Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Development of pathNav: A Pedestrian Navigation Tool that Utilizes Smart Data for Improved Accessibility and Walkability

Final Report for
Transit IDEA Project 87

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Development of pathNav: A Pedestrian Navigation Tool that Utilizes Smart Data for Improved Accessibility and Walkability

Final Report

September 10, 2019

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pathVu is developing pathNav, a pedestrian navigation web app that utilizes smart data and a connected network of sidewalk and pathway data to improve accessibility and walkability. Typical pedestrian navigation apps do not use the sidewalk network to provide navigation, nor do they know the quality of the routes that they direct their users. In addition, these tools are not user-friendly for people with disabilities. pathNav will implement a route accessibility index (RAI) that considers the quality of the pathway as determined by data collected through pathVu's PathMeT device and/or reported through their free pathVu mobile app. A web interface will be built allowing pedestrians to search for the most accessible routes to their destination based on their custom profile (e.g. wheelchair user, individual with low-vision or blindness).</td></tr>
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Chapter 1. Introduction

1.1 Project Overview

The goal of this project is to develop pathNav, a pedestrian navigation tool that utilizes a connected network of sidewalk and pathway data. We will implement our published route accessibility index (RAI) that considers the quality of the pathway as determined by data collected through our PathMeT device and/or reported through our free pathVu mobile app. A web interface will be built allowing pedestrians to search for the most accessible routes to their destination based on their profile (e.g. wheelchair user, individual with low-vision or blindness). Upon completion of pathNav and the web interface, we will conduct user testing to investigate usability and commercial viability. We hypothesize that pathNav will: 1) Increase safety and reduce trip and fall injuries 2) Reduce social isolation of people with disabilities and older adults 3) Increase public transit ridership 4) Reduce trip/fall personal injury cases of pedestrians 5) Be accepted by our user group, suggesting it is commercially viable.

This project has the following aim with five objectives:

Aim: Develop a pedestrian navigation tool that improves accessibility, walkability, and safety

- **Objective 1.1:** Recruit (n=20) wheelchair users, older adults, people with visual impairments, parents with strollers, and ambulating pedestrians to participate in a design advisory group
- **Objective 1.2:** Develop a pedestrian navigation tool that utilizes a connected network of sidewalk and crosswalk centerlines, curb ramp locations, pathway quality, and can be tailored based on a pedestrian's mobility profile.
- **Objective 1.3:** Implement route accessibility index (RAI)
- **Objective 1.4:** Create a web interface for pedestrians to access
- **Objective 1.5:** Recruit (n=20) wheelchair users, older adults, people with visual impairments, parents with strollers, and ambulating pedestrians to participate in user testing to collect feedback about pathNav usability

1.2 Problem

The 3.6 million wheelchair users in the U.S. and 70 million around the world face significant challenges to participate fully in their communities, and people with visual impairments limit their travel to familiar places. Among wheelchair users surveyed in the U.S., the wheelchair and the physical environment were the most significant factors limiting community participation[1]. In this study, 47% of the wheelchair users stated that the physical environment limited their access to the community, which was just slightly less than the 53% who indicated the wheelchair limited their participation. Furthermore, one in three older adults

[1] Chaves, E.S. et al. Assessing the influence of wheelchair technology on perception of participation in spinal cord injury. Arch Phys Med Rehabil. 2004;85: 1854–1858.

fall each year, the majority of which occur outdoors, costing $34 million in direct medical costs. Furthermore, tripping and falling is the leading cause of traumatic brain injury. The condition of sidewalks and pathways affect all pedestrians, but people with disabilities, older adults, and injured veterans are especially affected by them.

Reducing the barriers in the physical environment is extremely challenging because individual property owners are usually in control and responsible for making their sidewalks accessible, and often many are non-compliant. For example, every house, building, or park that a pedestrian walks in front of is likely owned by a different person or organization. The Americans with Disability Act (ADA) and the Architectural Barriers Act (ABA) require that pedestrian paths be accessible, and accessibility guidelines were published by the U.S. Access Board[2] over 13 years ago. Property owners are ultimately responsible for compliance with these laws, but enforcement is the job of local municipalities. At times, they are forced through litigation to comply with their obligations under the ADA and ABA. An example is the high-profile class-action lawsuit against the city of Los Angeles, who recently agreed to pay $1.4 billion to make their sidewalks accessible[3]. The consequences of the slow pace of this litigation are borne by people with disabilities and older adults, who have to struggle to travel along the unmaintained sidewalks, or find routes around impassable sections.

Wheelchair users are particularly influenced by poor quality sidewalks. In addition to the research noted above that wheelchair users and people with visual impairments cite the physical environment as a barrier to participation, pathVu's co-founders (Pearlman, Duvall, Sinagra) performed several research studies at the Human Engineering Research Laboratories and the University of Pittsburgh, investigating the consequences of poor quality sidewalks on wheelchair users. These studies revealed that uneven or rough sidewalks result in discomfort and may cause long-term health consequences for wheelchair users[4,5,6]. Research funded by the U.S. Access Board, which published guidelines to help municipalities comply with the ADA and ABA, supported the development of tools, including the PathMeT device[7,8] and a recently approved ASTM standard[9] to help municipalities ensure sidewalks are safe for wheelchair users.

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[2] Board UA. ADA accessibility guidelines for buildings and facilities. ADAAG, Sept. 2002.

[3] L.A. agrees to spend $1.3 billion to fix sidewalks in ADA case. Los Angeles Times. 1 Apr 2015. Available: http://www.latimes.com/local/lanow/la-me-ln-lawsuit-broken-sidewalks-20150331-story.html.

[4] Garcia-Mendez Y, Pearlman JL, Boninger ML, Cooper RA. Health risks of vibration exposure to wheelchair users in the community. 2013.

[5] Cooper RA et al. Evaluation of selected sidewalk pavement surfaces for vibration experienced by users of manual and powered wheelchairs. J Spinal Cord Med. 2004;27: 468–75.

[6] Pearlman J, Cooper R, Duvall J, Livingston R. Pedestrian Pathway Characteristics and Their Implications on Wheelchair Users. Assist Technol. 2013;25: 230–239.

[7] Duvall J et al. Development of Surface Roughness Standards for Pathways Used by Wheelchairs. Transportation Research Board 92nd Annual Meeting. 2013.

[8] Sinagra E, Duvall J, Cooper R, Stuckey D, Kortum A, Pearlman J. Development and Characterization of a Pathway Measurement Tool (PathMeT). In: Board TR, editor. Transportation Research Board. Washington DC; pp. 1–9.

[9] Duvall J et al. Proposed Surface Roughness Standard for Pathways Used by Wheelchairs. In: Sciences NA of, editor. Transportation Research Board Annual Meeting, 2014.

These new standards help clarify the specifications for safe and passable sidewalks, but as noted above, compliance with these standards is extremely slow and complex to achieve. Meanwhile, wheelchair users continue to find sidewalks a major barrier to participation, and could benefit from navigation tools to help them more actively participate[10].

1.3 Document Overview

This document outlines the development of pathNav, a prototype web app to facilitate accessible pedestrian navigation. It outlines the feedback from an advisory group that was established to provide design guidance. Further, it provides details regarding the backend development of a pedestrian navigation tool that considers pathway conditions, route quality, and user preferences. This tool utilizes a route accessibility index (RAI) developed by pathVu team members. Based on user feedback, pathVu has created a frontend interface that considers accessibility, user-friendliness, and implements the backend navigation. This document discusses the prototype version as of the date of this report.

The contents of this document show the completion of Objectives 1.1 – 1.5 outlined above.

[10] Ding D et al. Design Considerations for a Personalized Wheelchair Navigation System. 2007 29th Annual Intl. Conference of the IEEE Engineering in Medicine and Biology Society.

1.4 Background Technology

1.4.1 *PathMeT (pronounced path-met)*

Figure 1: PathMeT is a portable microcontroller-based system that includes an accelerometer, inclinometer, laser, camera and GPS.

pathVu has developed a tool called PathMeT that characterizes sidewalk and pathway conditions, including roughness, running slope, cross slope, level changes, images, and location (Figure 1). The current version of PathMeT (www.pathvu.com/pathmet) is a manually propelled device, and it automatically collects important pathway data as it traverses a surface. It utilizes a laser, encoder, inertial measurement unit (IMU), camera, and GPS, to collect high fidelity data with millimeter resolution. After a pathway is measured, the data is integrated into Geographic Information Systems (GIS) software and can be displayed in programs such as Google Earth or ArcGIS (ERSI).

PathMeT is used in this project to collect the pathway data in order to determine the optimal routes based on RAI. PathMeT can also be used to help cities of all sizes collect objective, high-fidelity data regarding their sidewalk and pathway conditions. This data and the RAI can help to develop a prioritized plan for improving the sidewalk infrastructure. PathMeT has been used to complete projects in numerous cities for projects of all sizes, including one to map nearly 1900 miles of sidewalk.

1.4.2 pathVu App

In addition to PathMeT, pathVu has developed the pathVu Navigation mobile app, available for free on Android and iOS smartphones, that allows pedestrians to submit reports about the locations of hazards and other conditions along sidewalks and pedestrian pathways. The pedestrian simply tags the location of the report, selects the type of report (tripping hazard, curb ramp, construction, narrow sidewalk, etc.), and takes a photo. Reports can be both positive (curb ramp exists) or negative (tripping hazard) in nature. The data uploads immediately to the pathVu database and can be viewed through the app or web interface. Using data collected with PathMeT and through the pathVu app, we have begun building a comprehensive and updated database of sidewalk conditions that can inform both pedestrians and municipalities. This data was used in this study through visual map icons so that pedestrians, especially people with disabilities, will be aware of the most accessible and safe routes. Screenshots of the pathVu app are shown in Figure 2.

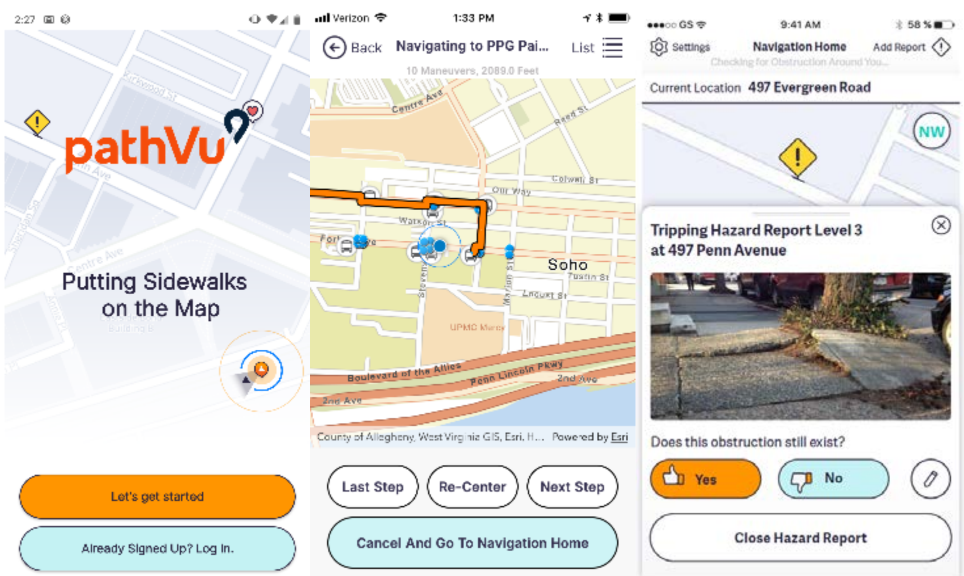

Figure 2: Screenshots of pathVu app. Welcome screen (left). Navigation map (center). Report details (right).

Chapter 2. Advisory Group Feedback

This chapter describes the objectives, protocol, and results of the Advisory Group discussions. The discussions were conducted during the months of January through April 2018 and led by Eric Sinagra, pathVu CEO and project manager. Twenty participants were involved in the discussions. This Chapter shows the completion of Objective 1.1 above.

2.1 Objectives

The primary objective of the advisory group and discussions were to hear from people with of varying abilities to understand how pathNav should be designed and which features to include. By listening to the needs of users, we can more accurately design the web app around what the user wants rather than based on our pre-conceived assumptions. The feedback allows us to understand how to incorporate accessibility-friendly functionality, which features are most important, and how the web app should look and feel from a visual and non-visual perspective. These objectives were met by identifying the answers to the four primary questions shown below.

1. How do users move around the community? What troubles do they have?
2. What apps and websites do they use on a daily basis?
3. What features do they like to see in apps/websites? What features do they dislike?
4. What design features are most important?

2.2 Protocol

The discussions were organized as an open discussion led by pathVu. Some discussions occurred in groups while others were individual interviews. Discussions occurred either in-person or over the phone. pathVu asked various open-ended questions, including the types of apps and websites participants use and how they travel around the community. A number of these questions are listed below. They are separated into General and Pedestrian Navigation specific questions. These questions do not encompass all of what was discussed but major categories of questions that were asked. Since it was an open discussion, the conversation flowed freely but with some guidance from pathVu.

During the discussion, participants were encouraged to speak freely about their experiences and in depth. While participants responded, pathVu took notes. Questions like “What mobile apps and websites do you use on a daily basis?” help to understand the types of designs that are most useful and that are user-friendly. Questions regarding the “frustration about the current navigation process” are framed to understand more in depth how users travel and how pathNav can be designed to help.

2.3 Participant Demographics

Table 1 presents the demographics of the twenty advisory group participants.

Table 1: Advisory Group Participant Demographics

Gender	Male	Female					
	13	7					
Age	18-39	40-64	65+				
	9	8	3				
Disability Types	Cognitive	Manual Wheel-chair User	Blind/Visually Impaired	Parents with Stroller	Power Wheel-chair User	None	Crutches
	2	2	4	3	2	6	1

2.4 Results

This section shows the results of the discussions. We have divided the chapter into two categories of questions: general app and pedestrian navigation questions. The major questions that were asked are presented under each category in italics. The participant responses and further explanation and clarification are provided under each question. These responses may include suggestions for possible design improvements for future phases. This section does not encompass all that was discussed, but includes major components and summaries from the discussions.

2.4.1 General Mobile App Usage Questions

1. *What mobile apps do you use on a daily basis? Do you use any navigation apps?*

- **ezRide Pittsburgh**: Participants use this to understand arrival and departure times of transit options in the city. Transit is an important component for the participants and they would like to see it integrated in future versions.
- **Facebook**: Participants use this to stay connected with friends and family, and for their social media interests.
- **Waze**: Participants use Waze to understand the road hazards along the route. They like the ability to view route information ahead of time and the ability to contribute data to others using the app.
- **Google Maps instead of Apple**: Participants said that they will use Google Maps instead of Apple because they can trust it more. Trust is an important attribute that participants often referenced during the discussion. pathNav should be built so that users can trust it.

- **Messenger:** Participants said that they use their phone's text messaging app the most.
- **News:** Participants use news apps to keep up to date with what is going on in the world.

2. *What is important to you about how an app works, the experience of the app?*

- **"Colors and Photos are important"**: Participants expressed interest in having controlled and purposeful use of colors and photos in the app. One sighted user commented that "the majority of the population are visual learners." Thus, the app interface should be designed in a way where the visual content has meaning. The colors should match what is typically seen in other apps and should be consistent throughout pathNav. Photos should be used to help people understand what is going on, whether through training or when depicting sidewalk problems. Visual content and reminders are very important.
- **"Simplified linear experience"**: Participants want a simplified design. They want the design to be as linear as process so that it is easy to follow and one screen directly follows another. The app should also be simple with little clutter and a clean design. Too much content on the screen could cause confusion and result in anxiety for users with cognitive disabilities.
- **User-friendly**: The web app should be user-friendly. It should flow correctly. It should be easy to use. It should be responsive. It should be reliable and trustworthy. Participants said that this is one of the most important features. If it is not user-friendly and they cannot trust it, then they will not use it.
- **Accessibility**: People with visual impairments stated that accessibility is extremely important to them. Having the ability to use a screen reader, contrast, and other accessibility features is the difference as to whether they can use the website or not. Too much content is difficult to comprehend. The concept of accessibility was common across most user groups and ties with the user-friendly and simplicity themes.

2.4.2 Pedestrian Navigation Questions

3. *When you travel locally, where do you go?*

- **Work**: Participants said that they most often travel to work. Some are coming from the city, while others come from the suburbs to get to work. Some take transit when they travel to work and walk a short distance from the bus stop to the building.
- **Parks:** Participants enjoying going to parks and taking walks for recreation. They often walk or take transit when traveling to the park.
- **Restaurants**: Participants said that they often travel to various stores and restaurants. In addition to knowing whether they can get to the restaurant, future versions should include the ability to know whether the restaurant is accessible.
- **Festivals:** Participants said that they enjoy going to festivals and events in the city. Those who live near the city are more inclined to take public transit than drive.

- **Grocery store**: While many who travel to the grocery store take a car, a number of participants said that they use public transit or walk to go shopping.

4. *Can you tell us what's frustrating about your current navigation process?*

- **"Not understanding the right direction…. not understanding current direction"**: Participants with disabilities expressed that one of their biggest frustrations when navigating is getting lost or turned around and not knowing the correct direction to travel. Knowing one's current direction and which direction to travel is invaluable. If someone started walking in the wrong direction, they would quickly become anxious and could potential enter into a dangerous situation if they are at a different location than they are expecting. This was a common point made by participants, but especially for those with disabilities.
- **Lack of sidewalks in suburban areas**: Those who live in the suburbs stated that there are often limited sidewalks near where they live. Understanding if there is even a sidewalk would be valuable to them. They often walk on the street because there is not a sidewalk. This makes them feel unsafe at times, and they are constantly aware of their surroundings.
- **Lack of benches**: Older adults expressed an interest in understanding the location of benches and places to sit. This includes transit stop details. This information would help them to understand how far they need to walk before having a place to rest, if needed. This feature was of interest to people with other mobility impairments as well.
- **Unsafe intersections**: Unsafe intersections was one of the most common discussion points and frustrations of participants. All participants expressed some level of frustration and anxiety crossing the street. This unsafe feeling was especially evident for people with disabilities. People with visual impairments often have difficulties staying in the crosswalk and may not know when to cross the street. Wheelchair users are sometimes difficult to see by cars. All participants at times felt unsafe crossing the street, especially at high traffic and high speed areas. Participants would like to understand which crosswalks are the safest and which are unsafe.

5. *What assumptions would you have about an app that proposes to help you navigate sidewalks more successfully?*

- **Simplicity**: Participants want the web app to be simple, similar to what was discussed above. They also want to be able to complete tasks with only one or two button clicks.
- **Send ETA or location**: Participants want to be able to share their ETA (estimated time of arrival) and current location with friends and family. This will help guarantee their safety and know that the person arrived safely.
- **Get notified of obstructions**: Participants would like notifications of some type to obstructions in their path. They are most interested in obstructions that will divert them to a different path. These notifications should alert them prior to taking their trip.

- **Simplified and unique iconography**: Participants would like different obstructions to have unique, but simple, icons. This is valuable so that they can easily identify a particular obstruction type by viewing the icon on the map. The icons should be simple so that it is not confusing and the screen remains uncluttered.
- **Wheelchair accessibility routes and different route options**: For users who also use a wheelchair, they would like to see the app display different route options based on user type. They would like to understand which routes are wheelchair friendly and which are not. This also allows our participants to have a backup plan in case of a closed path.
- **Nearby points of interests**: Participants would like to understand the location of nearby points of interest. This information is important because it can help them navigate by using the landmark as a point of reference. It also is important because they would like to find certain points of interest.
- **Crowdsourcing and group integration**: Participants were enthusiastic about the idea of crowdsourcing. The like the concept of a community effort to contribute information to help someone else. This allows them to be actively involved in what information is being used in navigation.
- **Weather**: Participants want to know what the weather is like prior to leaving their house. They want to know if it is raining, if they need a warm coat, and similar weather updates. At times, they can become flustered if they do not take the appropriate weather gear.
- **Customizable Experience**: While participants want the app to be simple, they also want a customizable experience unique to their abilities. They want to have the ability to turn on/off settings and adjust which routes they travel based on their unique settings.
- **Pre-trip planning**: Users want the ability to do pre-trip planning and do a virtual walk through of the route prior to taking the trip. This allows them to become familiar with the route ahead of time. If there is an obstruction on the route, they would know that a different route should be taken. They would be willing to take a longer route if there are too many obstructions, but the data needs to be accurate.
- **Simplified directions and instructions**: Similar to other comments regarding simplicity, the directions and other app instructions should be design to be simple. Participants suggested a maximum of three instructions at a time, however fewer is preferred.
- **Locate family restrooms and accessibility**: Participants want to know where family restrooms and other accessibility amenities are located nearby. This will provide them with improved independence and mobility.

6. *Are there any accessibility barriers you see when traveling?*

- **Obstructions on the sidewalk**: Participants said they often encounter obstructions along the route. They hate when those obstructions cause them to travel along a different route and change their plans. They would like to know about these conditions prior to starting their trip.
- **Missing curb ramps**: Wheelchair users said that one of the most frustrating things is travelling down a sidewalk to find out that there is not curb ramp to cross the street. This was a frustration for parents with strollers as well, but they said that they have the ability to go down the curb if necessary. Wheelchair users would like to know which locations do not have a curb ramp and the quality of the ones that do.

7. *How can your organization benefit from an app like pathNav?*

- **"Important for the staff to prepare for the journey with a patient"**: Staff at ACHIEVA, an organization that supports those with disabilities especially cognitive disabilities, often take walks with their patients around the nearby area. A pre-trip planning feature like pathNav would allow them to view the route ahead of time to prepare for the conditions ahead. This is especially important around this time since there is a lot of construction going on near the office.
- **"A learning tool… a comfort level… increase independence within a community"**: ACHIEVA staff participants expressed that pathNav could be used as a learning tool for their patients in order to teach them how to navigate sidewalk and intersections safely. They can review the routes ahead of time in a safe environment through pre-trip planning. Then, they can teach them how to safely maneuver in the community by training them on the web app. This will ultimately improve their independence and comfort navigating on their own.
- **"Increased level of safety"**: The number one concern of staff is patient safety. A web app like pathNav could improve staff and patient knowledge about safe routes, thus improving their safety when travelling.
- **"Won't feel alone and stuck out there winging it"**: ACHIEVA staff feel that a pedestrian navigation like pathNav would help to empower their patients. They expressed that their patients sometimes feel like they are "winging it" and pathNav would complement their abilities and provide that support so they do not feel alone.
- **"Routine is a big part of feeling independent. Do not want to have to relearn again"**: ACHIEVA staff reiterated the importance of routine for their patients. Routine means that the route will be the same and they do not need to learn a new route. If their patients have a routine, this means that they can have increased independence.

8. *Do you travel the same routes routinely? How often?*

    - **Yes, very often**: Participants with cognitive disabilities expressed that it is very important that they travel the same routes with which they are familiar. They do not often divert to different routes, even crossing to the other side of the street. A change in route or timing can cause increased anxiety for the users. If there is a change it their route quality, such as the existence of construction, it would be very valuable for them to know this ahead of time. Understanding if there is a change of course in advance would decrease their anxiety and make them feel much more comfortable. Further, all participants expressed some level of taking the same or similar routes as they travel to their destinations.

9. *What concerns would you have with using an app that proposes to help you navigate sidewalks more successfully?*

    - **Negative travel experience**: Participants expressed concerns in the event that there was a negative travel experience. They said that a negative travel experience may cause hesitation of using the web app in the future.

Chapter 3. System Requirements

This chapter summarizes the list of pathNav system requirements and discusses its design. The requirements and design features were based on the Advisory Group Feedback summarized in Chapter 2. The backend and frontend design are discussed.

3.1 pathNav Requirements

A. ***Map View***: A map will appear as the home screen, which will allow users to see the pathways and conditions around a particular point of interest.

B. ***User Accounts****:* Users can create an account to customize and save their settings. This will save their comfortability settings, favorites, profile information, and similar information identified below.

C. S***tep-by-step navigation using pathway/sidewalk network and route quality***: This pedestrian navigation will not only use the sidewalk/pathway network, but it will use the quality of the route. The quality of the route is determined by the PathMeT device and will total over 60 miles, primarily in the Oakland, Downtown, and Shadyside neighborhoods. The user will specify through the interface which sidewalk attributes are most important to them. Users will submit their starting and ending addresses by either entering the address or searching for a point of interest by name. One suggested route will be shown to the user on a map with step-by-step directions. Navigation will be for pre-trip planning purposes and will not include real-time directions.

D. ***Preview Mode***: Users can preview a destination and its surrounding pathway conditions. When previewing the destination, users enter the destination address or name, and the map will zoom to the desired point of interest.

E. ***Comfortability Settings and Alert Settings***: A settings menu will be available so that users can specify which sidewalk attributes are important and which they prefer to avoid. This information will go into the routing algorithms and determine the path the suggested path. Users will have the ability to turn on/off whether they would like to be alerted to potential hazards along their path.

F. ***Preset profiles***: In addition to having custom settings, users can select from wheelchair user, blind/visually impaired, cane/walker, or no disability user profiles. This is for users who prefer not to set custom settings.

G. ***Crowdsourced reports***: Users can submit reports regarding the location of pathway attributes, such as tripping hazards. Users can submit the location, image, and type of report. The data appears on the map once reported/approved.

H. ***Recent Paths***: pathNav will show recent paths and/or destinations that a user has travelled.

I. ***Favorites***: Users have the ability to create a list of their favorite destinations. Users can create a custom name for the destination and use the Favorites for quick access.

J. ***Web Interface***: The features described above are presented through a web app interface where users can access through a web URL.

3.2 High-Level Design

Figure 3 provides a high-level design of pathNav. It shows the different components and activities of the web app. The different components interact with the central database in different ways, sometimes calling data and sometimes sending data. The major components of the design are: Navigation (Set a New Path), Preview Destination, Comfortability Settings, and Reporting. These features have been described above.

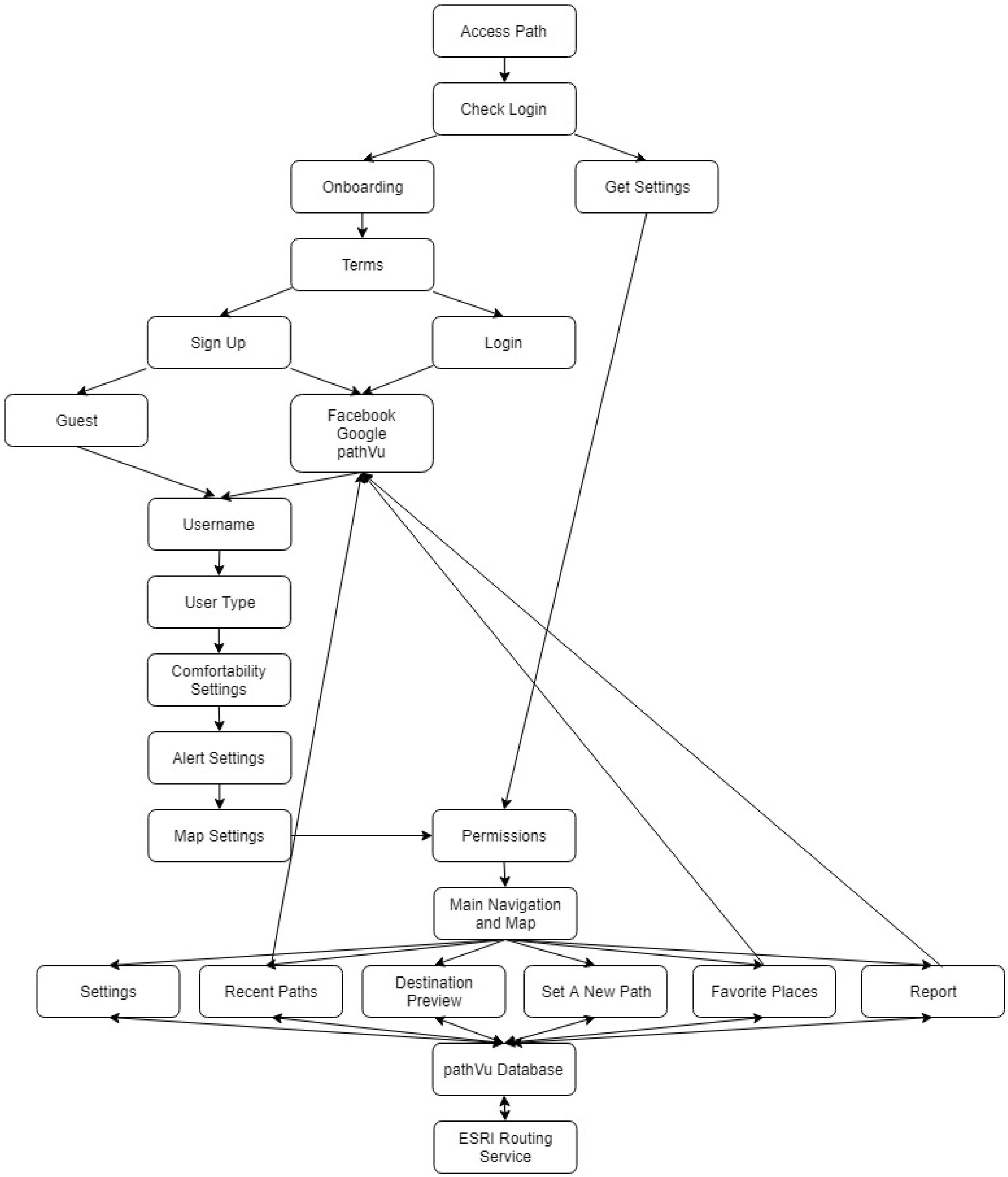

Figure 3: pathNav high-level design

Chapter 4. Backend Design

This Chapter describes the backend development and database design that are used in pathNav. Further, it discusses the implementation of the RAI and the navigation algorithms. The design characteristics discussed in this chapter are based on the feedback from the Advisory Group described in Chapter 2.

4.1 Database Design

Figure 4 shows a diagram of the database design and how the different data tables work together. This diagram shows the PathMeT image, crowdsourcing, favorites, recent paths, and user login, type, and settings data tables. A description of each element is provided below. Tables 2-4 show the pathway segment, curb ramp, and transit database structures and descriptions regarding location and attribute quality. The pathway segment, curb ramp, and transit data is stored in an ArcServer database and is identified in Figure 3 as ESRI Locator Service.

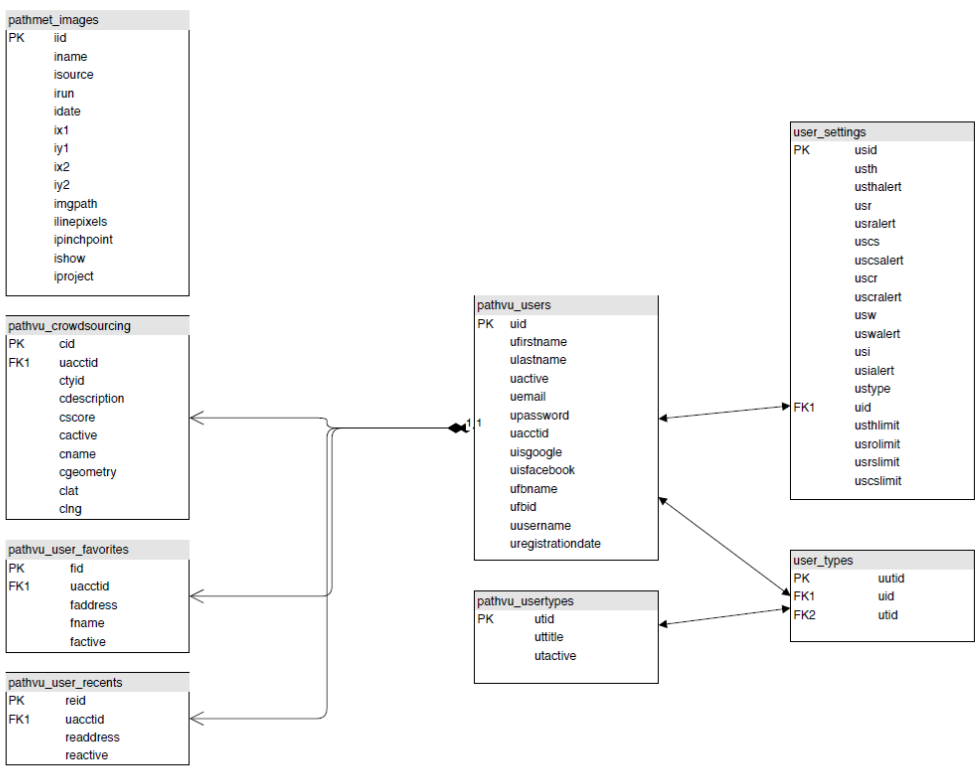

Figure 4: pathNav database design

4.1.1 Database Field Descriptions

pathmet_images – data about the images captured from PathMeT devices

- iid – primary key – unique identifier for each image
- iname – Image file name
- isource – the device that captured the image
- irun – the run for the Image
- idate – the date the image was captured
- ix1 – x coordinate for the first point used in the width measurement tool
- iy1 – y coordinate for the first point used in the width measurement tool
- ix2 – x coordinate for the second point used in the width measurement tool
- iy2 – y coordinate for the second point used in the width measurement tool
- imgpath – physical path to the image on the server, relative to the root share
- ilinepixels – total pixels between the clicked points in the width measurement tool
- ishow – Boolean to determine if the image should be listed in the width measurement tool
- iproject – project associated with the image

pathvu_users – registered users

- uid – primary key – unique identifier for each user
- ufirstname – user's first name
- ulastname – user's last name
- uactive – Boolean to determine if the user completed registration
- uemail – user's email address
- upassword – hash password; only if the user registers with email address
- uacctid – front facing unique account identifier; randomly generated
- uisgoogle – Boolean to determine if the login is a Google account
- uisfacebook – Boolean to determine if the login is a Facebook account
- ufbname – user's Facebook name
- ufbid – user's Facebook account ID
- uusername – pathVu username
- uregistrationdate – the date the user registered with pathVu

pathvu_crowdsourcing – crowdsourced

- cid – primary key – unique identifier for each report
- uacctid – foreign key to pathvu_users – identies which user submitted the report
- ctyid – type of report
- cdescription – report description
- cscore – report score based on user votes
- cactive – Boolean to determine if the report should be displayed
- cname – report name
- cgeometry – geometry to locate the report on the map
- clat – latitude
- clng – longitude

pathvu_user_favorites – users' favorite locations

- fid – primary key – unique identifier for each favorite
- uacctid – foreign key to pathvu_users – identifies which user owns the favorite
- faddress – address of the favorite
- fname – name of the favorite
- factive – Boolean to determine if the favorite should be displayed

pathvu_user_recents – users' recent locations

- reid – primary key – unique identifier for each recent
- uacctid – foreign key to pathvu_user – identifies which user owns the recent
- readdress – address of the recent
- reactive – Boolean to determine if the recent should be displayed

pathvu_usertypes – default user types

- utid – primary key – unique identifier for each type
- uttitle – type title
- utactive – Boolean to determine if users can use the type

user_settings – list of settings for each user

- used – primary key – unique identifier for each list of settings
- usth – tripping comfortability
- usthalert – Boolean for tripping hazard alerts
- usr – roughness comfortability
- usralert – Boolean for roughness alerts
- uscs – cross slope comfortability
- uscsalert – Boolean for cross slope alerts
- uscr – curb ramp comfortability
- uscralert – Boolean for curb ramp alerts
- usw – width setting
- uswalert – Boolean for width alerts
- usi – intersection setting
- usialert – Boolean for intersection alerts
- uid – foreign key to pathvu_users – identifies which user owns the settings
- ustype – the type of user
- usthlimit – tripping hazard limit
- usrolimit – roughness limit
- usrslimit – running slope limit
- uscslimit – cross slope limit

user_types – list of users and their types

- uutid – unique identifier for each user-type pair
- uid – foreign key to pathvu_users
- utid – foreign key to pathvu_usertypes

4.1.2 Map Data Attribute Descriptions

This section provides a description of the fields stored in the database. Tables 2-4 describe the pathway segment, curb ramp, and transit field attributes, respectively. More fields can be added in the future, if necessary. This data can be used in the navigation algorithm or shown to the user via the map in the future, where necessary.

Table 2: Pathway segment data attributes

Field	Description	Units
FID	Unique ID for pathway	None
Picture_Di	Image distance from the beginning of the run	Feet
Max_Roughn	Maximum roughness for that segment	mm/m
Max_Runnin	Maximum running slope for that segment	Degrees
Max_Cross_	Maximum cross slope for that segment	Degrees
Max_Trips_	Maximum tripping hazard over 0.25 inches for that segment	inches
Num_Trips	Number of tripping hazards greater than or equal to 0.25 inches	None
Max_Dep_in	Maximum depression over 0.25 inches for that segment	inches
Num_Dep	Number of depressions over 0.25 inches for that segment	None
Overall_Le	Total length of a particular run (same file name)	Feet
Segment_RA	Route Accessibility Index (RAI) of that segment	None
Run_RAI	Average RAI of all the segments of a particular run	None
Picture URL	URL for image	None
File Name	File name of a particular run	None
Picture Name	Unique ID for image	None
Flags	Subjective hazards flagged during data collection	None
PictureFile	HTML to make image appear in popup window	None
Length	Length of segment	Feet

Table 3: Curb ramp data attributes

Field	Description*	Data Range
FID	Unique ID for each curb ramp	N/A
Detectable Warning	Does it have detectable warning	Yes/No
Lippage (1-Poor, 3-Good)	Quality of transition from street to curb ramp or curb ramp to sidewalk	1-3
Width (1-Poor,3-Good)	Quality of width of curb ramp	1-3
Slope (1-Poor,3-Good)	Quality of running or cross slope of curb ramp	1-3
Obstructions	Are there obstructions on or near the curb ramp	Yes/No
Overall Condition (1-Poor,3-Good)	Overall quality of curb ramp	1-3
CreationDate	Creation date of this curb ramp	Date
Creator	Creator of this curb ramp on map	N/A
EditDate	Date data was last edited	Date
Editor	User who last edited data	N/A
ImageURL	URL to access image	N/A
Passability	Is the curb ramp passable or note	Passable/Not Passable

Table 4: Transit data attributes

Field	Description*
FID	Unique ID for each transit stop
StopID	Unique ID given by port authority for each transit stop
Stop_Name	Name/Location of stop
Direction	Direction into or out of downtown
Routes	Transit routes that stop at this location
Latitude	Latitutde of transit stop
Longitude	Longittde of transit stop
Mode	Mode of tranportation this stop supports
Shelter	Type of shelter
Stop_type	Type of transit stop

4.2 Data collection/visualization

The test data that is being used for this project is comprised of approximate 60 miles of pathway data in Downtown, Oakland, and Shadyside neighborhoods in Pittsburgh. Figures 5 and 6 show a screenshot of the data in the Downtown and Oakland/Shadyside neighborhoods, respectively. The pathway centerline data was collected with the PathMeT device. The pathways are shown as ten-foot segments and contain the data in Table 2. The pathway segments have been color-coordinated based on quality: green (good), yellow (moderate), red (poor). Curb ramps are shown as the blue icon with the accessibility symbol. The data associated with each curb ramp is shown in Table 3. This data was collected by a pathVu technician who walked the paths. Lastly, the transit data is shown by the black icons. The transit types include bus and rail. This data comes from open data on the ESRI database, created by the Port Authority of Allegheny County. pathVu would like to continue to gather data in additional neighborhoods and cities, but for the purposes of functionality and design testing only the 60 miles was used.

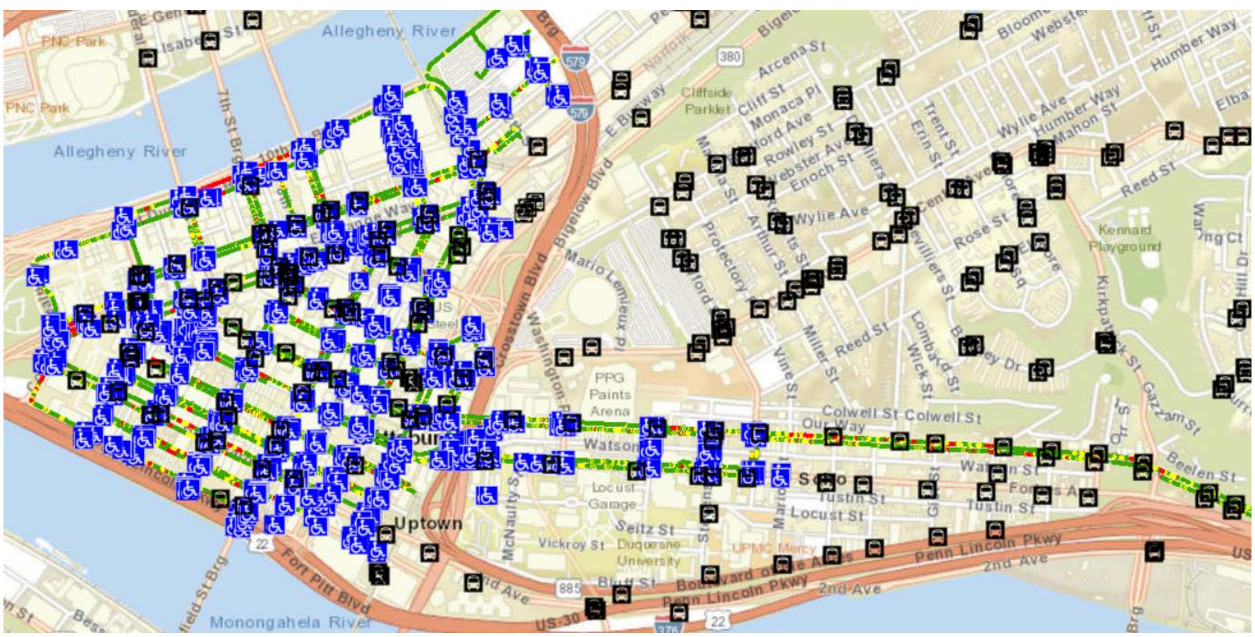

Figure 5: Downtown Pittsburgh data screenshot

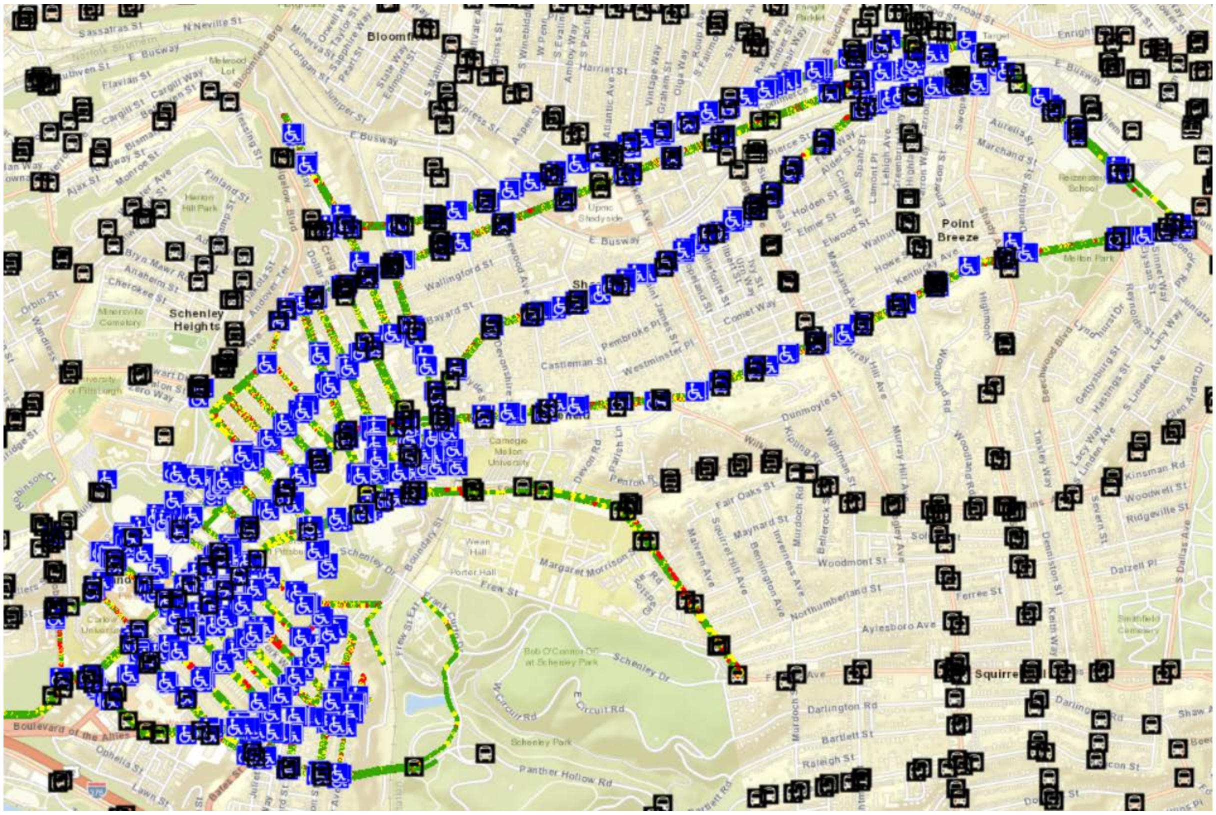

Figure 6: Oakland and Shadyside, Pittsburgh data screenshot

4.3 Backend navigation

pathVu has developed a proprietary method to determine the optimal route for pedestrians based on their comfortability settings, pathway locations, and pathway quality. This was previously referred to as the RAI and is implemented during this step. Since there are proprietary components, we will not discuss the actual algorithm, but the overall functionality. First, the user sets his/her comfortability settings for each of the obstruction types (Figure 7). Next, the value selected by the user from each category is sent to the pathNav/RAI algorithm. Based on these user settings, the algorithm identifies weights for each of the obstruction types. These weights, along with the pathway quality and length of routes are used in the algorithm to identify the route that is optimal for the user based on those settings. Figure 8 shows an example of the navigation algorithms working through a test interface using ArcGIS. It can be seen that the route shown is along the pathway network and does not show the shortest route in this case. Typical navigation products show only the shortest route based on the road network. This example shows a use case where a user preferred to travel a more accessible route rather than the shortest one. This milestone shows the completion of Objectives 1.2 and 1.3, identified above.

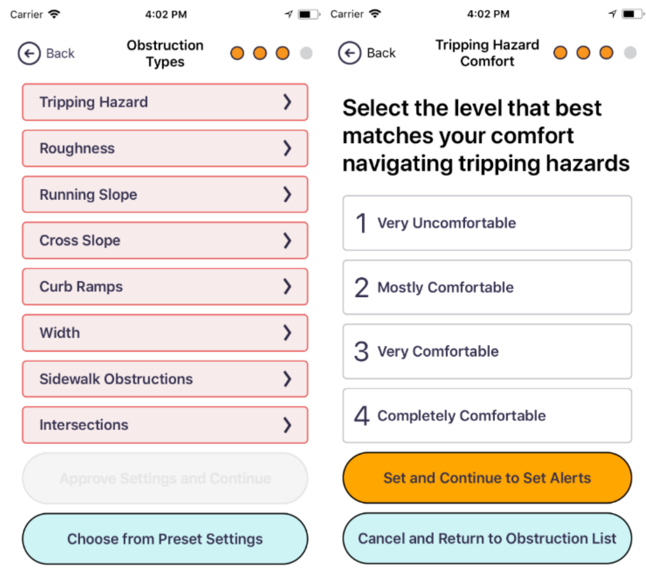

Figure 7: User Comfortability Settings screens

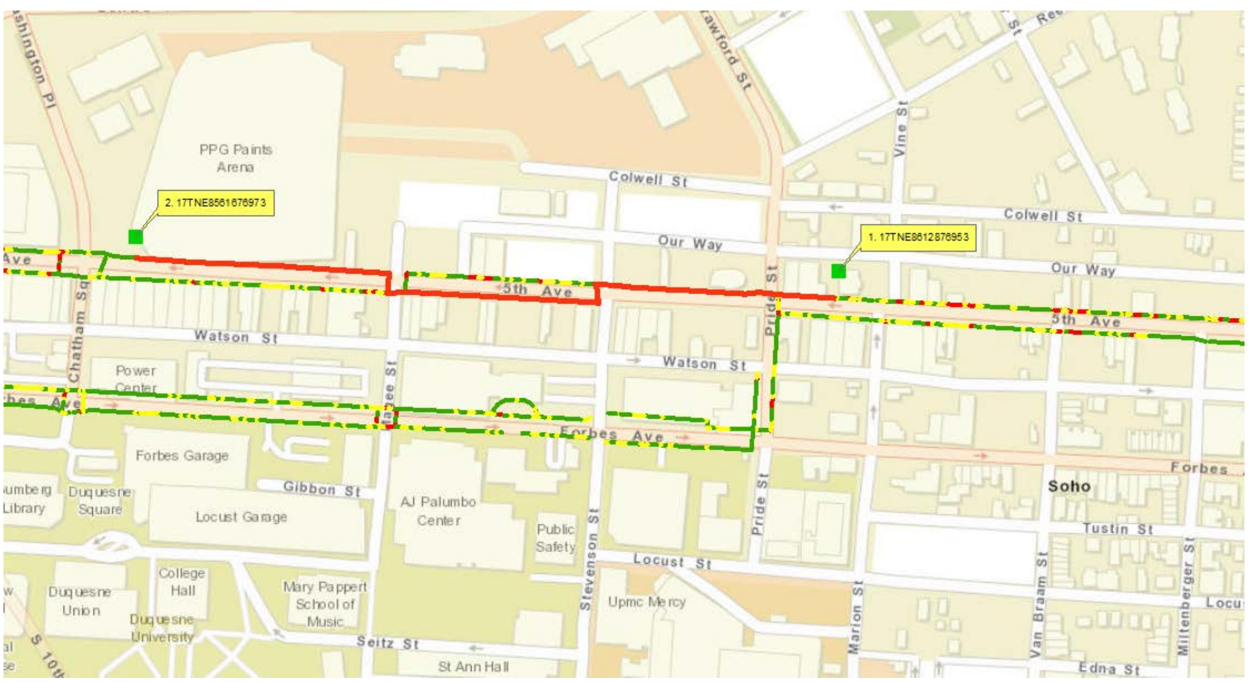

Figure 8: Sample pedestrian route based on user Comfortability Settings and shown in ArcGIS

Chapter 5. Frontend Design

5.1 Interface Design

In order to establish the design of the interface, pathVu worked with a Pittsburgh small business called Fine Humans. Figure 9 shows the mood board that was created to express the types of design and style characteristics that were considered for pathNav. The mood board does not necessarily represent the colors that were considered for the design. The mood board is intended to show aspects such as button size and placement, text style, map representation, color contrast, level of simplicity, and similar design features. This mood board was used when considering the final pathNav interface mockups. The mood board and designs are generally shown as mobile app because the pathNav design is intended to be dynamic so that it can be used on mobile platforms.

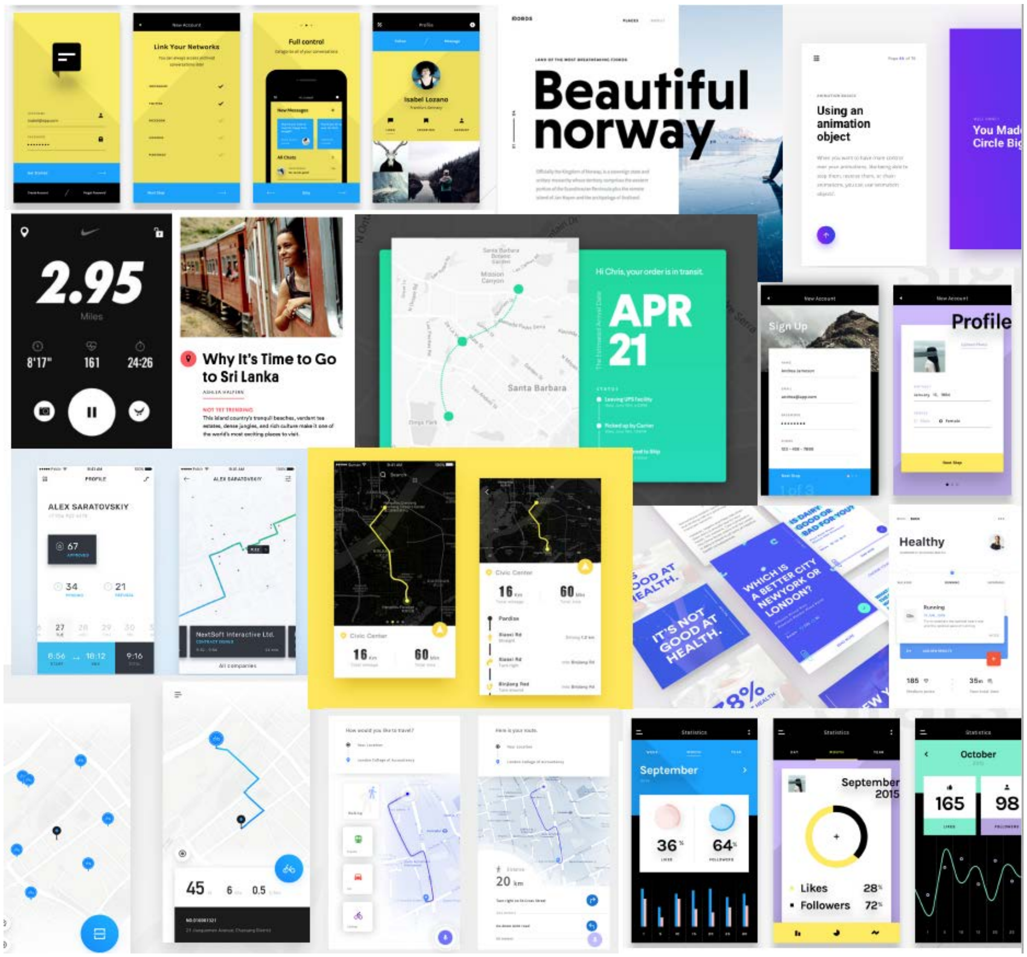

Figure 9: pathNav mood board design

5.2 Interface Mockups

Figure 10 in this section shows the interface mockups for select pathVu Navigation mobile app screens being developed as part of another project. The mobile and web platforms were designed to resemble one another to provide a seamless transition for users who will use both platforms. pathVu and Fine Humans went through approximately three or four design iterations prior to establishing these final versions. The Advisory Group Feedback was used to identify the design characteristics, such as level of simplicity, button size, button placement, and flow. Future iterations may be necessary as more features are added and as user feedback is received.

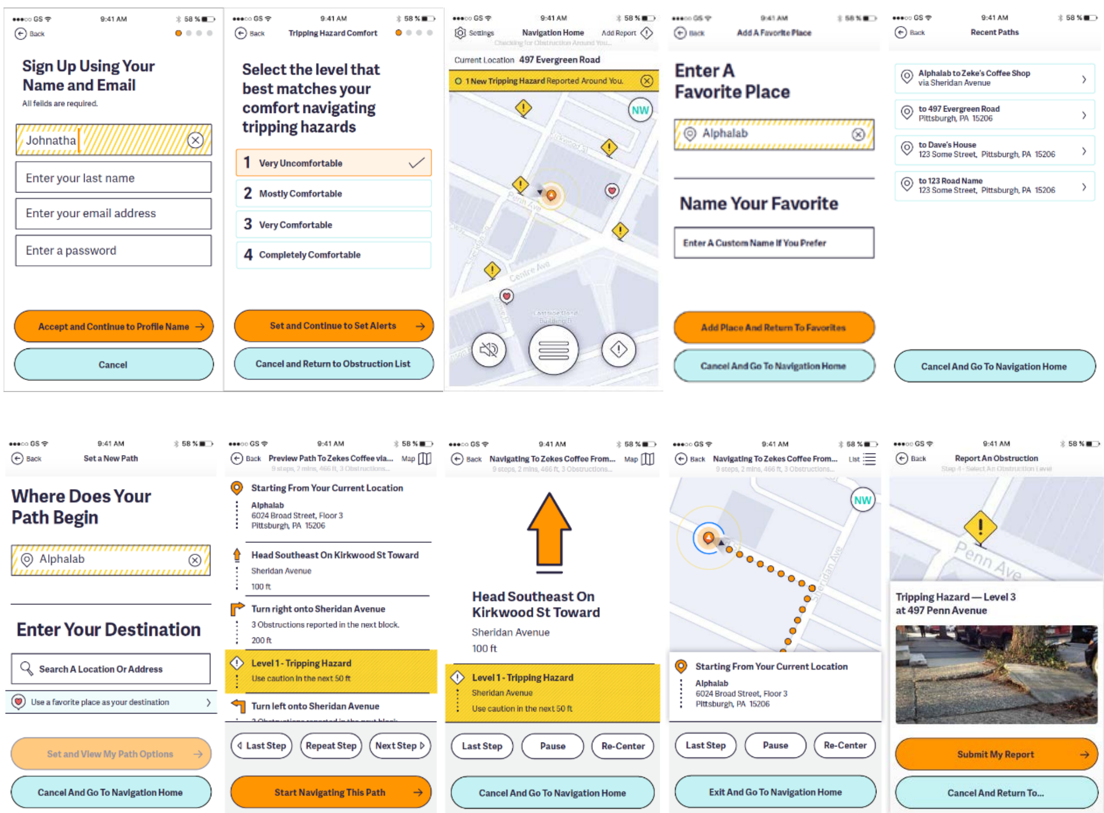

Figure 10: pathNav Design Mockups

Chapter 6. pathNav Features

This chapter summarizes the features implemented as part of the pathNav web app. The link below can be used to access the pathNav app. The app and features listed in this section represent those completed as of the date of this report. Additional development and refinement will be completed following the completion of this project. The status of this web app may be represented as a working prototype of pathNav that can be used to provide pedestrians with accessible directions based on the comfort settings. This Chapter shows the completion of Objective 1.4, identified above.

pathNav URL: https://pathvudata.com/pathvu/navigation/index10.php

The list of features below, A through J, match those requirements identified by the Advisory Group in Chapter 3. Figure 11 shows where each feature has been implemented in the web app.

A. ***Map View***: A map appears as the home screen, allowing users to see a heat map of the pathway conditions. The pathway centerlines are color coordinated as good (green), moderate (yellow), and poor (red). Users have the option to view curb ramp, crowdsourced hazard data, and transit stops by selectin the appropriate layers in the Settings menu. The map also provides a route for users when they choose to "Get Directions." Currently, the map does not support the ability to view data about the pathway, curb ramp, transit, or other feature quality. This will be implemented in the next phases of development after this project.

B. ***User Accounts****:* Users can create an account to customize and save their settings. Users have the ability to set their comfort settings regarding tripping hazards, roughness, running slope, cross slope, and width. This information is used in calculating the optimal route for the user based on those settings. Further, users create a username and identify their pedestrian type (i.e. blind/visually impaired, walking and sighted, wheelchair/scooter user, or cane/walker user). Users also have the ability to save their favorite places for quick access in the app. This profile can also be used in the pathVu Navigation mobile app.

C. S***tep-by-step navigation using pathway/sidewalk network and route quality***: This pedestrian navigation not only uses the sidewalk/pathway network, but it uses the quality of the route. The quality of the route is determined by the PathMeT device. The pilot area covers over 60 miles of pathway, primarily in the Oakland, Downtown, and Shadyside neighborhoods. The user specifies through the interface which sidewalk attributes are most important to them. Users submit their starting and ending addresses by either entering the address or searching for a point of interest by name. This is typically done after the user selects the “Get Directions” button. One suggested route will be shown to the user on the map with step-by-step directions. Directions and suggested route are for pre-trip planning purposes and do not include real-time directions like in typical driving apps. Figure 12 shows a sample route and directions.

D. ***Preview Mode***: Users can preview a destination and its surrounding pathway conditions. When previewing the destination, users enter the destination address or name, and the map will zoom to the desired point of interest.

E. ***Comfortability Settings and Alert Settings***: A settings menu is available so that users can specify which sidewalk attributes are important and which they prefer to avoid. Users have the ability to set their comfort settings regarding tripping hazards, roughness, running slope, cross slope, and width. This information is used in calculating the optimal route for the user based on those settings. Further, users create a username and identify their pedestrian type (i.e. blind/visually impaired, walking and sighted, wheelchair/scooter user, or cane/walker user). Users have the ability to turn on/off whether they would like to be alerted to potential hazards along their path. This Comfort and Alert Settings menu allows the user to set these alert settings but the app does not currently provide alerts. This feature will be implemented as part of the next phase of development following this project.

F. ***Preset profiles***: In addition to having custom settings, users can select from blind/visually impaired, sighted and walking, wheelchair/scooter user, or cane/walker user profiles. This is for users who prefer not to set custom settings. Figure13 shows a close-up view of this screen, which appears in the left panel of the interface.

G. ***Crowdsourced reports***: Users can choose to view hazards that have been reported in the pathVu Navigation mobile app. Figure 14 shows a close-up view of the Map Settings that appears in the left panel on the interface allowing the user to select the features to be shown on the map, including crowdsourced reports. Users cannot yet submit reports regarding the location of pathway attributes, such as tripping hazards. In the next stage of development, users will be able to submit the location, image, and type of hazard report. The submitted data will appear on the map once reported/approved.

H. ***Recent Paths***: pathNav shows recent destinations that a user has travelled. Users can use this menu to quickly select from points of interest recently searched.

I. ***Favorites***: Users have the ability to create a list of their favorite destinations. Users can create a custom name for the destination and use the Favorites for quick route access. Also, users can use their Favorites in the pathVu Navigation app to be alerted as they approach their favorite destinations.

J. ***Web Interface***: The features described above are presented through a web app interface where users can access through a web URL: https://pathvudata.com/pathvu/navigation/index10.php.

Figure 11: pathNav Interface with Features A-J Identified

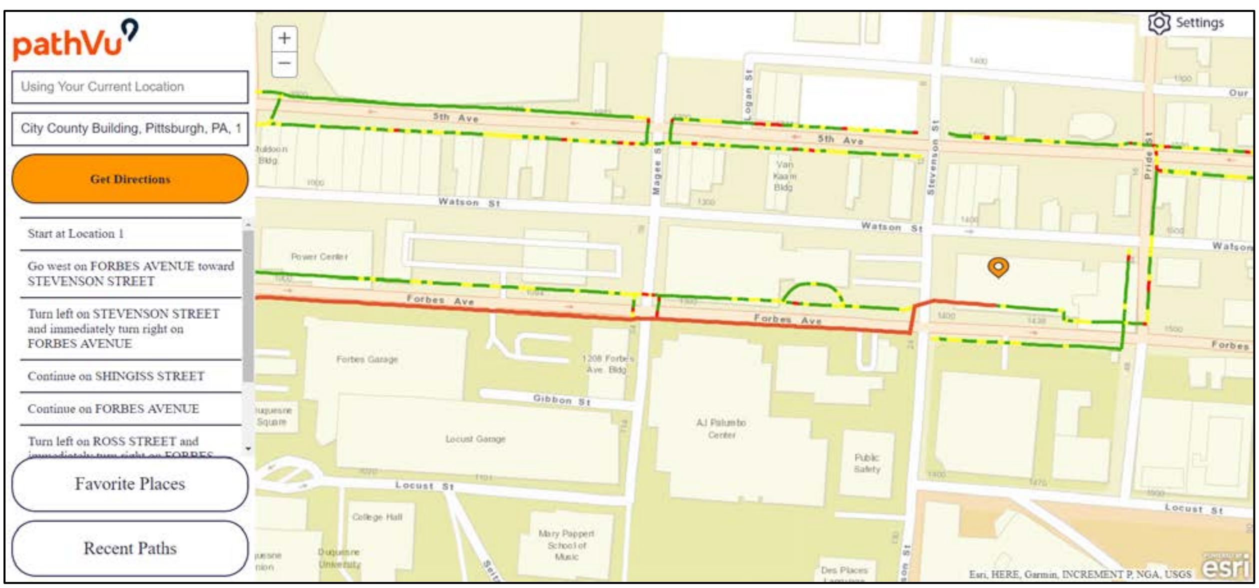

Figure 12: pathNav Navigation and Directions

Figure 13: pathNav Preset Profiles

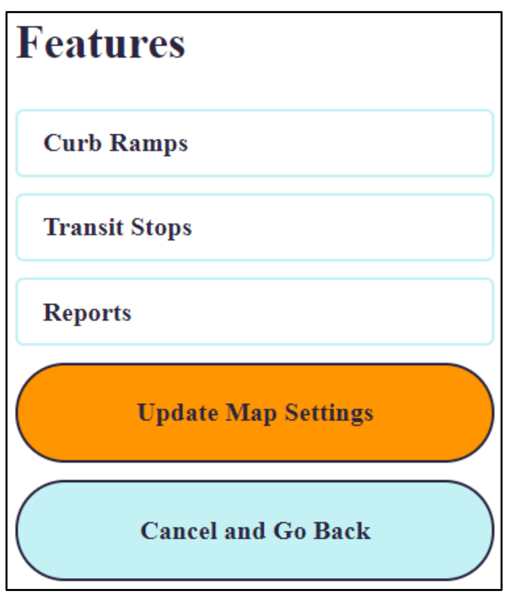

Figure 14: pathNav Map Settings of Features to Appear on the Map

Chapter 7. pathNav Testing and Feedback

This chapter describes the objectives, protocol, and results of a survey completed by twenty participants to review pathNav functionality. The surveys were completed once the prototype pathNav navigation functionality was completed. There were some pathNav features that were not implemented fully prior to testing, but have since been implemented. These features include: the ability to view and change one's settings and the ability for the app to resize based on the hardware (computer vs. tablet). This Chapter shows the completion of Objective 1.5 above.

7.1 Objectives

The primary objective of the survey and testing were to receive feedback from people with of varying abilities to understand how well the pathNav prototype had been designed, what types of improvements are needed, if it is usable by people with disabilities, and which features should be implemented first. By listening to the needs of users, we can more accurately design the web app around what the user wants rather than based on our pre-conceived assumptions. This testing and feedback should be an ongoing process in design, even when products had not been finalized as it was during this testing. The feedback allows us to understand how to incorporate accessibility-friendly functionality, which features are most important, and how the web app should look and feel from a visual and non-visual perspective. Although not all features can be incorporated immediately, the feedback provides a basis for the most important outstanding features to be incorporated.

7.2 Protocol

The testing was organized as a survey and review of the web app. Users were given eight (not including demographics) questions or tasks to complete. If the participant was given a task, they would go to pathNav app, complete the task, then return to the survey and answer how easy that task was to complete. Testing occurred in April and May 2019. The following represents the survey questions that were asked:

1. Create an account. On a scale of 0-100, how easy was the process?
2. Use "Preview Destination" mode to search for a nearby destination (Example: PPG Paints Arena). On a scale of 0-100, how easy was the process?
3. Use "Get Directions" mode to navigate from A to B (Example: David L Lawrence Convention Center to PPG Paints Arena). On a scale of 0-100, how easy was the process?

4. Add a Favorite Place. On a scale of 0-100, how easy was the process?
5. On a scale of 0-100, rate the interface. Specify what you like and dislike in the comment section below.
6. On a scale of 0-100, rate the map. Specify what you like and dislike in the comment section below.
7. On a scale of 1-10, how likely are you to use this once a week?
8. What features would you like to see? Please add comments regarding the tasks completed. Additional comments?
9. Demographics
    a. Name
    b. User Type (Wheelchair, Blind, Stroller, Cane, Walker)
    c. Age
    d. Email Address

7.3 Participant Demographics

Table 5 presents the demographics of the twenty survey participants. Some of the participants were part of the Advisory Group discussed above, while others were individuals who saw the web app for the first time.

Table 5: User Testing Participant Demographics

Gender	Male	Female					
	11	9					
Age	18-39	40-64	65+				
	9	6	5				
Disability Types	Cognitive	Manual Wheel-chair User	Blind/Visually Impaired	Parents with Stroller	Power Wheel-chair User	None	Crutches
	1	3	3	1	6	5	1

7.4 Results

This section shows the results of the survey. Table 6 shows the question and question number, average score, minimum score, and maximum score. Each question was rated by participants on a scale of 0-100, where 0 represented a very poor score and 100 represented an excellent score. If part of the web app was not working during the survey, participants were instructed to give a low score. The responses to question 8 are below Table 6, which include comments and suggestions for improvements.

Table 6: pathNav User Testing Survey Questions and Scores

Question No.	Question	Average	Minimum	Maximum
1	Create an account. On a scale of 0-100, how easy was the process?	77	10	100
2	Use "Preview Destination" mode to search for a nearby destination (Example: PPG Paints Arena). On a scale of 0-100, how easy was the process?	88	51	100
3	Use "Get Directions" mode to navigate from A to B (Example: David L Lawrence Convention Center to PPG Paints Arena). On a scale of 0-100, how easy was the process?	84	51	100
4	Add a Favorite Place. On a scale of 0-100, how easy was the process?	83	66	100
5	On a scale of 0-100, rate the interface. Specify what you like and dislike in the comment section below.	70	10	100
6	On a scale of 0-100, rate the map. Specify what you like and dislike in the comment section below.	74	0*	100
7	On a scale of 0-100, how likely are you to use this once a week?	59	1	100

* User is blind and was unable to navigate the map.

Question 8: What features would you like to see? Please add comments regarding the tasks completed. Additional comments?

Note: These comments are taken directly from the survey with some paraphrasing.

- See turn-by-turn directions with a street view snapshot
    - It would help in being able to navigate in terms of specific mobility issues
- Trouble following the map. Looked like a triangle, which was confusing (Bug has been fixed).
- Too many symbols, which can be confusing. Have a legend!!
- The wording of some of the questions is phrased oddly
- Logo should take you back to the homepage
- Add some sort of "celebration emoji" after a picture is sent
- Give more details of what the X number of hazards are along the route
- As a blind person, I would have liked to know what streets I would be crossing.
- What are the 21 hazards that were identified on my route and where are they for someone who is not sighted.
- Include distances between steps
- Further testing with a screen reader
- Logo should be hyperlinked to homepage
- Being able to enter address information manually rather than selecting from a dropdown.
- Include accessible parking with pictures
- Dislike typeface
- Add animation/live interfaces
- Add pop-up/confirmation when you submit something
- App should have a "My Location" button
- In Favorites, add error handling to make sure a name is entered
- Add other city locations

Chapter 8. Conclusion

8.1 Discussion

The goal of this project was to develop pathNav, a pedestrian navigation tool that utilizes a connected network of sidewalk and pathway data. The Advisory Group was formed to provide guidance on the design of pathNav, meeting **Objective 1.1**. By taking a user-centered design approach, we listen to what the end user wants, and design based on what they want rather than based on our assumptions of their needs. The Advisory Group identified a number of pathNav features that are important to consider, including simplicity, accessibility, clean design, the importance of including transit details, and other design and navigation related components. The Advisory Group feedback included features for the current version of pathNav as well as future versions.

Based on the Advisory Group feedback, a list of pathNav requirements was established. These requirements provided a foundation for the backend and frontend design. The frontend design of pathNav was designed to be dynamic in order to function on both mobile and web platforms. Similarly, the design resembles pathVu's mobile app that is in development to provide consistent branding and design elements.

The navigation feature of pathNav was designed to take the following information into account when determining the suggested route: user's comfortability settings, pathway centerline location, and pathway quality collected with PathMeT (**Objective 1.2**). This information goes into the pathNav algorithms (**Objective 1.3**) to identify the best route based on the user's ability and settings.

The backend and frontend components were combined into the resulting pathNav web app and interface (**Objective 1.4**) that can be used in Pittsburgh Oakland and Downtown neighborhoods by following the URL provided above. The web app contains the system requirements identified by the Advisory Group. Some requirements and "like-to-have" features were not fully completed because of time constraints. One of these features is the "reporting" functionality that allows a user to submit reports about dangerous or problematic sidewalk conditions.

Following the creation of the pathNav web app, user testing was completed by having twenty participants review the app, execute tasks on the app, and complete a survey answering questions about its usability (**Objective 1.5**). Participants provided quality feedback about the design and functionality. Some of the primary feedback was: 1) Include a legend so that users understand the features that are shown on the app. 2) Include better feedback and communication regarding what is going on in the app. It should resemble similar web apps that people are familiar with using. 3) Improve usability for people with visual impairments, adding better compatibility with a screen reader. 4) When can it be used in other cities? Some of the feedback has already been addressed, however we will continue to improve the usability of pathNav by addressing these comments and continuing with user testing throughout the process. On average, the scores from Table 6 are promising, considering it is a prototype web app. The low scores reflected in the Minimum column are typically a result of people with visual impairments' difficulty using the web app with their screen reader. Even with continued guidance from people with visual impairments, implementing certain features was difficult to perfect. Thus, it is very important in to continue to improve this feature in the future and continue to keep people with visual impairments involved so that they are able to use pathNav. The future development efforts are discussed is Section 6.2 below.

As pathNav continues to be developed and refined, we believe that its implementation will increase safety and reduce trip and fall injuries, reduce social isolation of people with disabilities and older adults, increase public transit ridership, and reduce trip/fall personal injury cases of pedestrians. This project is the first step in achieving that mission and reaching these goals. The web app completed as part of this project is a prototype that is being tested in Pittsburgh, PA. Additional testing and development will be and ongoing process for the pathVu development team in order to produce a tool that can be used in any city and will improve accessibility, walkability, and overall pedestrian safety.

8.2 Future Development

This report shows the completion of Objectives 1.1 – 1.5. This section summarizes the next steps and future development opportunities. Based on the user feedback and stage of development, the list below shows suggested next steps of development, in no particular order.

- Street-view imagery during directions: Incorporating a street-view image or an image from the PathMeT device in the step-by-step directions would help users understand their location on a map, providing them with better directions. This street-view imagery can also be implemented by showing an image when a user selects a pathway segment.
- Ability to view map data and imagery: Users should receive a certain level of detail regarding the quality of a particular map attribute when clicking on it. For example, incorporating this feature will allow users to click on a curb ramp, where a pop-up window will appear showing them an image and the quality of the curb ramp as reported by pathVu or through crowdsourcing. Similar functionality will be implemented for pathway segments, all crowdsourced reports, transit stops, and similar pathway attributes.
- Legend: A legend or map key should be implemented so that users understand the symbology shown on the map. They should easily be able to understand that the blue icon represents a curb ramp, and similar for other attributes.
- Additional testing and implementation for blind users: Additional testing should be conducted to ensure pathNav functions well with screen readers. Similarly, future

development should consider ways in which a blind user can operate the map and understand its details without a visual representation.

- Expand to other cities: Future development should consider ways in which more cities can be quickly implemented into pathNav. Such methods may include using open data, crowdsourced data, or a strategy to scale using pathVu technology.
- Additional accessibility information: Additional accessibility features and data should be included to help users understand every aspect of their pedestrian journey. Accessibility data for consideration includes: location of accessible entrances, accessible parking, quality of accessibility inside a point of interest, transit stop accessibility, transit vehicle accessibility, and similar features.
- Additional transit implementation: One of the long-term visions of this project is to implement a multi-modal component to the navigation. This means that transit routes and similar multi-modal travel methods will be incorporated, not only the portion of the trip that includes sidewalks. For example, a multi-modal trip planner might tell the user the most accessible pedestrian path to take to the bus stop, at which accessible stop to wait, which transit vehicle to ride, when to disembark the vehicle, the accessible pedestrian path to take to the point of interest, and how level of accessibility of that point of interest. In order to achieve this vision, additional time and resources are required.