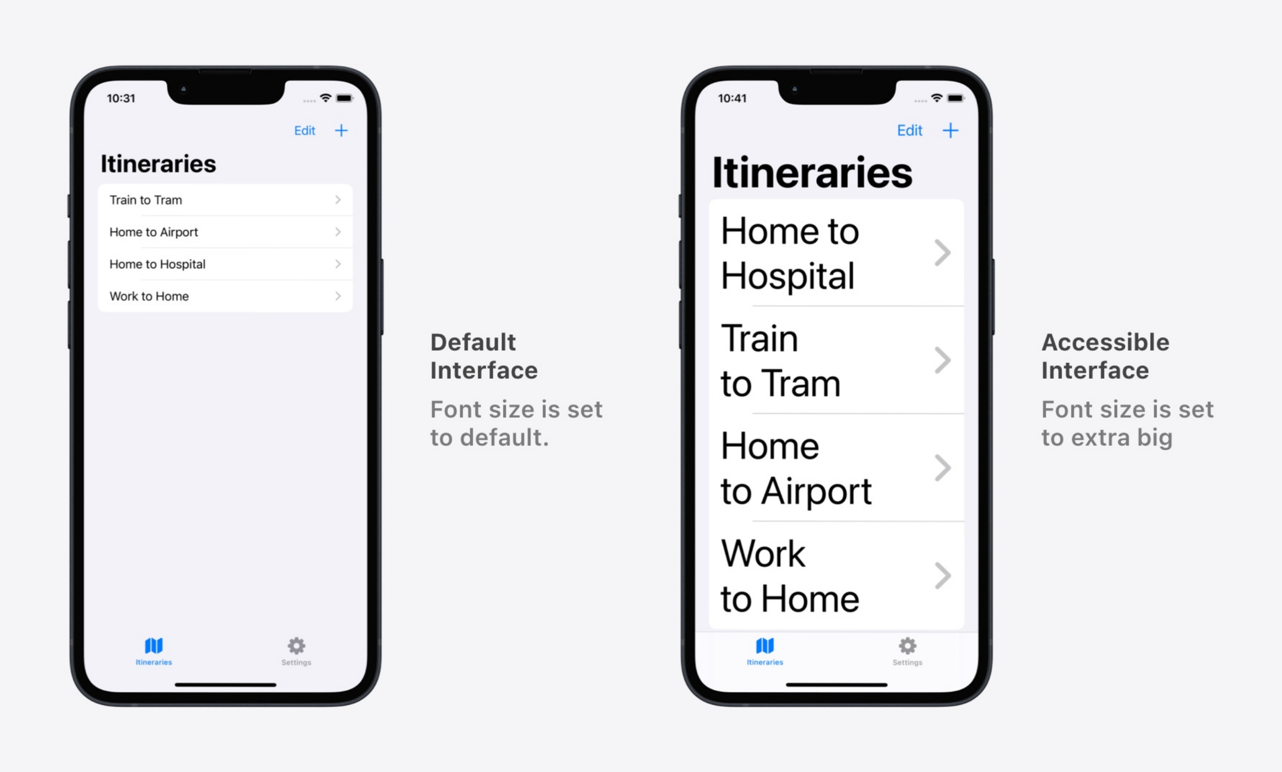


Figure 6.3: Illustration of the effect of increased font size.

In addition to the size, Dynamic Types can also become heavier. Figure 6.4 illustrates the result.

6.2.2 Contrast

An equally important notion of accessibility is contrast. Like fonts, colors require special attention from developers to respond to user requests to increase contrasts.

In the case of HapticMap, the result illustrated in figure 6.5 are subtle but improve usability for visually impaired users. Pay attention to the bottom bar buttons and arrows on the list.

If the user wants to go a step further, using a dark mode can be a valuable tool. Consequently, developers and designers have to create an alternative color palette specifically crafted for this setting. Figure 6.6 illustrates this alternative version.

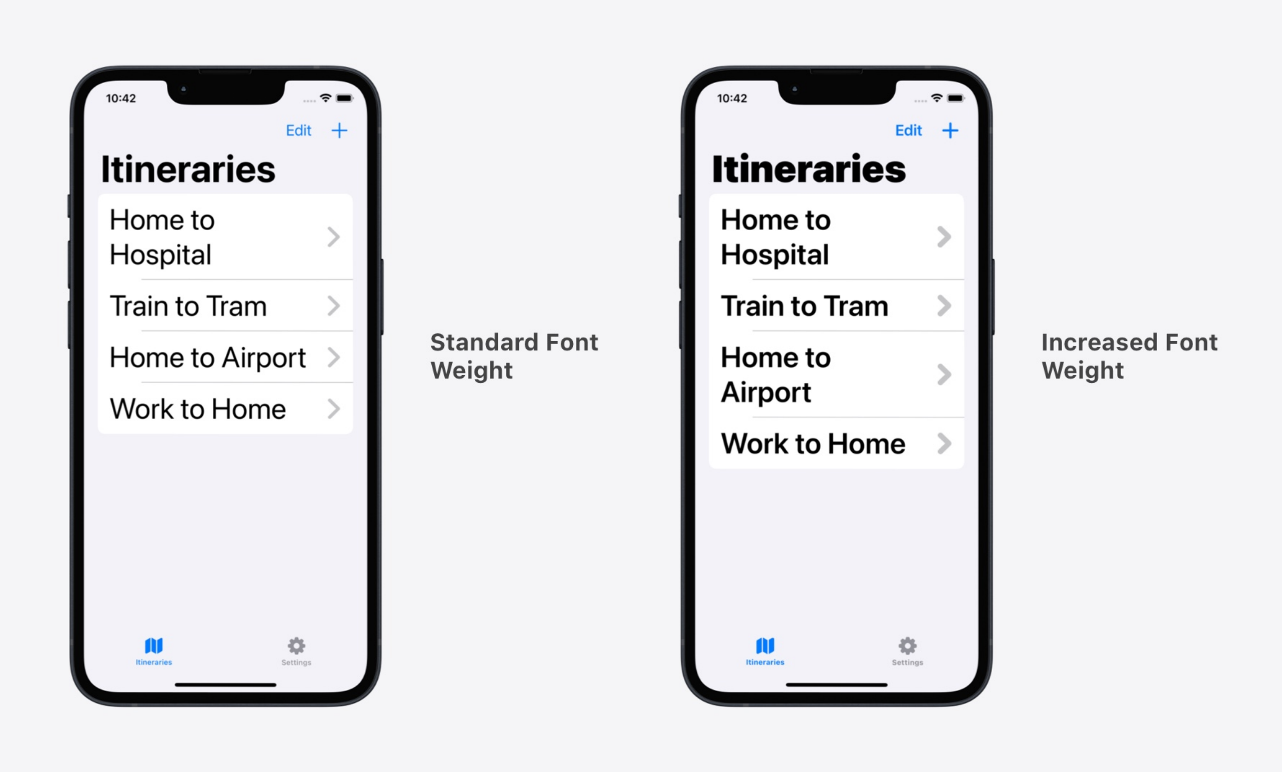


Figure 6.4: Illustration of the effect of increased font weight.

6.2.3 Button Shapes

Modern UIs often intentionally omits buttons shapes or border to create a lighter and clearer interface. While this can be esthetically pleasing to many users, it can reduce accessibility and make it hard to discern buttons from texts or even see them all together. An accessibility setting allows users to display button shapes clearer. However, as with the other accessibility features, developers have to pay special attention to those while designing the interface. See figure 6.7 for results.

6.3 Language and SDK Choice

Software developers often have two options when starting a new project. Either go native, resulting in having to code two different apps for Android or iOS, or go cross-platform with the benefit of having a lot of shared code between the two.

We decided to go fully native using Apple's SwiftUI language. Reasons for that are:

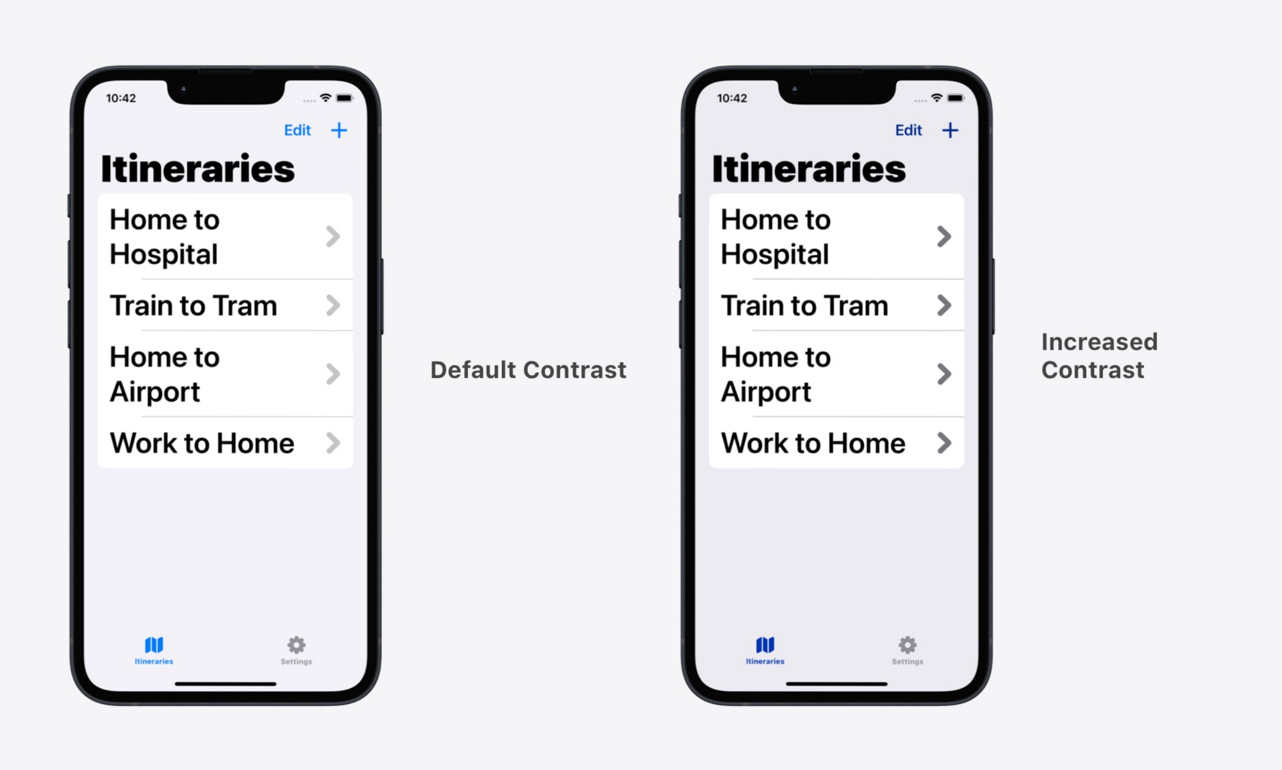


Figure 6.5: Illustration of the effect of increased contrast.

- Quicker development time
- Easier for providing state-of-the-art accessibility.
- Familiar UI and design language with SwiftUI.

6.3.1 Previews

Following those good accessibility practices requires little effort if implemented from the start. However, as projects become bigger and bigger, how can one know the interface is still correctly displayed in those different configurations? For example, how can one know that if the font size is set to extra large, that the texts will not be truncated?

A benefit of using SwiftUI is SwiftUI Previews, integrated into the IDE [1]. In short, this allows developers to display previews devices while specifying different settings such as the device type, orientation, language, and in our case, accessibility features. In chapter "code structure",

[1]Integrated Development Environment

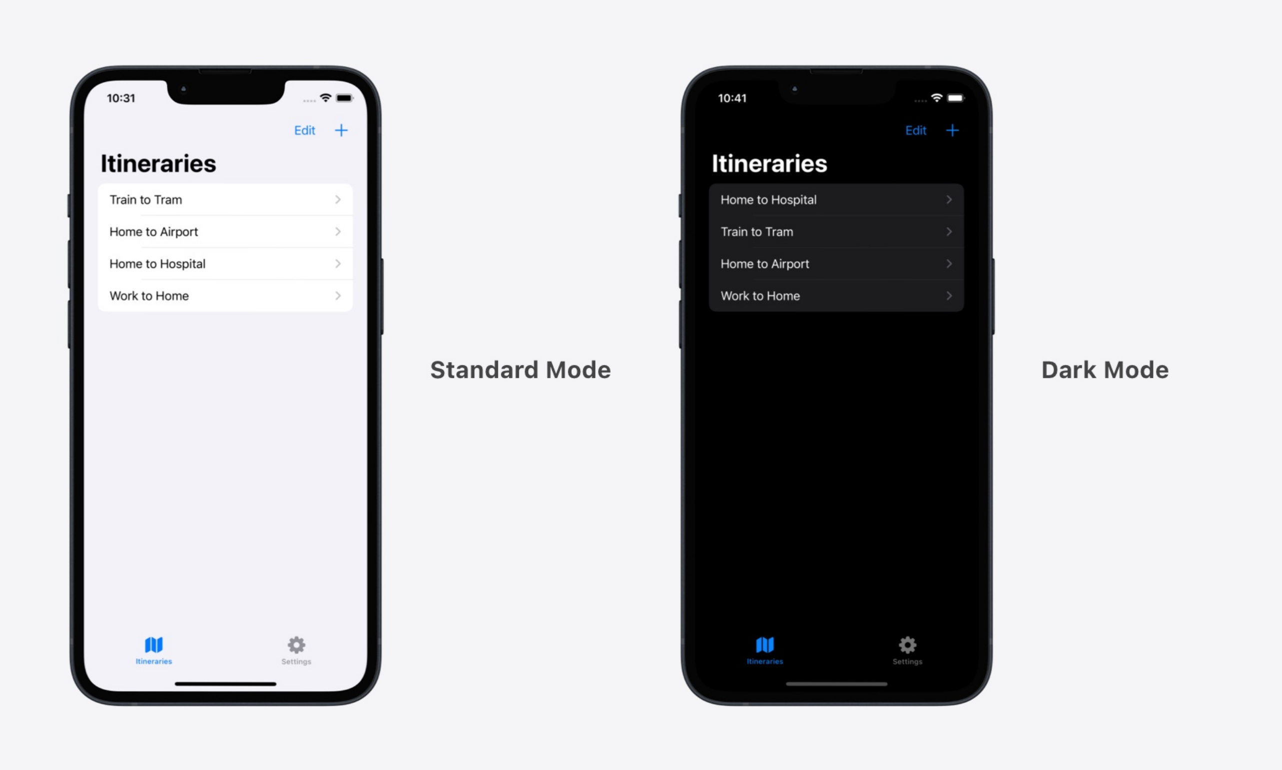


Figure 6.6: Illustration of dark mode.

we will see that by using specific patterns, such previews are easily mocked and thus can display different states.

As a result, interfaces can be quickly checked and improved if needed without running the application on a simulator for each configuration, inducing improved development speed and quality.

6.4 Code Structure

SwiftUI is a new, powerful SDK to build iOS applications, dramatically reducing the amount of code needed compared to legacy methods such as UIKit. The downside is that it comes with no code architecture good practices. It is up to the developer to adopt its own architecture suited for their needs.

We noted the importance of having SwiftUI Previews as mentioned in chapter 6.3.1. However, code needs to be adequately organized and separated to display such previews. Moreover, as a

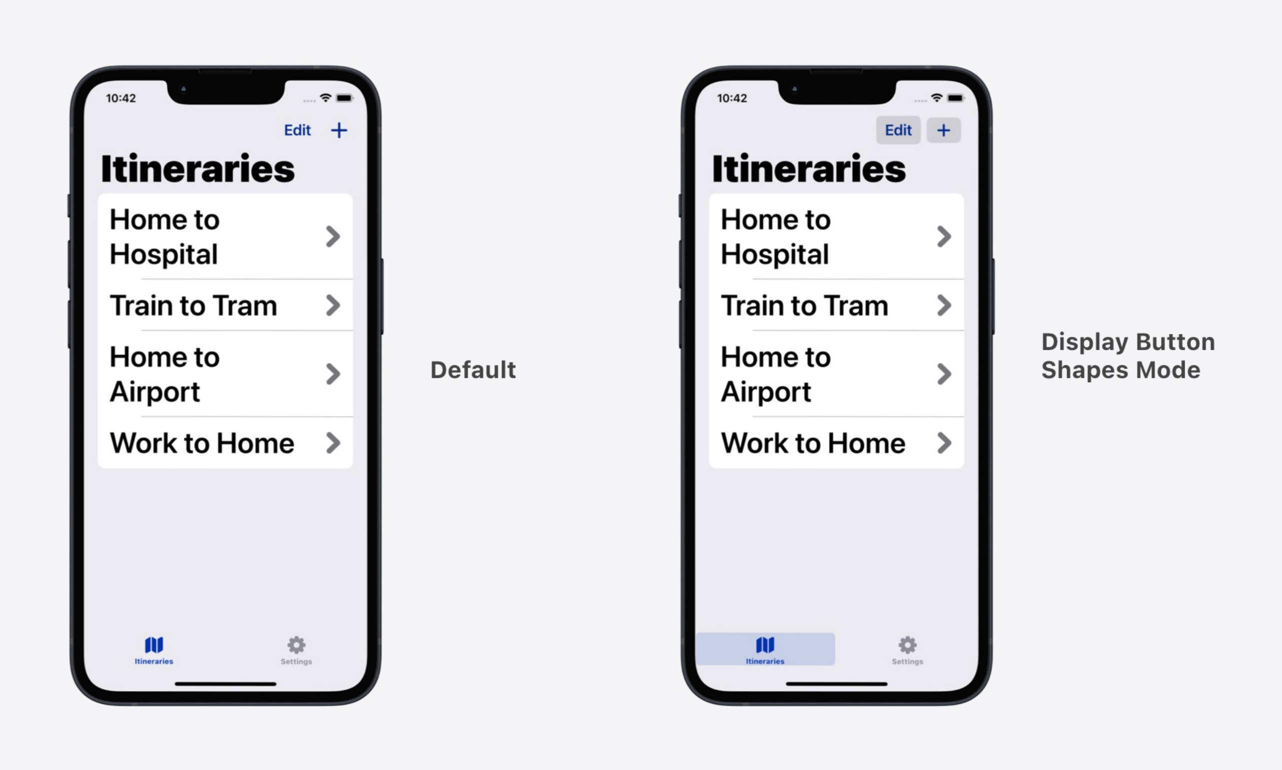


Figure 6.7: Illustration of button shapes

direct design requirement, the app should be highly reliable.

To address those challenges, we have decided to implement the *Model View ViewModel* or *MVVM* pattern, a technique beautifully described by the AppBakery Team [36]. By doing so, Models, Views, and ViewModels would be wholly separated and easily testable on their own. Also, we will then be able to mock some parts of the interface to test the maximum number of scenarios possible.

6.4.1 Views

Views are fully written using the Apple SwiftUI framework, allowing for a declarative approach for building UIs. This section of the code will be responsible for the interface layout, accessibility features, and receiving user input. However, the logic of the interface and different states are fully handled by the ViewModels classes described in section 6.4.2.

Moreover, to speed up the development process, we would live to fully use the capabilities of

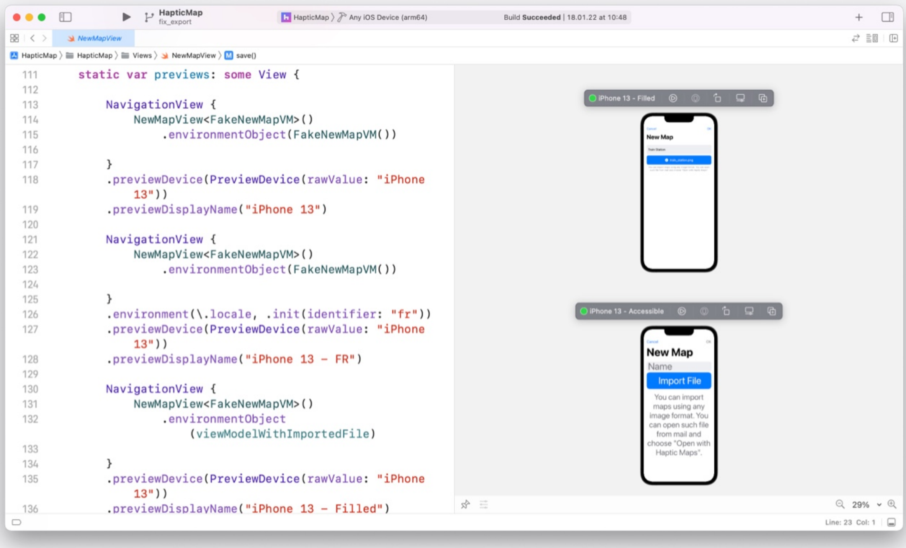


Figure 6.8: Example of SwiftUI Live Previews

SwiftUI previews, directly displayed next to the code. The value of such reviews is to directly test multiple states of the software and ensure that the interface is adapted in every case, even corner cases.

Therefore, our *Views* needs to accept two types of ViewModels. The real implementation that is shipped with the app and fake view models, faking some interface state. To do so, we create a *Protocol* for each *ViewModel*, describing the interface such classes should have. Here is an example of such protocols for the list of itineraries in action:

```
/// ItinariesView ViewModel Protocol.
protocol ItinariesVMProtocol: ObservableObject {

    // MARK: - Variables

    /// The selected itinerary used to present a `ActivityView`
    /// or `UIActivityViewController` instance for sharing purposes.
```

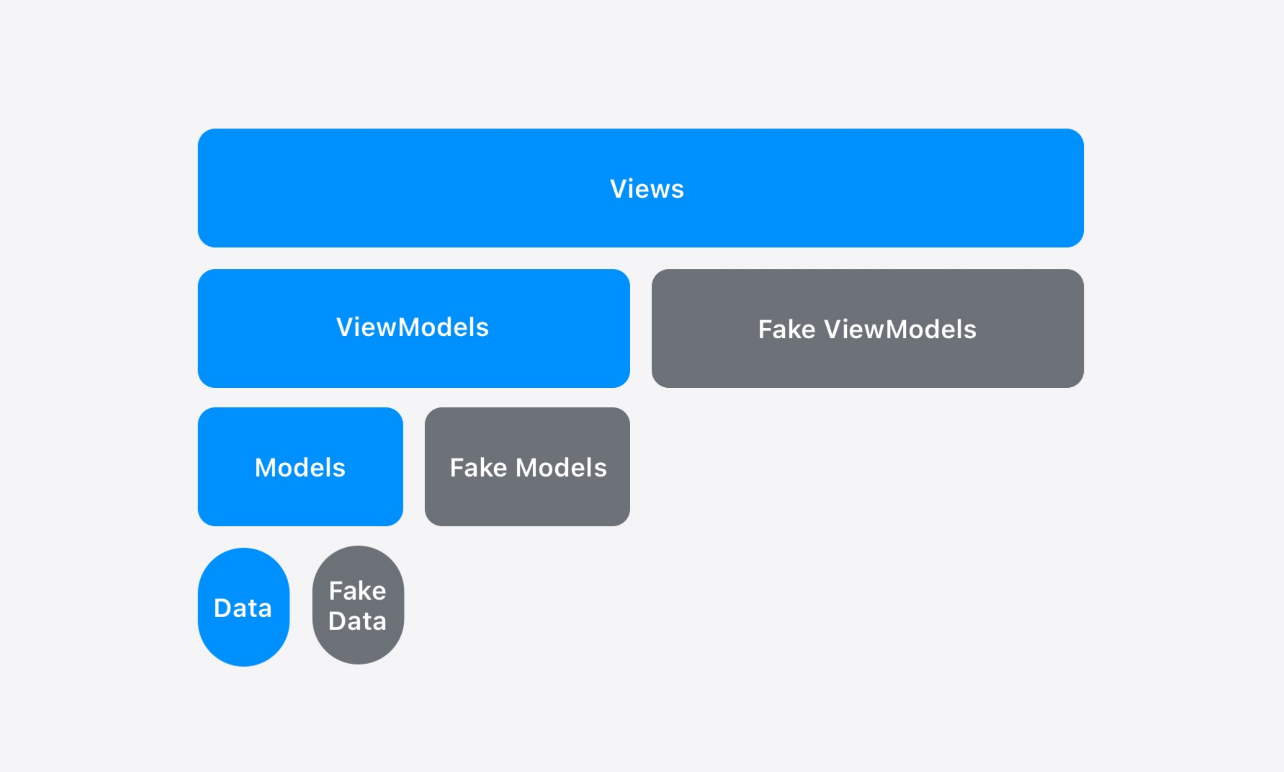


Figure 6.9: Structure of the code.

```
    var activityItem: ActivityItemWrapper? { get set }

    /// The itinerary is currently edited by the user.
    var editingItinerary: Itinerary? { get set }

    /// Error Packet containing informations if an error occurred.
    var errorPacket: ErrorPacket? { get set }

    /// The list of itineraries, ordered by alphabetical order.
    var itineraries: [Itinerary] { get set }

    /// Boolean indicating if the view should display
    /// an interface to create itineraries.
    var showNewItinerarySheet: Bool { get set }

```

```
23      // MARK: - Methods
24
25      /// Permanently delete the itinerary displayed at the given offsets.
26      func delete(itineraries: [Itinerary])
27
28  }
```

To illustrate the power of such code architecture, let us look at line *17*, a variable containing a list of itineraries. With the real implementation, the *ViewModel* would fetch records from the database and populate this variable. However, when the fake *ViewModel* implements this Protocol, it will simply populate the variable with a hardcoded set of itineraries.

We can also use this property for line *14*, where the actual implementation would store actual errors in this variable, whereas fake implementation could store a fake error, to test the interface in our SwiftUI Previews. Moreover, it is effortless to pre-condition the interface quickly when performing automated UI Tests. In the example below, when can see the syntax to instantiate a view for UI Testing, using fake viewmodels.

```
1  init() {
2  ...
3  case "scenarioItinerariesView":
4      contentView = ItinerariesView<FakeItinerariesVM>()
5                        .environmentObject(FakeItinerariesVM())
6  ...
7  }
```

At line *4*, we instantiate our view, passing our Fake ViewModel type as a type parameter. We then instantiate our Fake ViewModel at line *5* and assign the whole to our main container. It is that simple.

6.4.2 ViewModels

ViewModels acts as a link between are *Models* and *Views*, primarily handling states. In the example of itineraries, *ViewModels* would fetch the records on the database and either store the result on the corresponding variable or flag an error that might have occurred. It is also responsible for checking users' inputs before committing data to our models.

In a similar fashion as our *Views*, it is important for our *ViewModels* to accept both real and fake implementations of *Models*. By doing so, we can easily test our ViewModels in isolation. We can also pass fake implementation our models to simulate database failures with no results or unexpected formats.

6.4.3 Models

Models are the lowest abstraction in our *MVVM* architecture. It is responsible to represent models and make the necessary calls to internet, local database or even files.

We chose to use a relational database as our underlying data structure in our case. Apple offers a native implementation of such database and is called *CoreData*. By using such tool, we would avoid using external libraries, benefit from great integration with iOS search engine and iCloud synchronization, and avoid having to use internet.

6.5 Colors Detection

Since maps are represented as simple images, it is important to detect the colors contained in them so the user can quickly learn what to expect when exploring the map.

The initial idea was to analyze the whole image each time the user opens the corresponding interface, as the hypothesis was that such computation would not require a high computation power and would also avoid having to store the data on the device.

Method	Computation time [minutes]
Naive approach	2:10
Sampling	0:58
Sampling + efficient color store	0:32
Sampling + efficient color store + naive parallelism	0:15
Sampling + efficient color store + batch parallelism	0:04

Table 6.1: Execution Time of Different Color Detection Implementations.

However, we realized that computation time was significant after the first implementation, up to 2 minutes. (Table 6.5)

Naive approach The algorithm is simple, start from the first pixel and iterate through all the pixels contained in the image, storing the color in each pixel in a memory array. Then, we would:

1. Count the number of occurrences of each color.
2. Sorting the colors by number of occurrences.
3. Starting from the most detected colors, we would analyze the rest of the array and remove any color that is similar. Indeed, due to compression and loss, colors do not have the same hexadecimal code but differ slightly while looking the same.
4. Finally, we obtain a list of colors found on the map.

This method is extremely inefficient in term of complexity and memory access.

Sampling With the sampling approach, we tried to analyze only a fraction of the pixels, ten times less.

Sampling + efficient color store In addition to the sampling technique, we also revised the data structure. Instead of storing every color in an array, we would create a dictionary, storing the number of occurrences a color is detected.

Sampling + efficient color store + naive parallelism We then tried to parallelize the process by subdividing the image by the number of threads available.

Sampling + efficient color store + batch parallelism This time, instead of dividing the image by the number of threads, we would divide it by the number of cores on the device, reducing the overhead of creating a background thread and merging the results.

We found that 4 seconds was acceptable for this version of the application. Further improvements are possible with more advanced algorithm and data structures.

6.6 iPad Support

The use of SwiftUI greatly simplified the development of the iPad version of the app. To follow Apple's Human Interface Guidelines [37], we have carefully adapted each screen to take advantage of the iPad's large screen. Figure 6.10 and figure 6.11 illustrates the differences between the iPhone and iPad versions. Figure 6.12 illustrates the Slip View Interface. With the great modularity of the *MVVM* architecture and code isolation, two instances of the app can run in parallel on the same iPad. Expert users often use this feature to replicate the notion of windows often found on computers. By doing so, users can drag and drop maps between itineraries or even drag-and-drop a file inside a mail (Figure 6.13). Note that drag and drop also works natively with VoiceOver for users with no visions, facilitating sharing even more. Finally and most importantly, maps can be displayed horizontally to take full advantage of the large screen and help users discover maps more comfortably. (Figure 6.14)

6.7 Final Result

See figures 6.15 and 6.16 for screenshots of the main resulting applications. Only the most relevant parts are illustrated.

The code resulting from this project can be found here (upon request if the repository is not switched to public yet):
https://github.com/SBV-FSA/HapticMap/releases/tag/v1.0.0

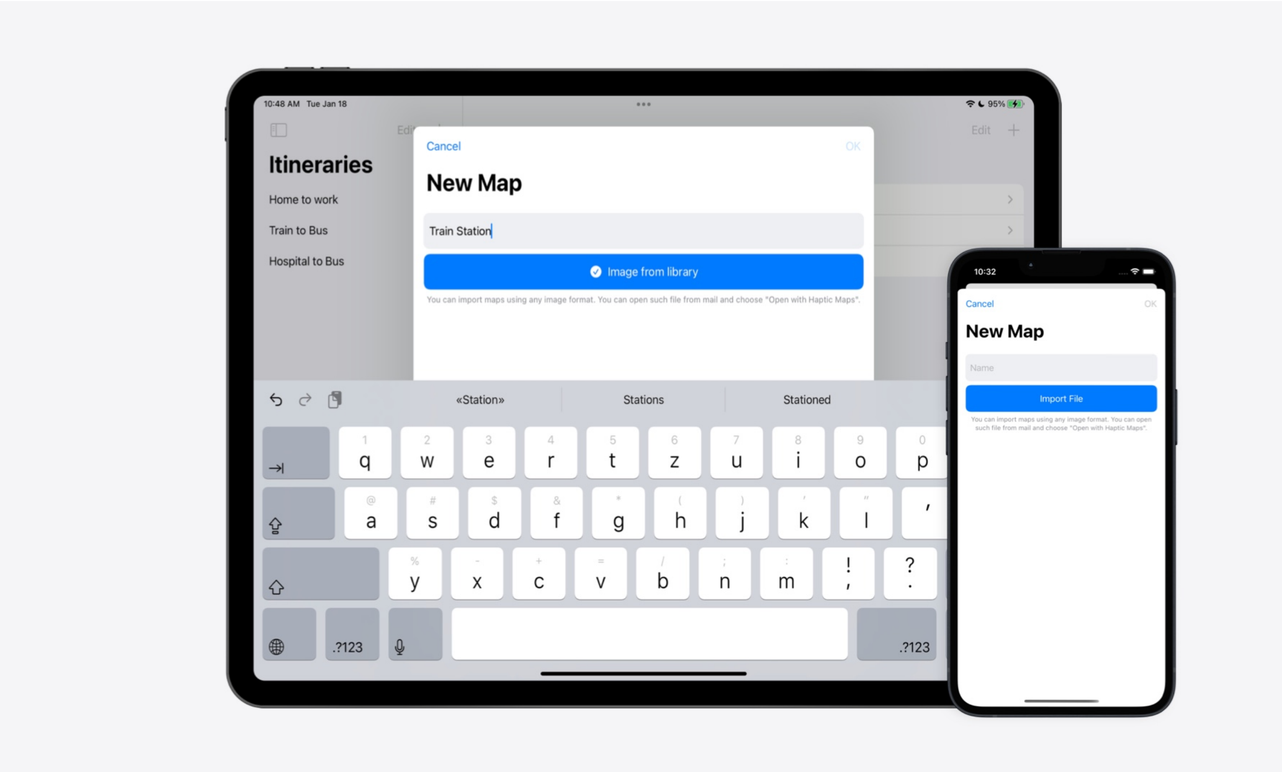


Figure 6.10: Illustration of the iPad version next to the corresponding iPhone version.

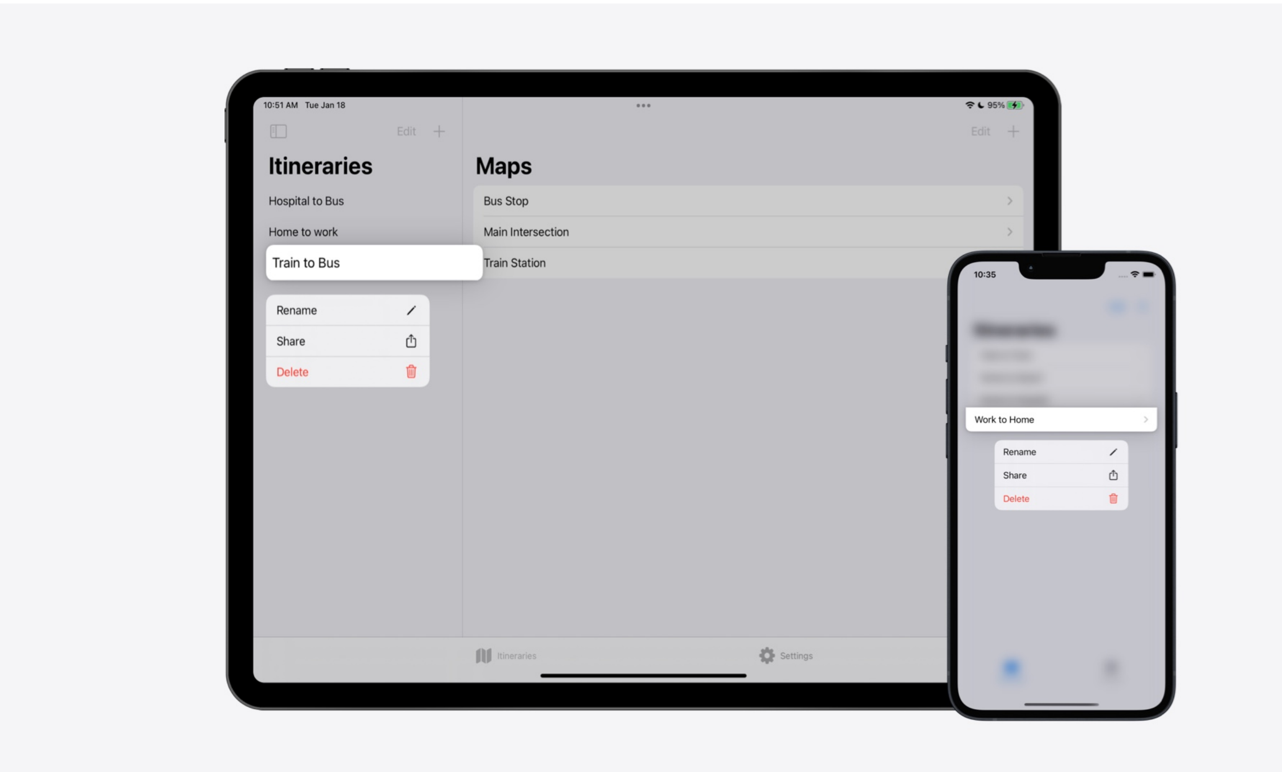


Figure 6.11: Illustration of the iPad version next to the corresponding iPhone version.

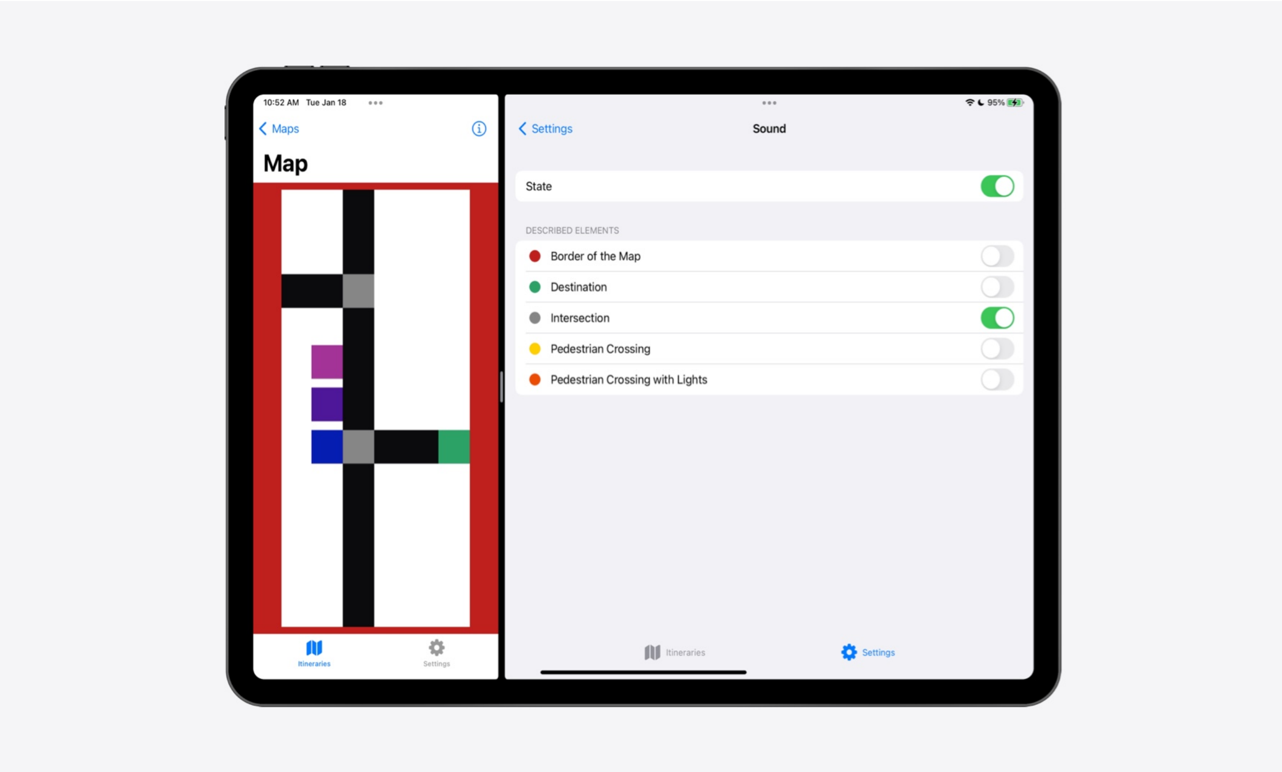


Figure 6.12: iPad Split View Mode

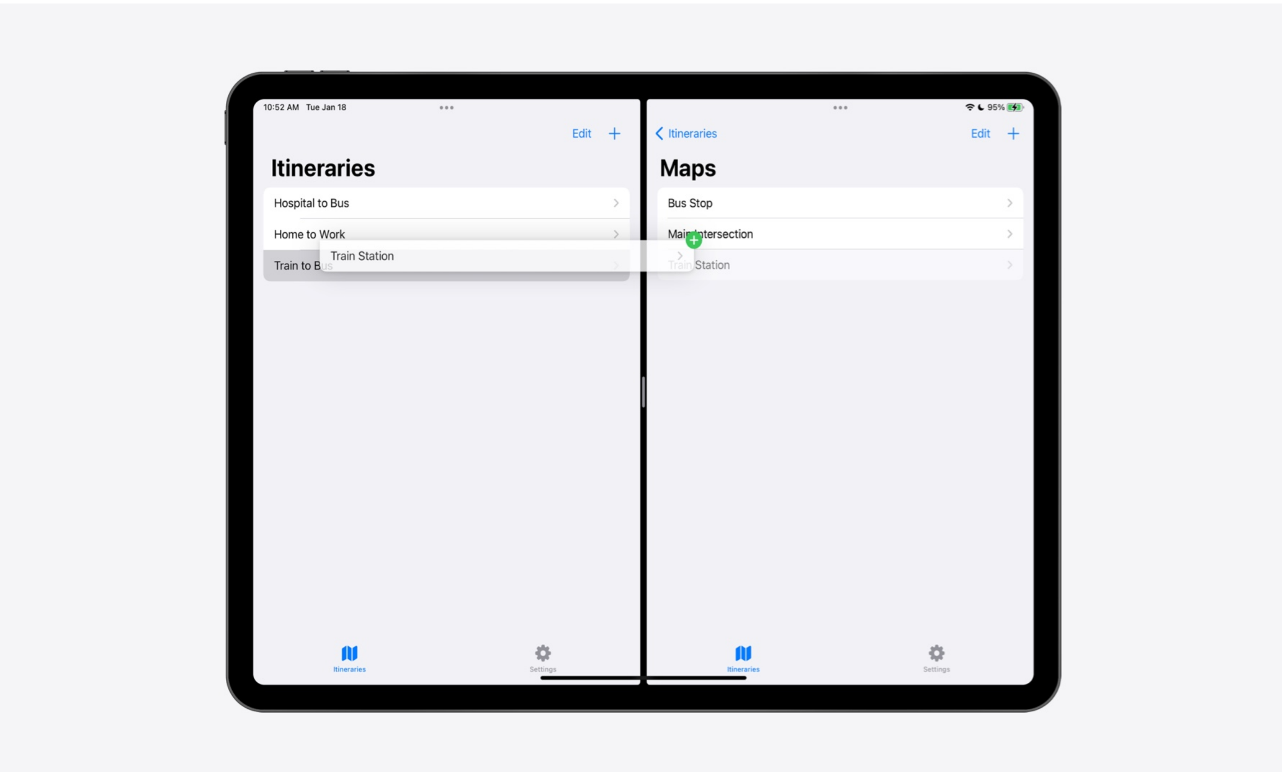


Figure 6.13: iPad Drag and Drop Mode

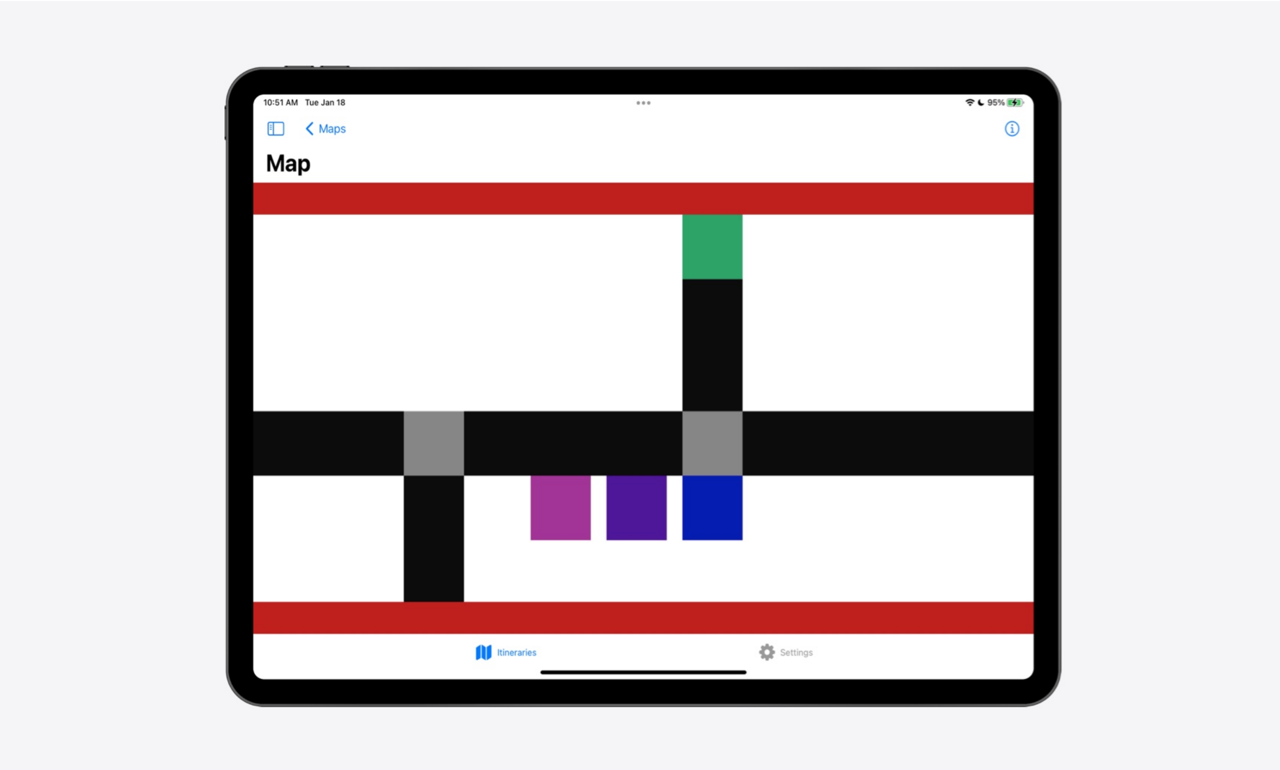


Figure 6.14: iPad Screenshot of a map

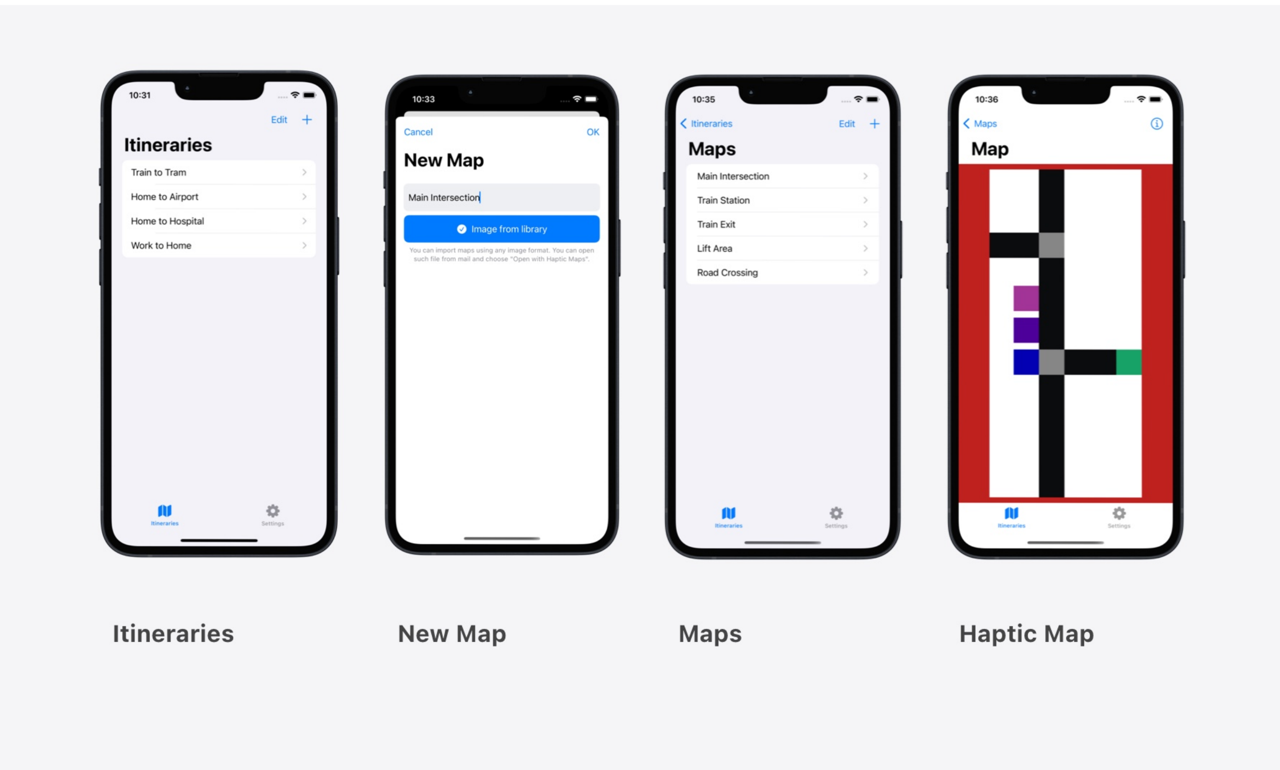


Figure 6.15: Final application.

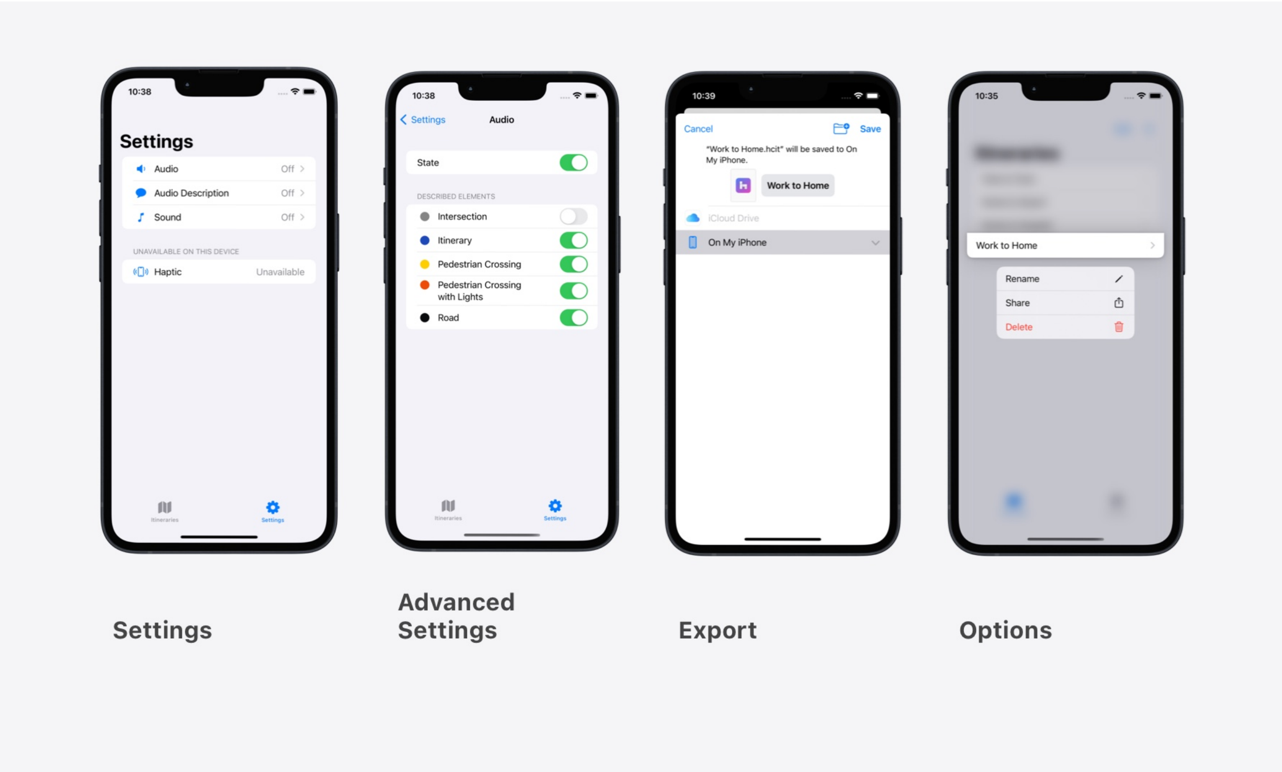


Figure 6.16: Final application.

Chapter 7

User Feedback

User testing is out of scope for the objectives of this project. However, we continued to interview four potential users and three subject matter experts during the implementation part and were able to gather feedback and improve the interface along the way quickly.

We have handed a version of HapticMap to the user U7, who shows similar behavior patterns to our primary persona. The feedbacks were greatly positive, even mentioning, "I would be happy spending hours at home trying to understand a subway map and go there on my own without bothering my family.". He asked to try more maps and described them orally to see if he understood them correctly. He also mentioned that he would be a user of such a product if it were to be available. On the subject matter experts side, S6 was especially surprised by the possibilities offered by the application and projected herself using it, asking questions about "How will I be able to create maps for my patient?", "Where can I download the app?".

7.1 Custom Categories

Subject matter experts and users gave valuable feedback, such as the need for custom categories on maps, as the demo only displays predefined categories. We have then implemented this feedback, and the results are illustrated by figure 7.1

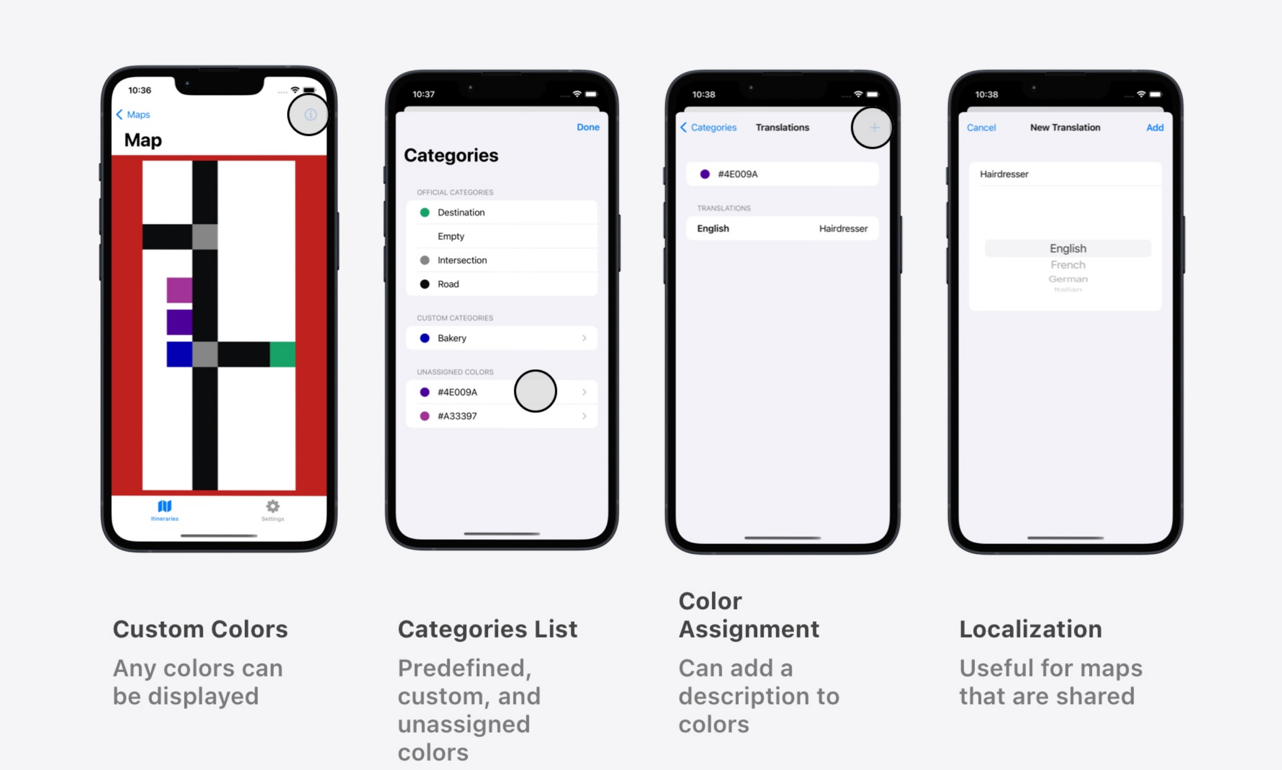


Figure 7.1: Interface to list and add categories.

We have added the followings:

- Users can have an unlimited number of colors represented on the map, as long is it is not too similar to the predefined categories.
- Blind users cannot know in advance which categories to expect on the map, thus making it hard to know if they missed an item or were simply absent. To solve that, users can click on the "details" button on top of the map and learn about the colors displayed on the map. A specific gesture for VoiceOver, two fingers swipe down, to read the whole list at once.
- Users can assign colors to custom categories. It initially requires a person with vision's help but is then stored on the maps and included even if the map is shared. When exploring the map, the device reads custom categories to the user.
- Some users and subject matter experts noted the importance of creating maps for multiple persons at once, such as train stations with shops. Therefore, we have added an interface to add localized descriptions.

7.2 Settings

During interviews, we have also noted the importance of allowing users to set preferences for the types of feedback given by the application. A new user might what an audio description of all the items under his fingers while a more expert user will only use vibrations. Changing those settings would also allow us to perform more tests with different feedback types combinations to improve the reading experience. 7.2

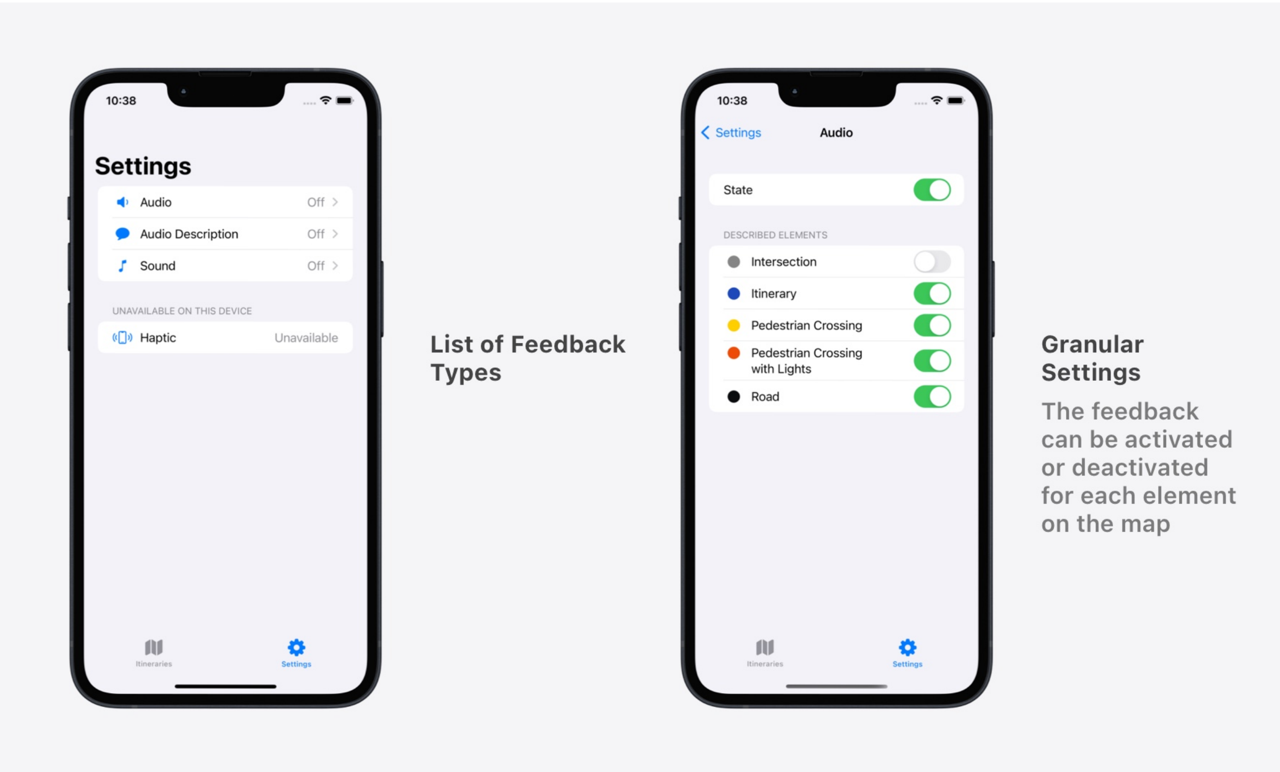


Figure 7.2: Interface to customize feedbacks.

Moreover, we have moved the settings section in the bottom toolbar.

7.3 Two Finger Mode

While observing users exploring maps on-screen using their fingers, we have noticed a tendency to stop a finger somewhere while moving a second finger on the screen, effectively using the first finger as an anchor. Figure 7.3 illustrates such a user. The app's current interface does not allow such behavior and only recognizes the first finger touching the screen. To improve the interface, we have conceived a mode behaving as follows:

Figure 7.3: Illustration of a user using two hands.

1. The user opens a map and starts reading by moving one finger.
2. The user stops his finger somewhere.
3. When touching the screen with his second finger, that app emits a sound and specific vibrations indicating that the second finger is now detected.
4. While moving the second hand, the app would consider it instead of the other to analyze the colors under the finger and give appropriate feedback.
5. The user can now use his first finger as an anchor point.
6. When lifting the second finger, the app emits a sound and vibration to indicate that the first finger is now considered and the app behaves as before.

We have received validation of this feature from two subject matter experts and one user. However, due to the limited time, we could not implement this feature.

7.4 Colors and Contrast

We designed the interface to respond to accessibility settings such as increased contrast and dark mode. However, we have received feedback from two subject matter experts to improve the contrast of maps. We initially chose colors of predefined elements on the map to be close to reality, such as gray for roads and yellow for pedestrian crossings. However, since low vision users can also use this application, we needed to improve contrasts. Therefore, we have created an improved color palette with greater contrast and chose appropriate colors for the most frequent type of color blindness. (Figure 7.4)

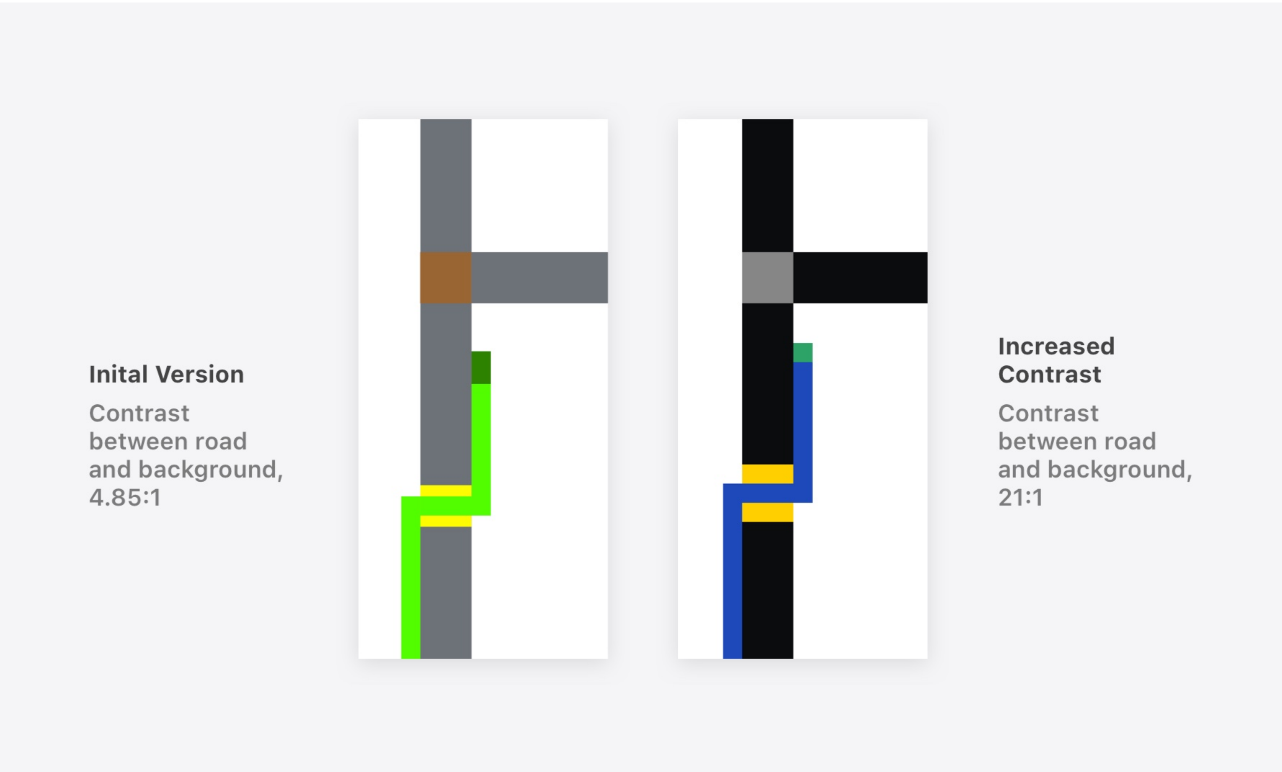


Figure 7.4: Comparaison between the initial color palette and improved one.

Chapter 8

Discussion and Conclusion

8.1 Future of the Project

The final product gained significant traction among low vision and blind individuals. The feedback from early testers is impressive, and we have identified multiple other use cases. As this project can positively impact people's lives, *ELCA* and the *Swiss Federation of the Blind and Visually Impaired* (FSA) have agreed to open-source the resulting software and pursue the development. The latter expressed its willingness to integrate the system into their audio GPS application *MyWay Pro*, allowing users to not only hear the itinerary but feel it directly on the smartphone. Moreover, the Federation is interested in exploring the feasibility of integrating it into the application from the *Swiss Federal Railways* application or publishing it as a standalone application.

8.2 Discussion

8.2.1 Limited Ressources

While this initial traction is encouraging, it is important to note that time and human resources were severely limited to conduct the UX Research part of the project. While we think our two provisional personas represent a good approximation of the underlying reality, more interviews are needed to identify behavior patterns clearly. We believe improved design can be achieved by conducting users tests and iterating on the current version of the software.

8.2.2 Embracing Accessibility in a Company

Accessibility is often seen as a time-consuming practice and the final touch to a product's design. However, through audits of existing products, subject matter experts interviews, and practice, we believe accessibility should represent everyone's focus from the start. Time and budget constraints are often used as excuses to postpone or ignore accessibility for software projects; however, we are convinced that adequate accessibility can be achieved with little effort if included in the development process from the start. While providing disabled users with an ideal interface can be viewed as a moral obligation, it also increases the product's value to a significant proportion of the population, implying great business opportunities. Moreover, by making sure an interface is usable by disabled users, one can also be assured that it is easy to use for others. Lastly, automated testing is also simplified, especially on platforms like iOS. Embracing the question of inclusion among stakeholders requires training and commitment.

8.3 Conclusion

Through contextual inquiries, we have successfully identified a substantial need among the blinds and visually impaired. Understanding maps without requiring costly hardware helps them achieve greater autonomy and confidence. Using precise haptic feedback, we have also demonstrated the potential for a new set of advanced user interactions. Additional time and resources are still necessary to conduct user tests and iterate the design. However, we are convinced that such a product has its place among the wide variety of assistive technologies. From a company perspective, the project also highlights that research focused on accessibility fosters innovation and creates business opportunities. It also raised awareness among stakeholders and shined a spotlight on an integral part of the population.

Appendix A

Object Finding Exploration

During the initial research phase of this project, we have quickly identified the loss of objects as being a potential problem for blind and visually impaired people, forming a cluster in our affinity wall (Figure 2.13). Multiple interviewees mentioned the loss of objects as being time-consuming and psychologically challenging. However, about half of the interviewees also mentioned that they would avoid losing objects by being ordered. Therefore, during the early interviews, we have decided to explore the feasibility of a system that would allow users to find specific objects without additional hardware, such as AirTag (We already discovered that the price of hardware is a problem).

A.1 Proof of Concept Goal

The goal of this proof is concept is to detect sunglasses using image recognition and estimate the distance to the object using LiDAR. By doing so, we would be able to implement an similar interface as AirTag (Figure 2.12) or SBB Train Door Detection Interface (Figure 2.4).

A.2 Machine Learning Model

We started by taking 40 pictures of sunglasses in different places around an apartment (Figure A.1). For example, on a desk, under a chair, or on the floor. We also made sure to take images with both opened and closed branches. In order to avoid overfitting specific cases, we have made sure to include an equal number of sample images for each situation.

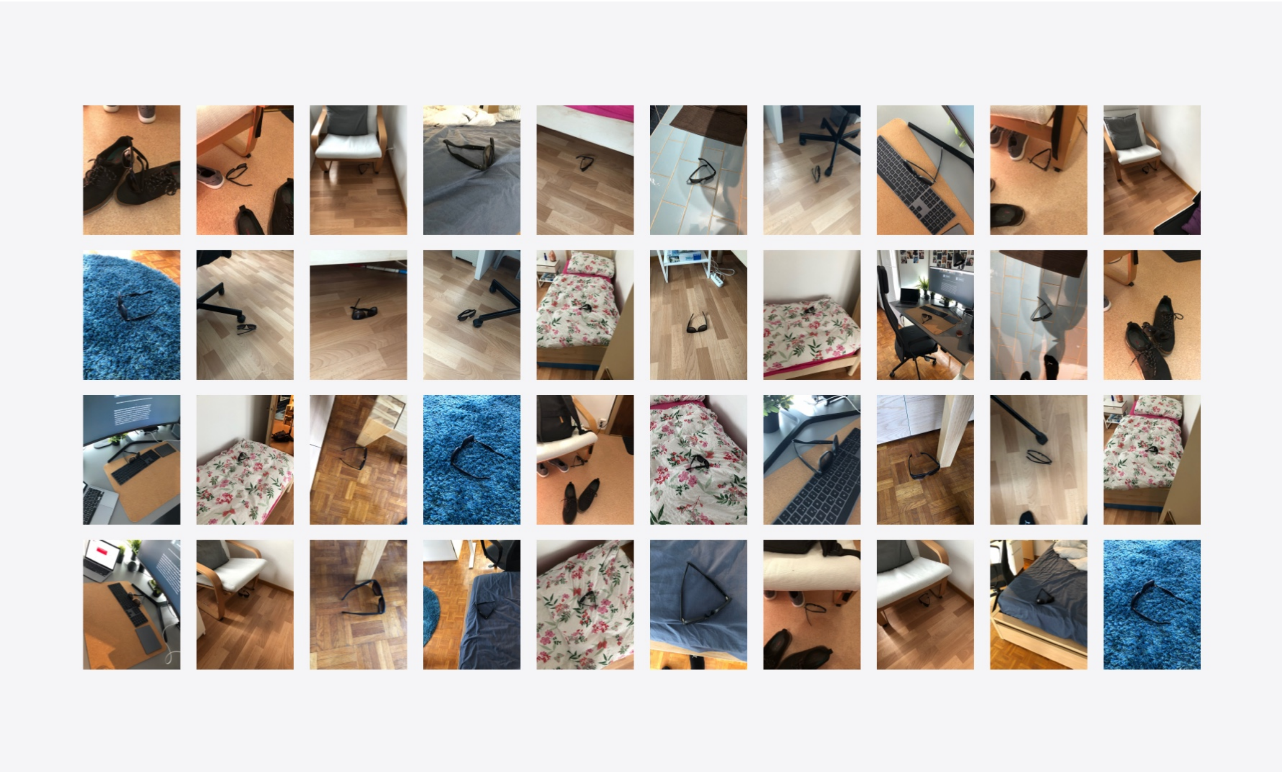


Figure A.1: Set of training images.

Using IBM Labeling tool, we have bounded each sunglasses (Figure A.2).

Then, we used the CreateML software to train our image recognition model, with 2000 iterations, achieving a loss of 0.41. (Figure A.3).

A.3 Result

Finally, we have integrated this newly created model into an ARKit Scene on an iPad equipped with LiDAR. We were successfully able to detect sunglasses in different environments, even with

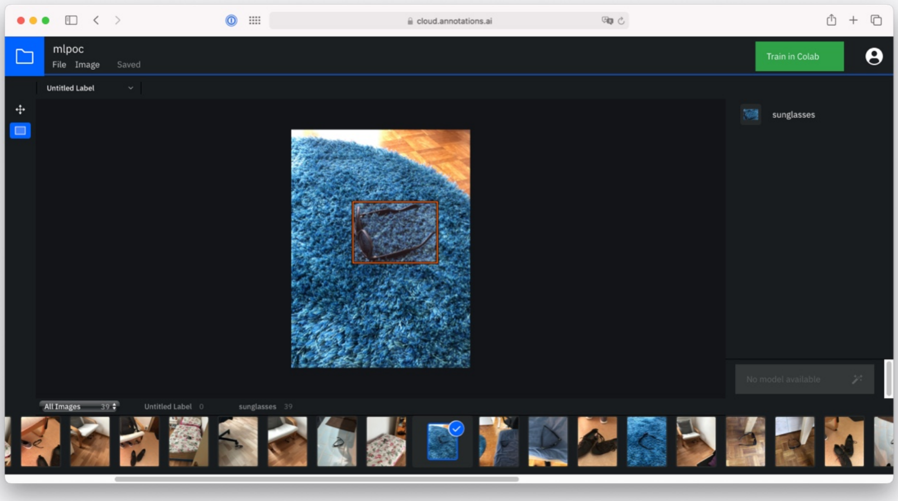


Figure A.2: Screenshot taken during images labeling.

environments not included during training with good reliability (Figure A.4). With LiDAR, we could also compute the distance between the device and the object accurately.

Having continued user observations and interviews, we have identified a more substantial need for the project described in this report. Moreover, detecting sunglasses is a great start, but we have later identified that the most commonly lost items are the ones that are not necessarily typical, such as small items like bottle caps. Therefore, we would have to train the model for a significant number of items to be helpful.

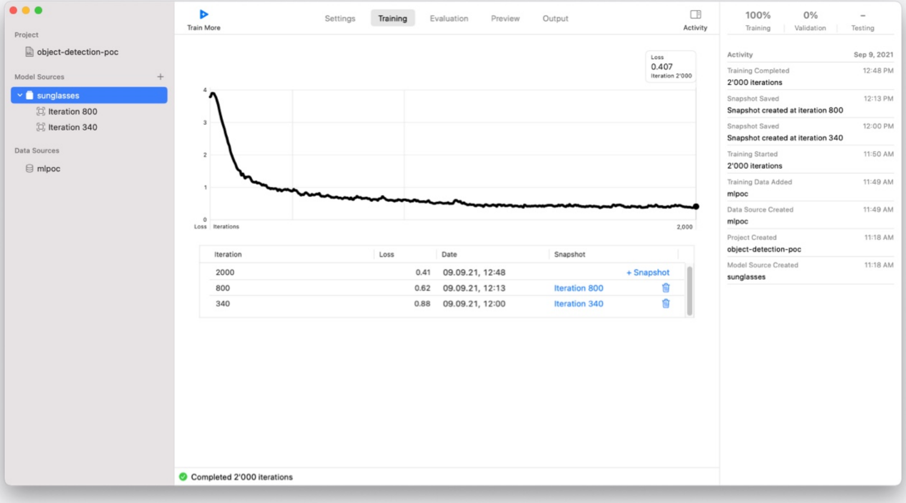


Figure A.3: Screenshot taken during model training.

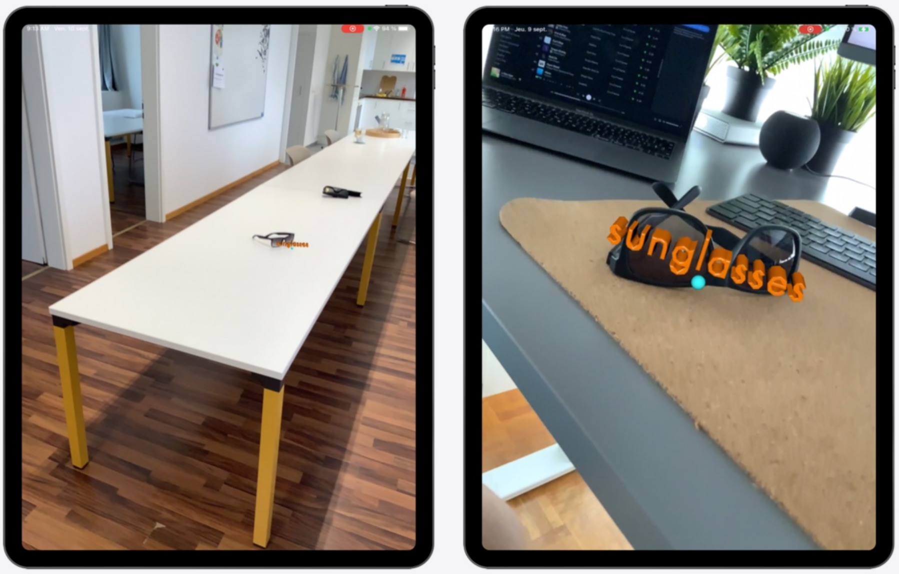


Figure A.4: Result of Proof of Concept

Appendix B

Early Interviews Guide

B.1 Participants

List of participants

B.2 Overarching Question

What is it like to live with a visual impairment and what are the main challenges of daily life?

B.3 Introduction

- Self-introduction
- Purpose of the interview and subject of the course
- 1h-1h30 interview with some questions
- Talk to me as if I know nothing about the field
- This conversation is confidential, no names will be mentioned. Possibility to delete the data of this interview.

B.4 Warm-up

Who are you and what is your background?

- Schooling ?
- Work? Courses?
- Hobbies ?

B.5 Disability 1

Can you tell me about your disability?

- When did it start?
- How do you know?
- Visual acuity?
- Type of vision?
- Reading?
- Navigation?
- Adaptation period?
- Will it get worse?

B.6 Learning 1

What was your path to accepting your disability? How did you learn to live with it?

- Main challenges
- Did you need an occupational therapist?

B.7 Learning 2

What was the hardest thing for you to adjust to and how did you overcome it?

- Navigation
- Social life
- Independent Living

B.8 Difference 1

So far I have mainly interviewed people who are visually impaired but have gradually lost their sight. Are there any differences in your opinion between people who lose their sight during their life and those who are born with it?

- Senses
- Adaptation

B.9 Autonomy 1

Let's first look at your life in your apartment. We are currently in your apartment, can you show me how you get around inside. For example, make a coffee.

B.10 Autonomy 2

How do you get around in an indoor location that you don't know?

B.11 White cane 1

Do you have a white cane? If so, can you tell me about it?

- Have you ever tried it?
- In which cases?
- What do you dislike about it?
- Do you use other aids to get around?
- A dog?

B.12 Mobility 1

Can you tell me about a trip that particularly affected you? One where you needed something besides a cane.

B.13 Mobility 2

Can we walk a little way together to see how you get around?

B.14 Unknown indoor location

Is indoor orientation more complicated than outdoor?

- Obstacles
- Orientation
- Building exits

B.15 Lost 1

How do you deal with lost objects? Think back to the last time you lost something. Can you describe what you lost and how you went about finding it?

- Type of item
- Technique for finding the object
- Time

B.16 Smartphone 1

Can you tell me about your iPhone, what do you use it for?

- Functions
- Difficulties
- Speed
- Computer?
- Things you can't do?

B.17 Super LiDAR

Now I'll show you an app available on the App Store. (Demo). What do you have to say about an app like this?

- Advantages
- Disadvantages
- Object search functionality?
- Would it have helped you at home at the beginning of your disability?
- Would you see a use for such a system, maybe differently?

B.18 Apps

Would you see a use for such an application?

B.19 Recruitment

Would you know other visually impaired or blind people? Would it be possible to meet them?

B.20 Conclusion

- Thank you very much
- Anything to add?
- Feel free to contact me if you think of anything or have any questions
- I can also send you the report once the project is finished

- Can I contact you again if I have any questions?
- Thanks again for your time
- Offer a gift for the time given

Appendix C

App Wireframes

The app relies on GPS to displays maps quicker, sort them by distance and more.

Decision has been made to ask for location authorization up front, contradicting UX good practices, in order to simplify the user experience of the rest of the app. Contrary to users with vision, displaying an unexpected message to a low vision user when he needs the feature is disturbing.

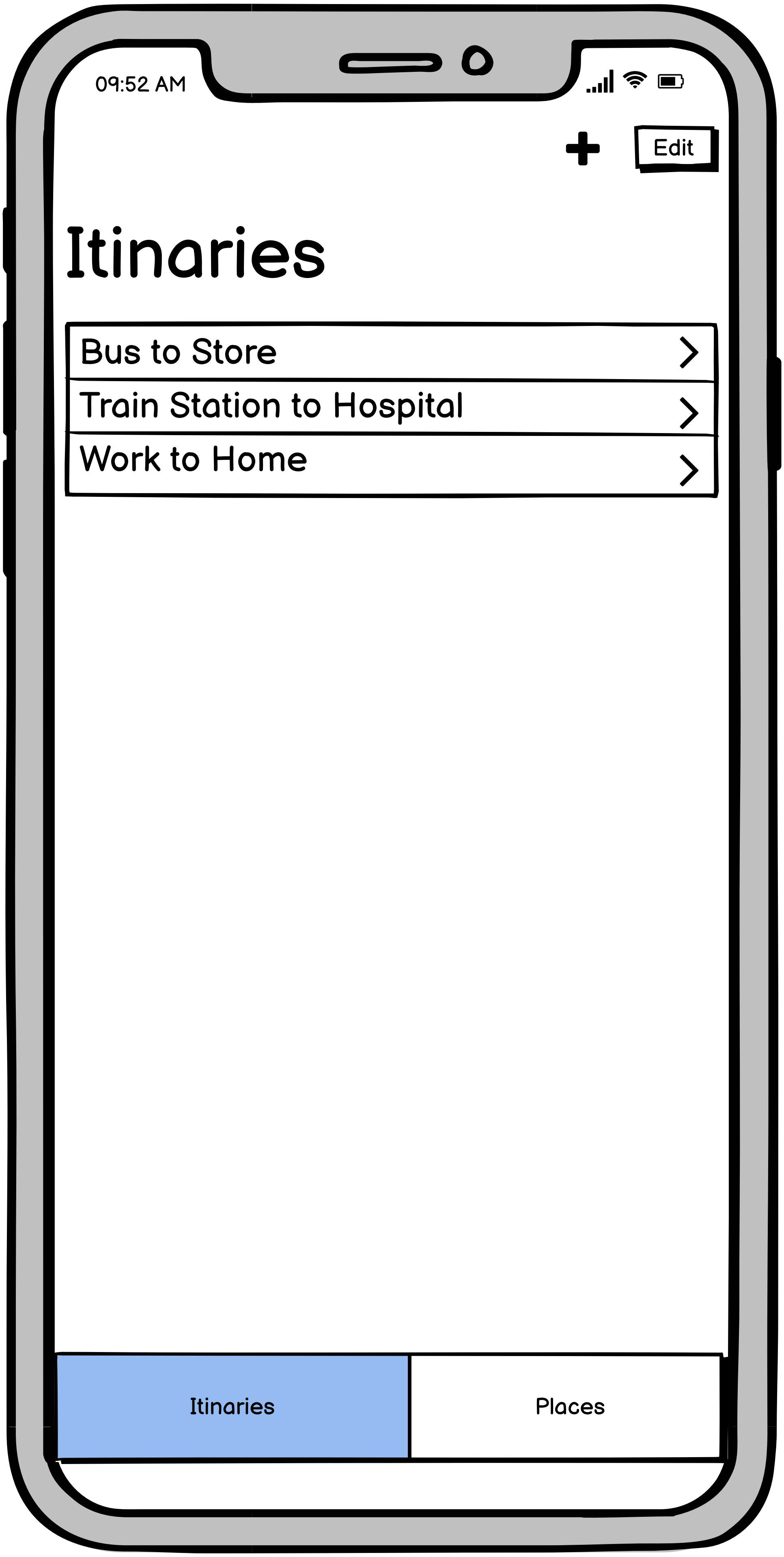
Standard iOS popup once the user has clicked "Allow".

By clicking "Cancel", the user is not able to use the app and is redirected to "Location Authorization - Denied" state.

By clicking "Allow", the user is redirected to the main screen of the app.

It explains the user that the app has not the authorisation to user the user's location. iOS does not allow to display the popup here, instead, the app opens the settings if needed.

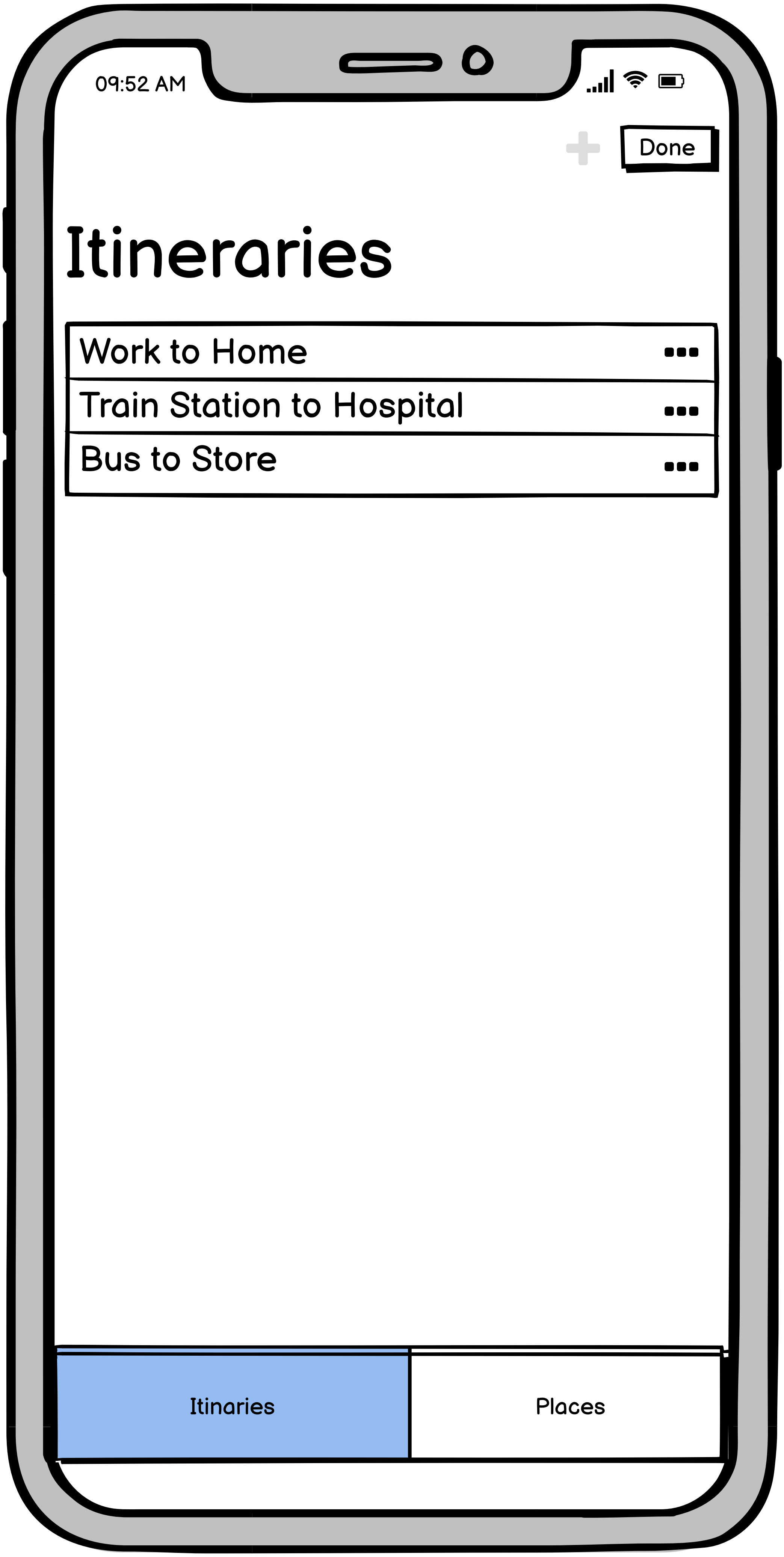
It can happen that GPS is out of order or that parental control restrictions exists. In that case, the app has no additional informations and cannot help the user.



User's itineraries are displayed using a standard iOS List, sorted by alphabetical order.

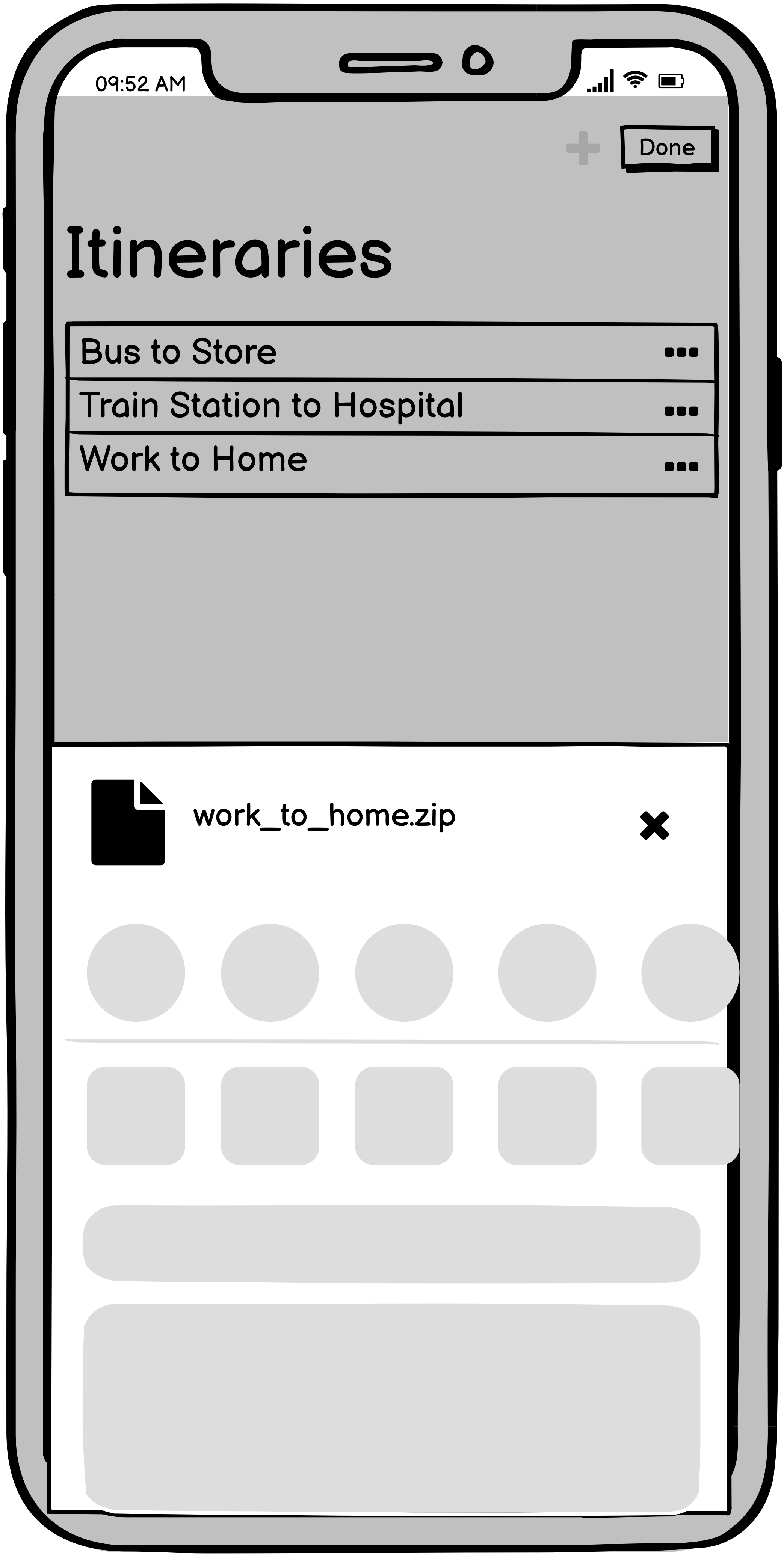
Options exist to add a new itinerary, and switch the list into edition mode.

Clicking on a itinerary opens the related list of maps.

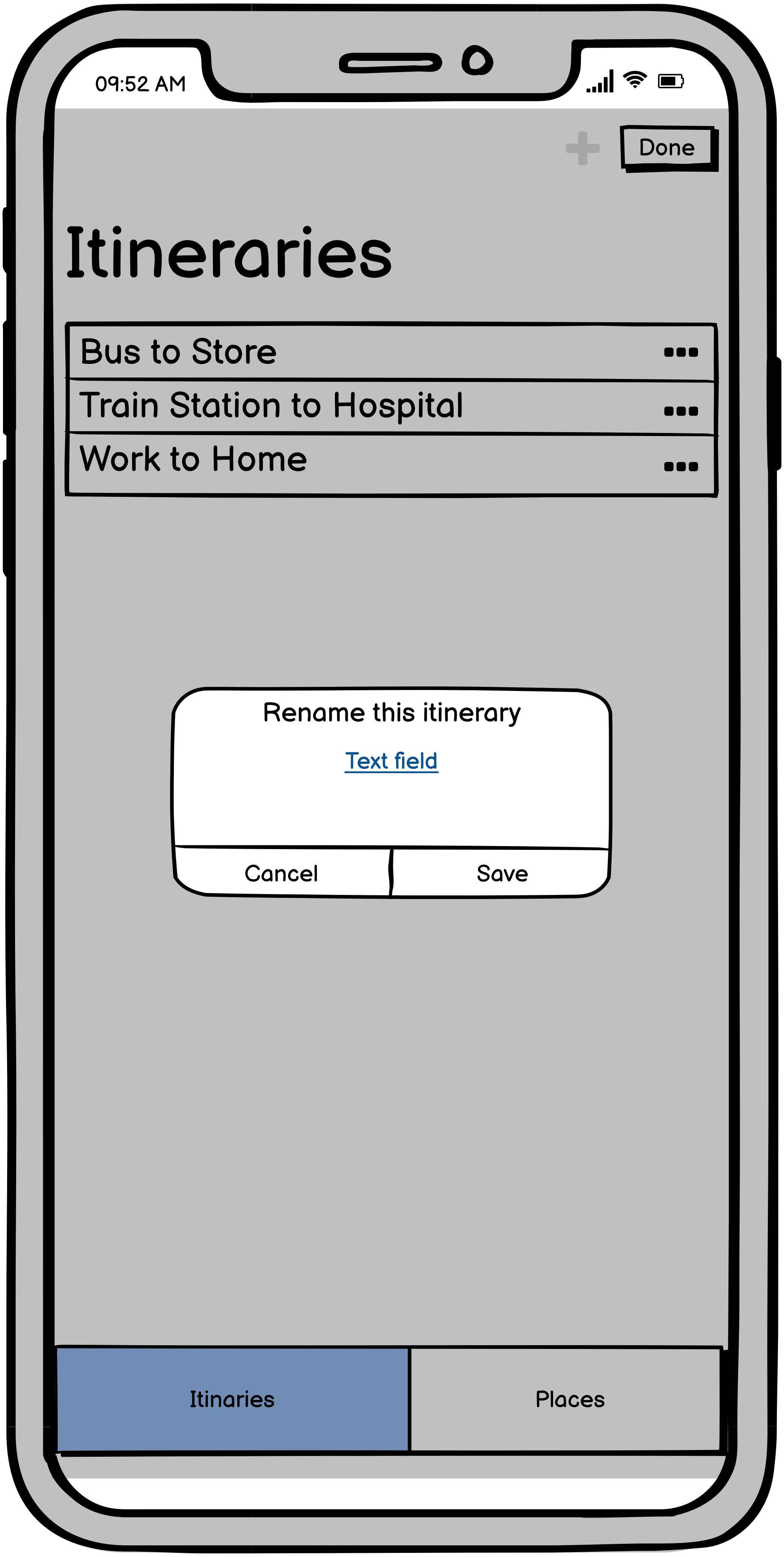


Edition mode allows for deletion, sharing or renaming of itineraries.

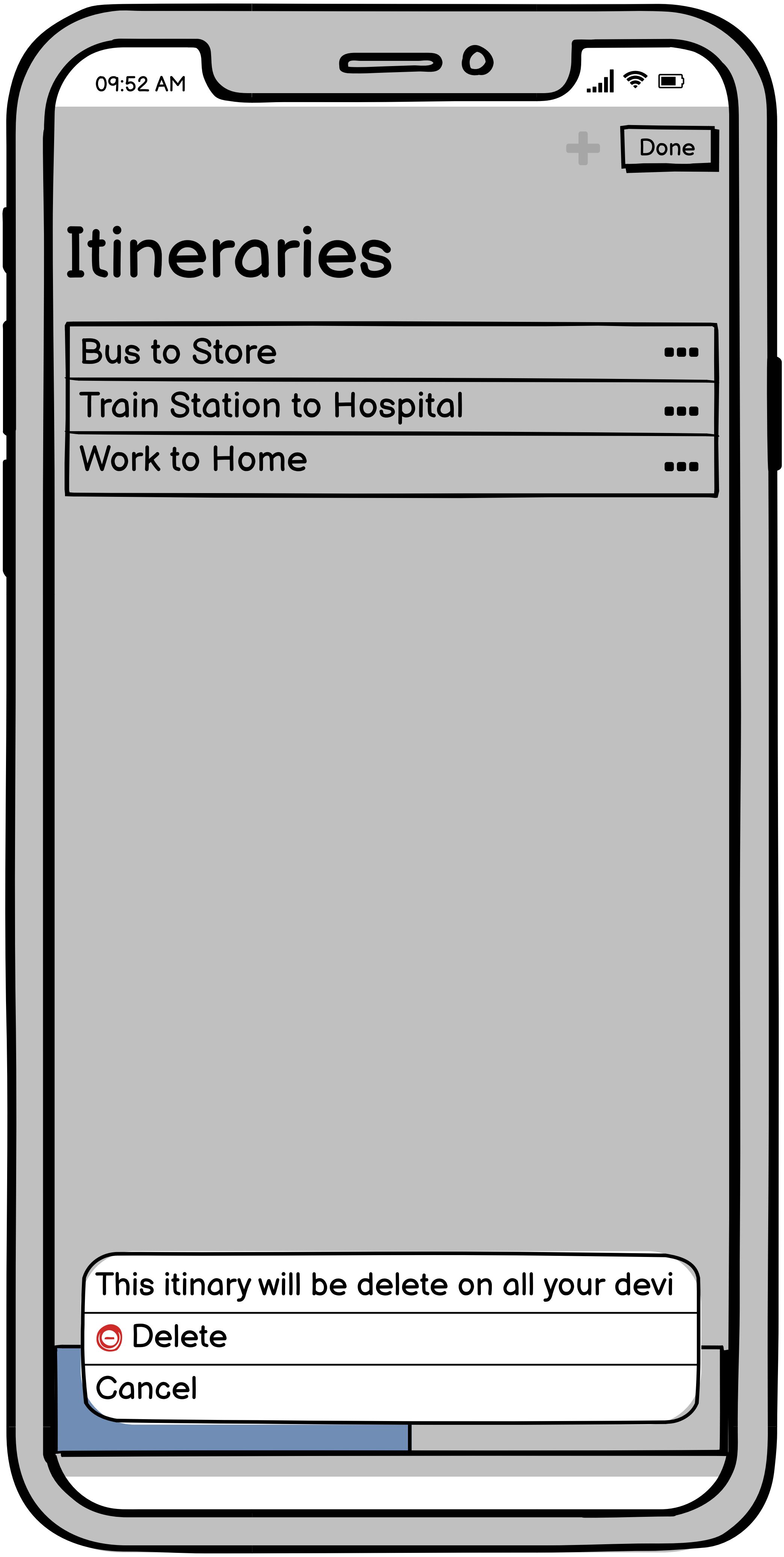
A standard options sheet is displayed when the "..." button is pressed.



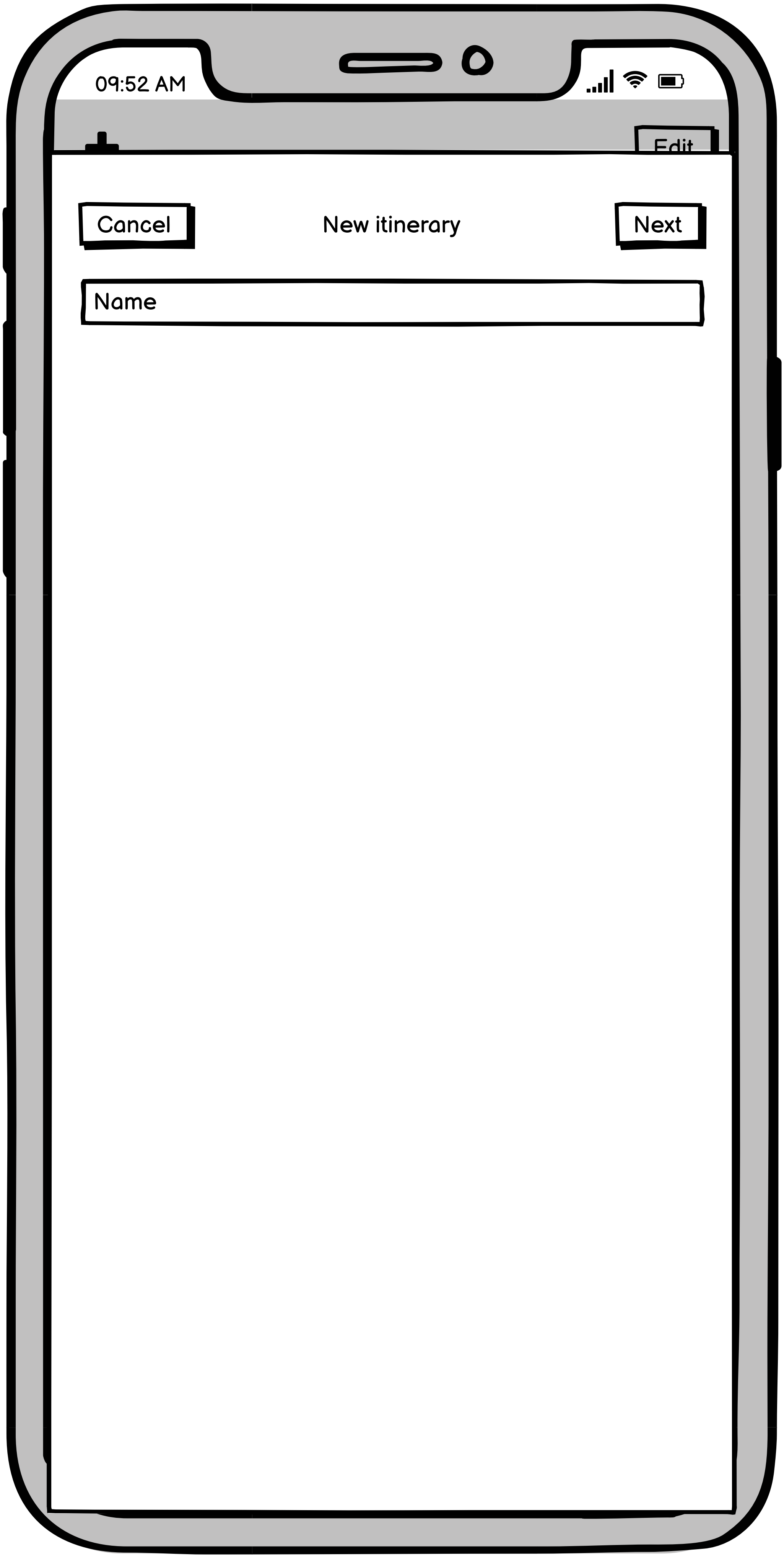
Standard iOS share sheet.



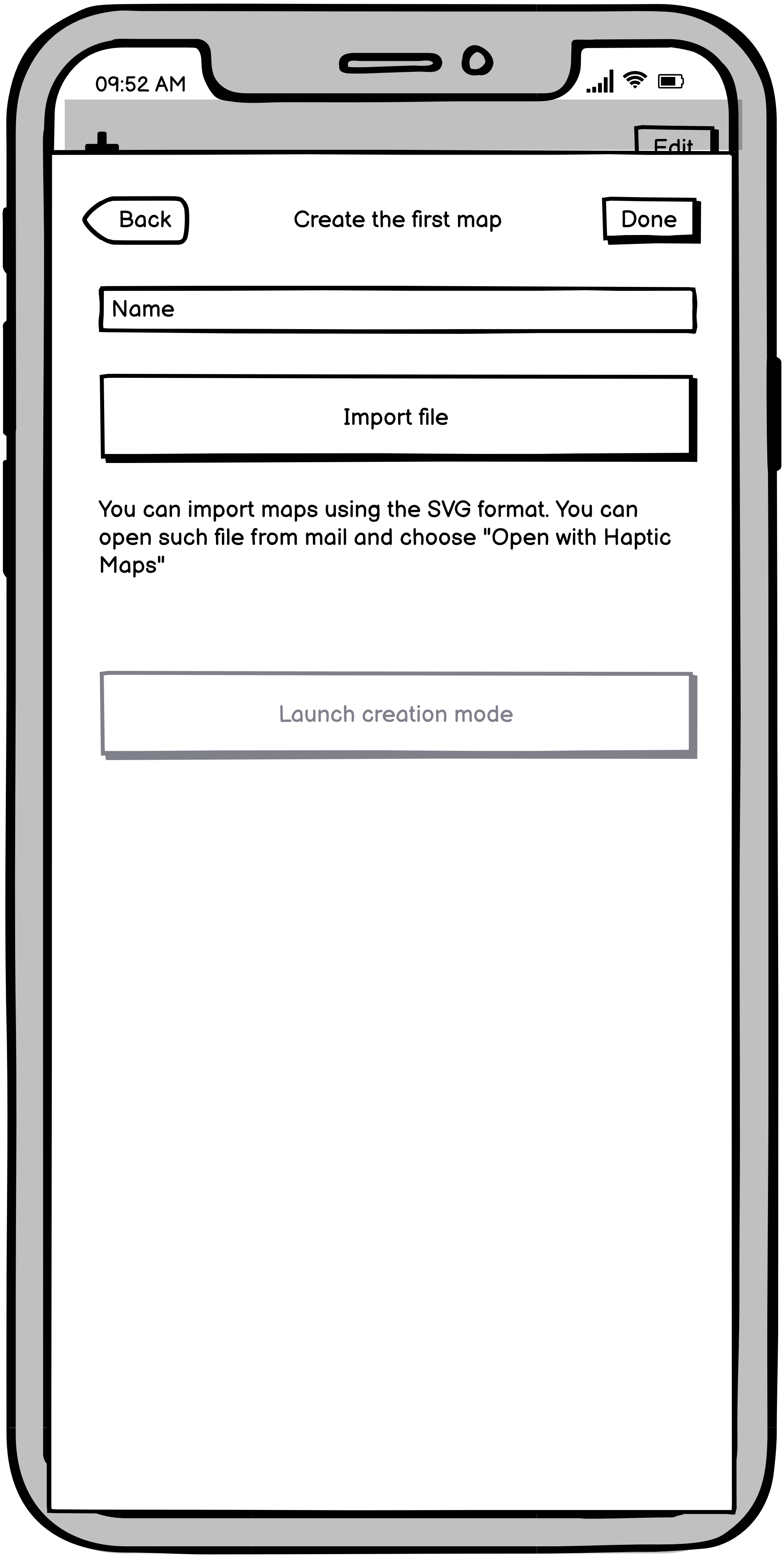
Standard iOS popup including a text field to enter the new itinerary name.



Standard iOS alert asking for deletion confirmation.

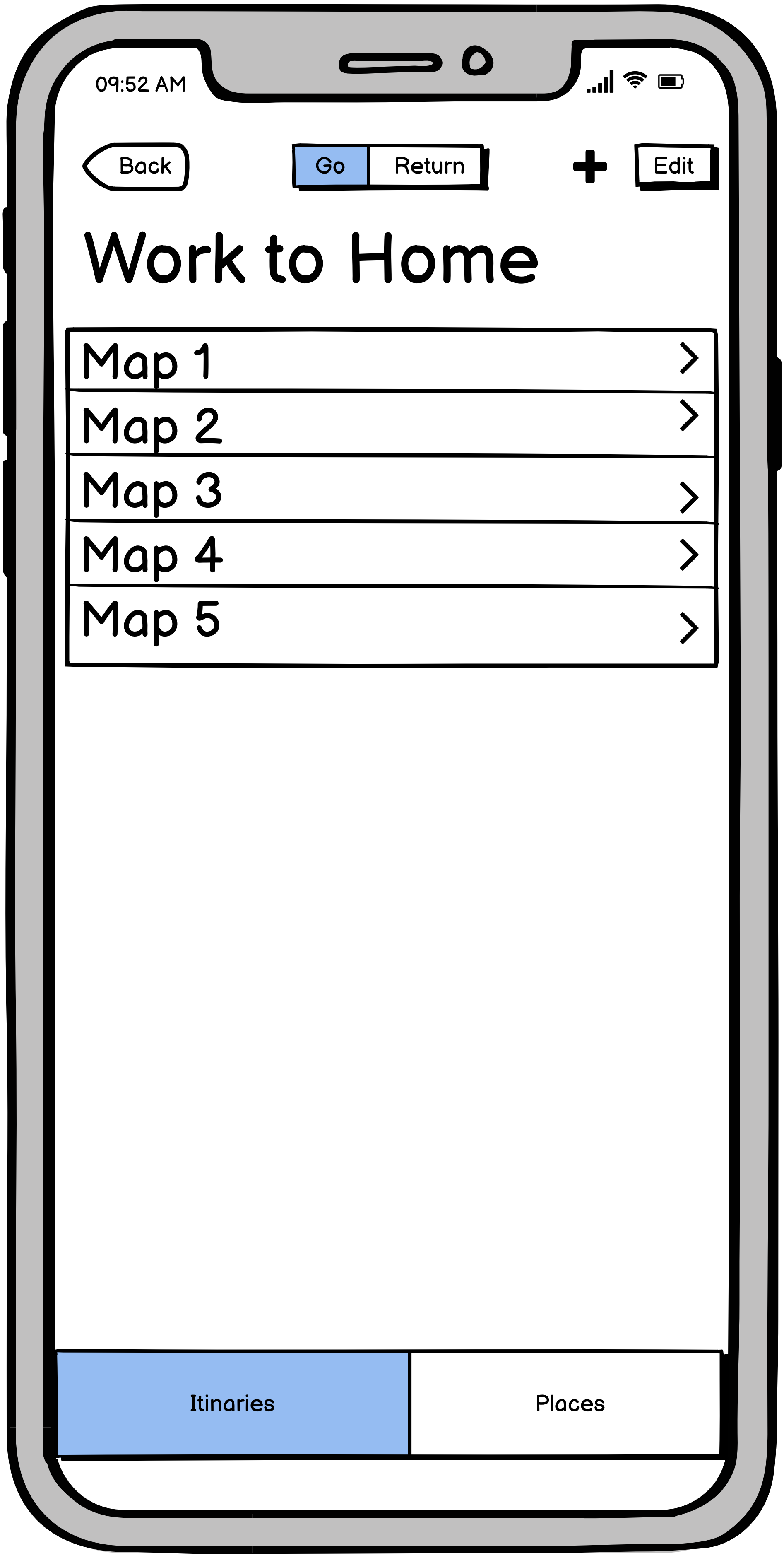


When creating a new itinerary, the first step is to name it, as an itinerary with no name by default would be very hard to find for a blind person using VoiceOver.



Then, the user is immediately invited to create a first map by importing an SVG map.

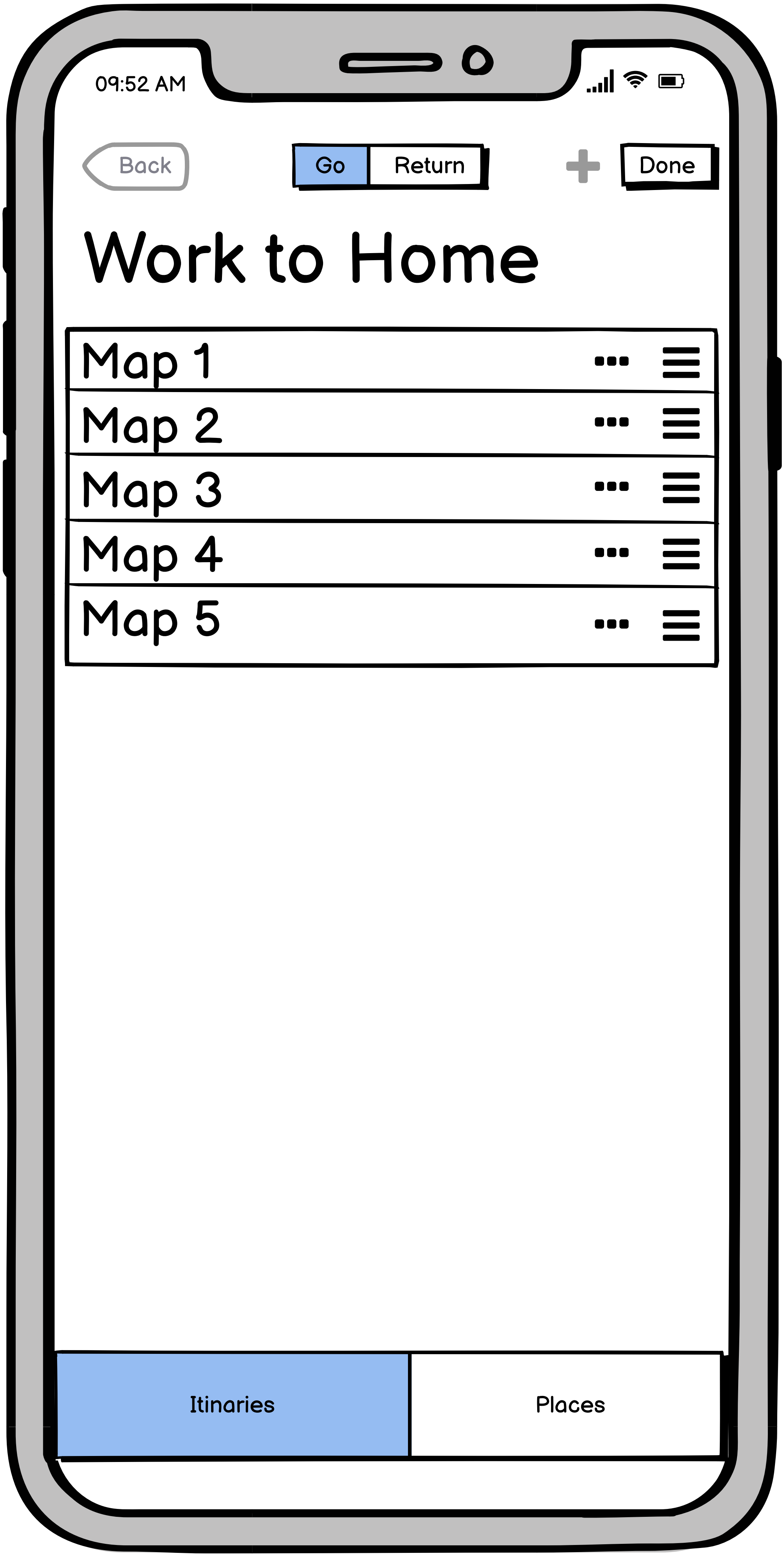
An AR creation mode will appear here when available.



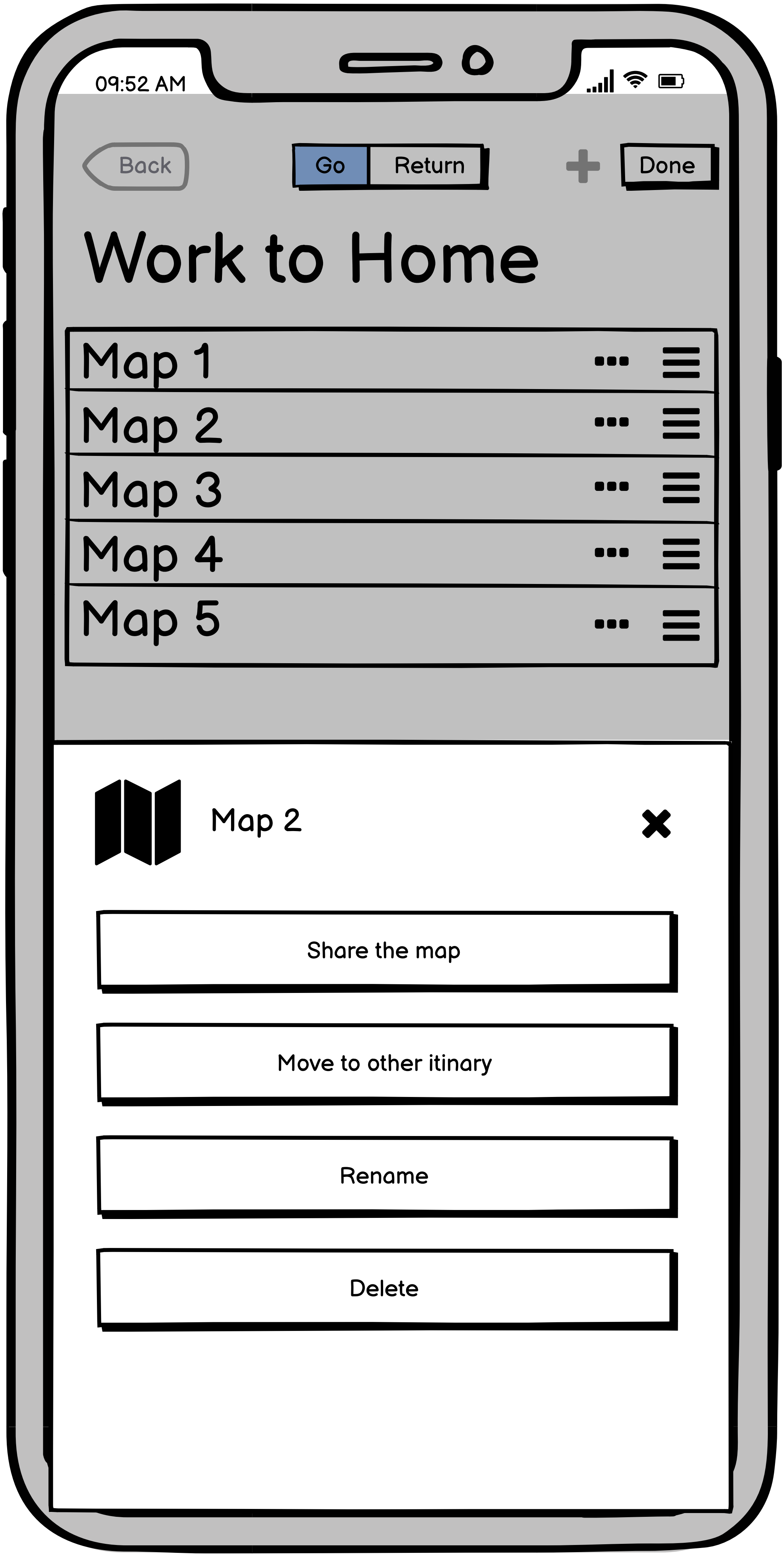
Maps are displayed sequentially in the order of which they appear on the itinerary. The user can use the top buttons to reverse that order if needed.

Users can also use the edit mode to reorders maps.

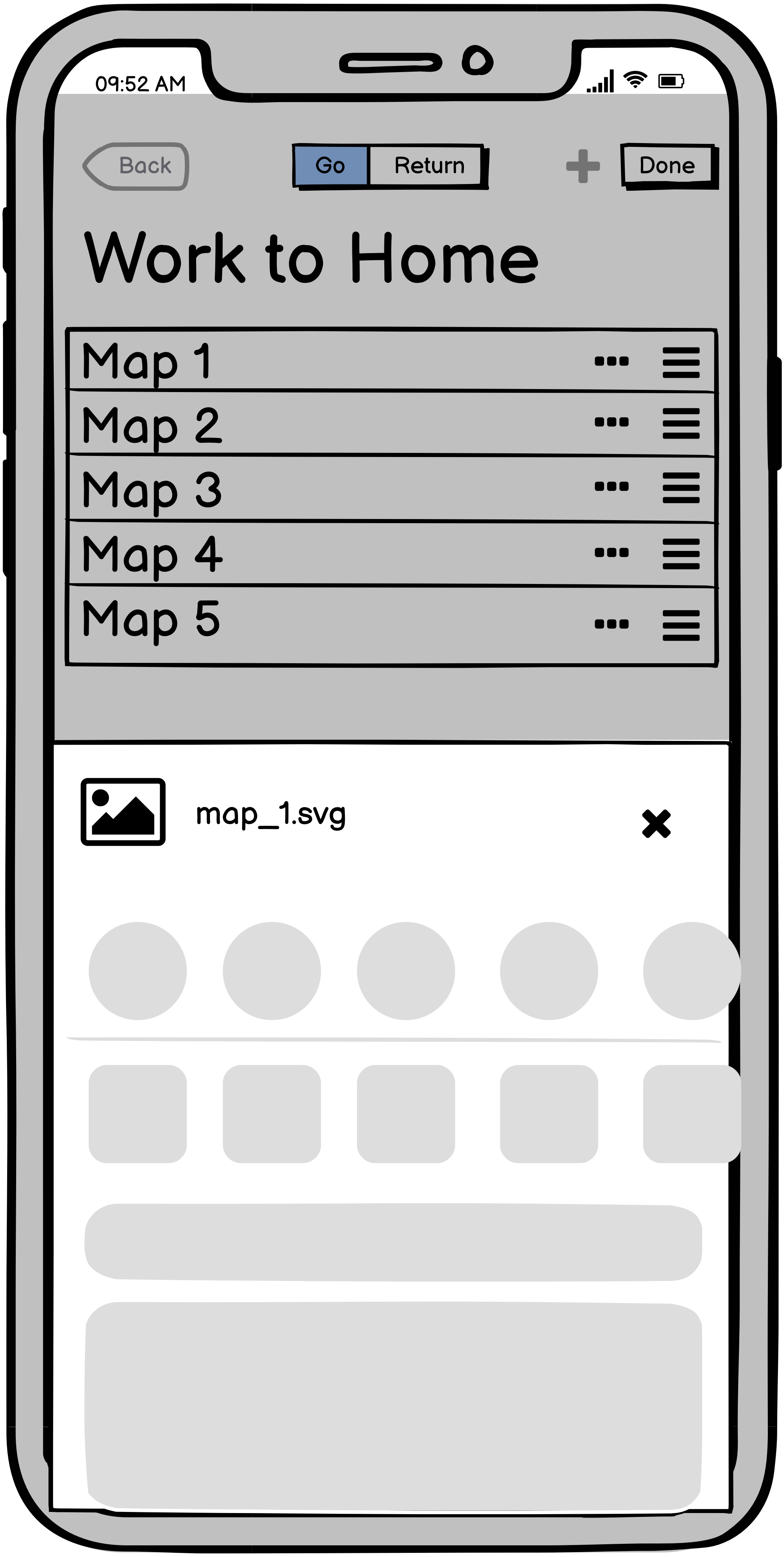
The user can also add new maps and edit the list.



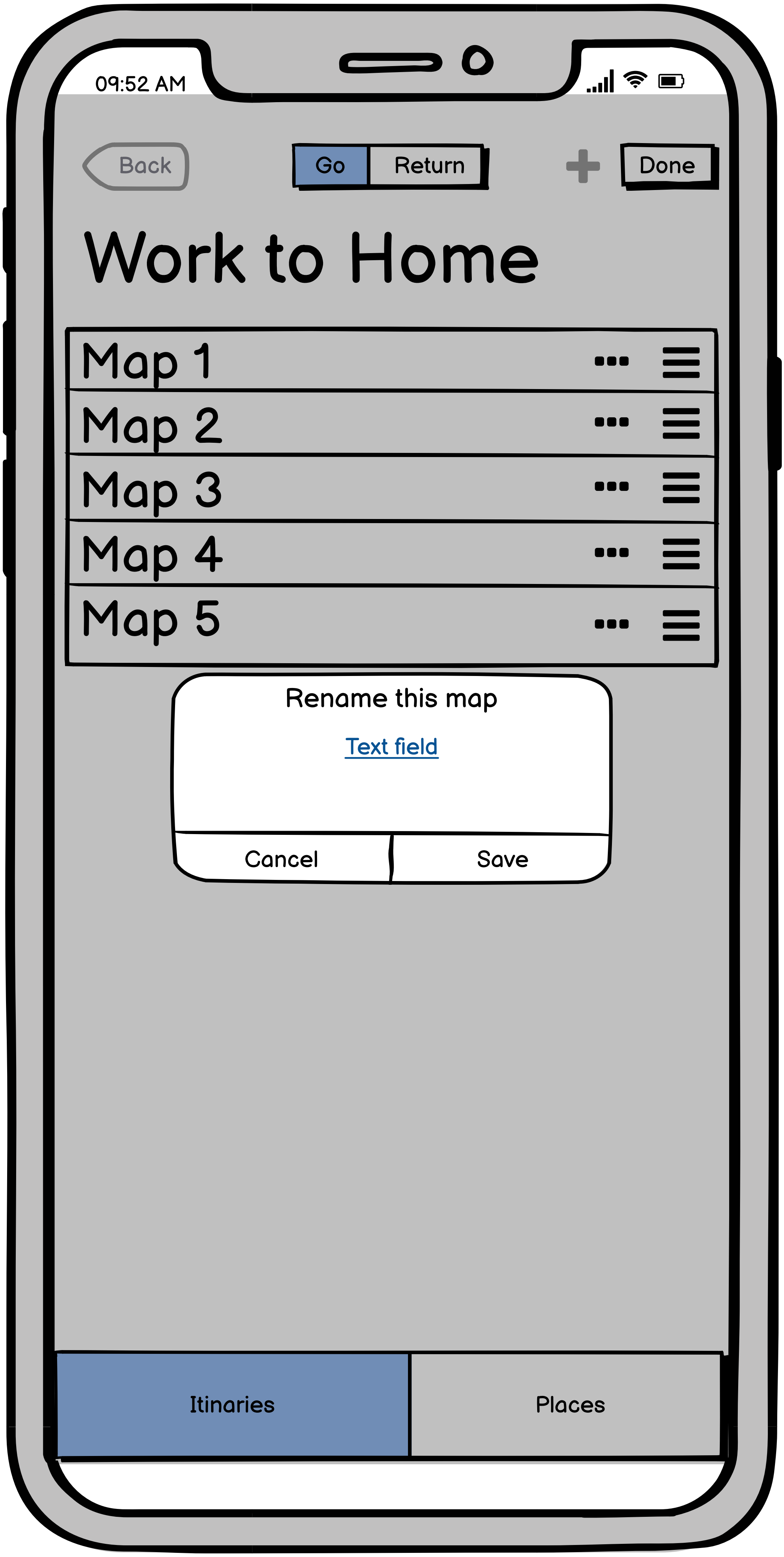
Edition includes maps reordering.



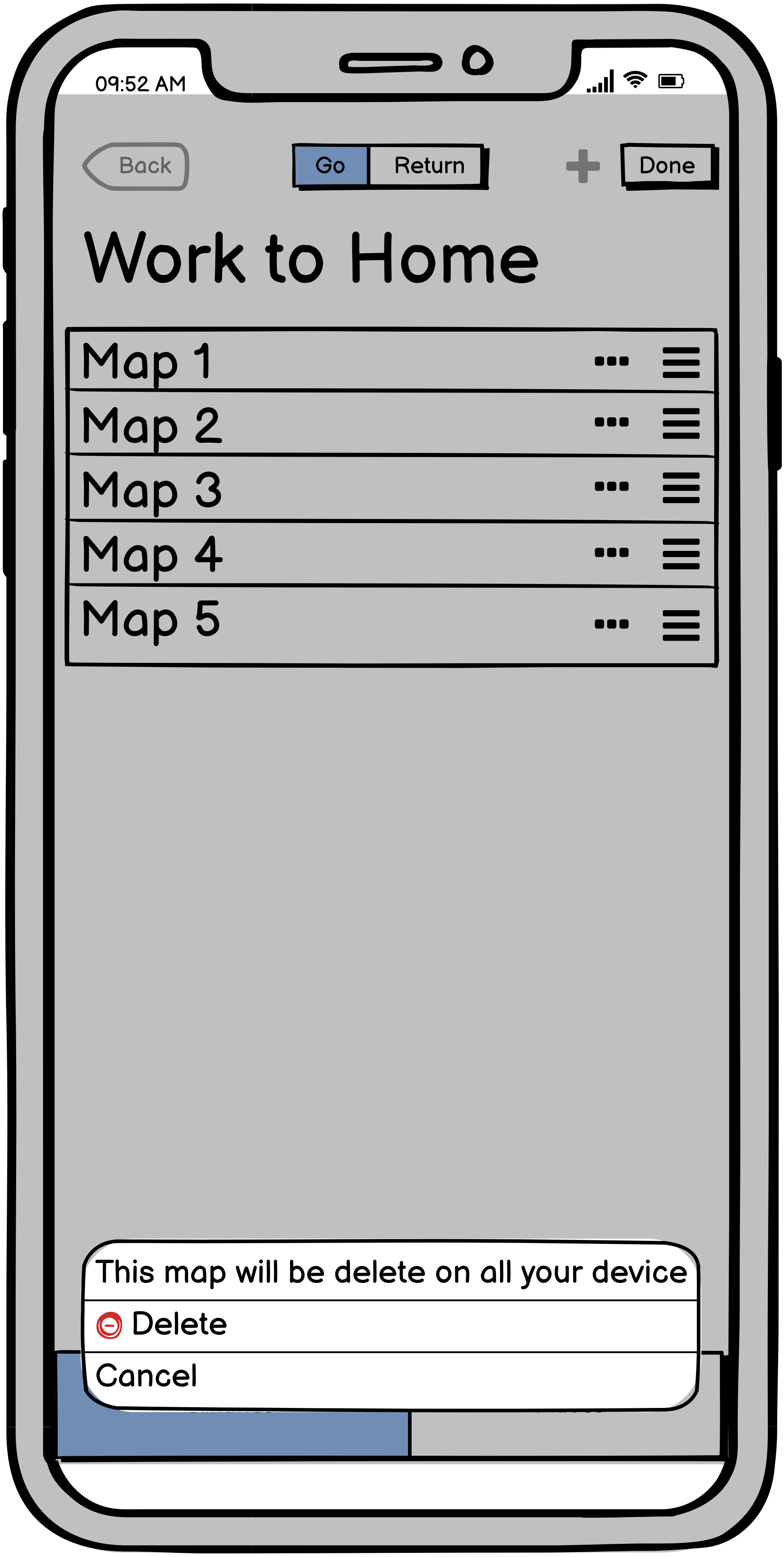
A standard options sheet is displayed when the "..." button is pressed.



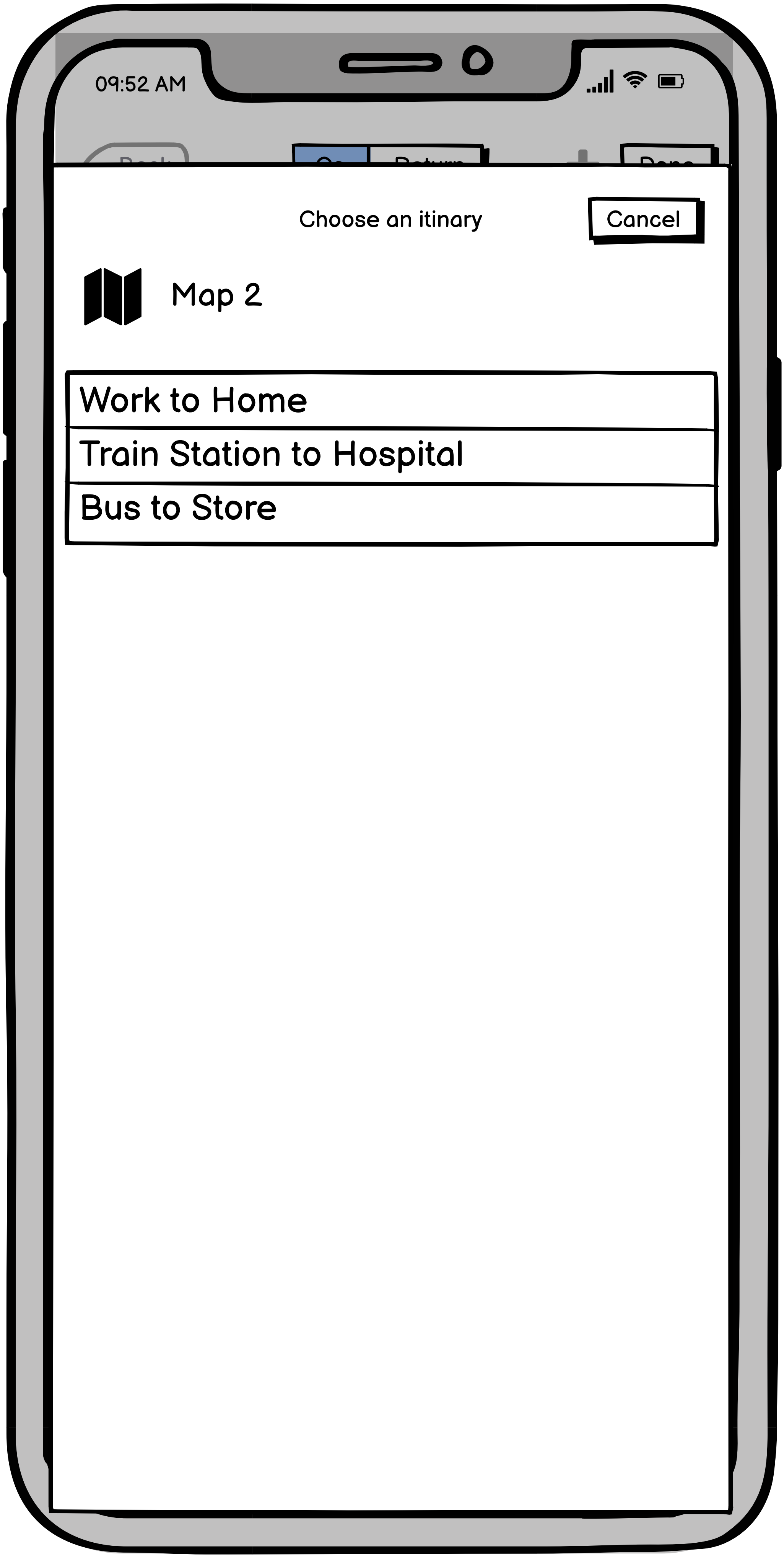
Standard iOS share sheet.



Standard iOS popup including a text field to enter the new itinerary name.

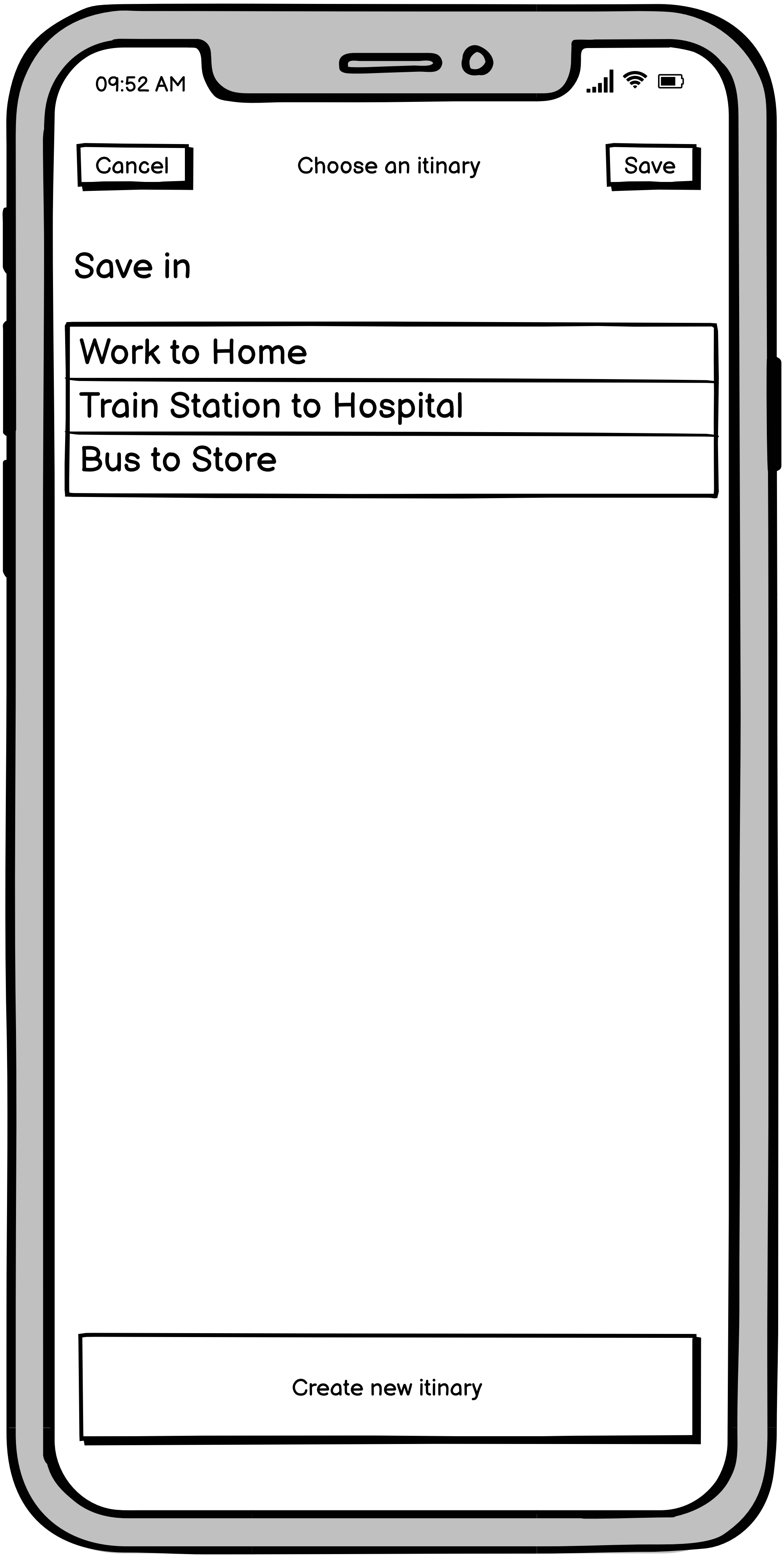


Standard iOS alert asking for deletion confirmation.



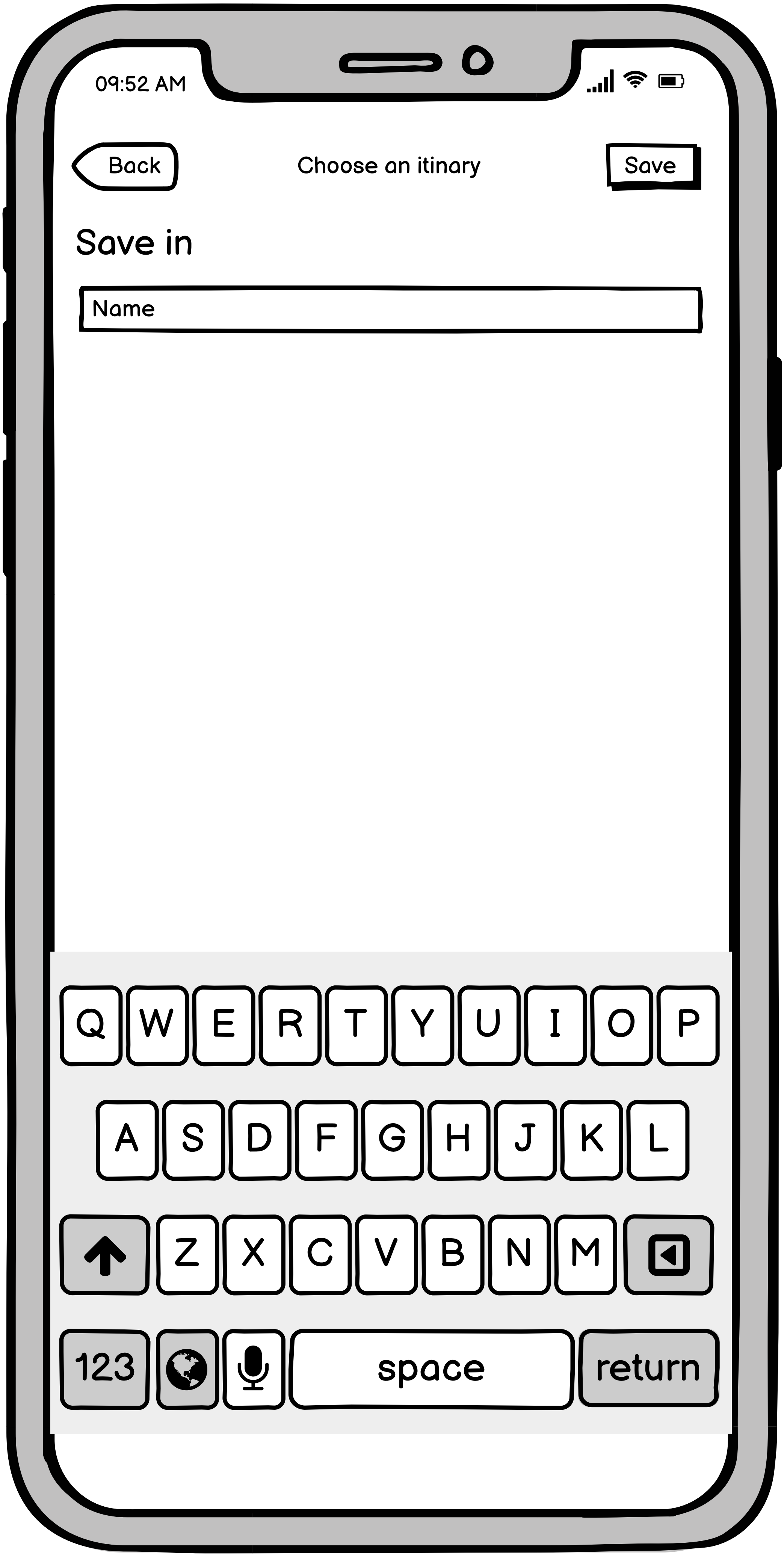
The user has the possibility to move to map into another itinerary. By clicking the itinerary, the map is moved and the modal is immediately closed.


09:52 AM
Cancel
Standard iOS file picker

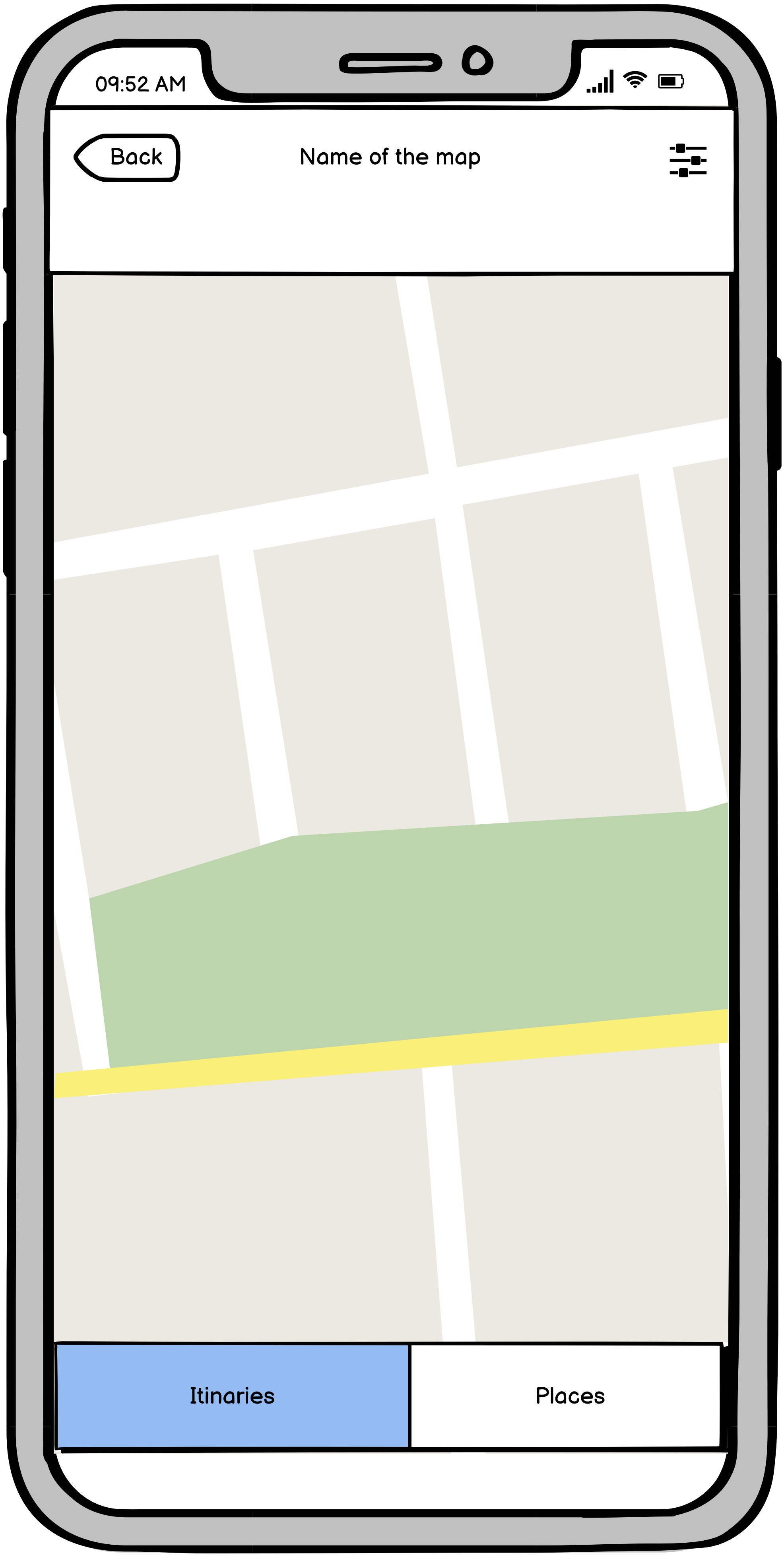


The same screen has in the "Itinerary - Move" is used for imports.

If the user opens a supported file type using the app, this screen is presented.

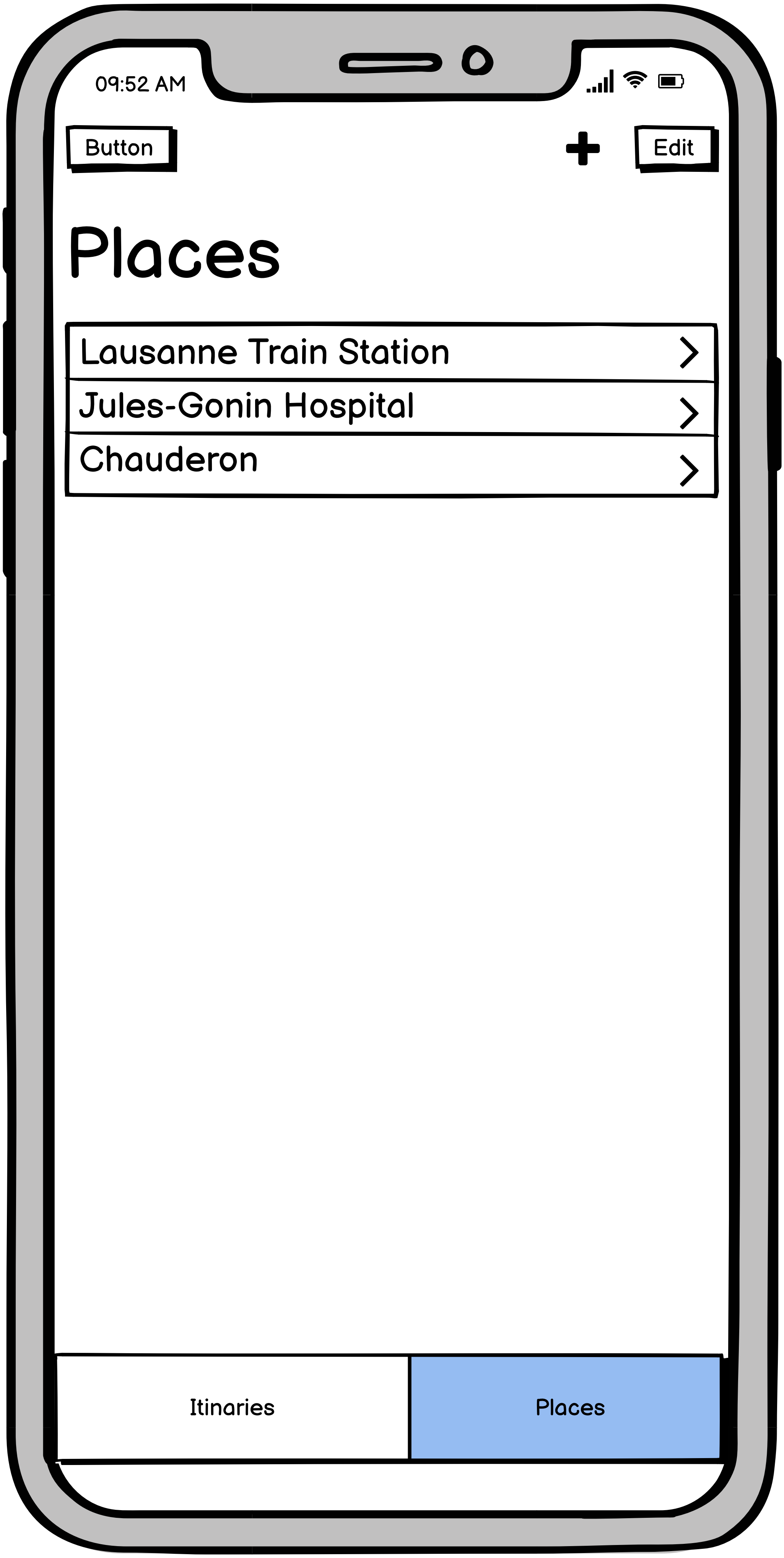


The same screen as "New itinerary - Step 1" is used.



Settings to select POIs, level of detail and potentially zoom.

Ajouter sound limit en bas et en haut.



Places are maps not linked to any itinerary. Those can include places like train stations or public places.

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