Custom Pedestrian Routing for Visually Impaired People:

Expanding the Capabilities of AccessMap

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August 28, 2020

1 Introduction

Background Navigating while visually impaired provides unique challenges. These challenges, in part, are informational gaps. AccessMap is a tool that provides custom sidewalk and footpath routing directions based on a personal ability profile [7]. Thus, the main hypothesis of this project is that the AccessMap model can be used to fill some of the informational gaps experienced by people with visual disabilities during wayfinding and navigation. Ultimately, we want to give visually impaired users the opportunity to express their routing preferences and help them safely navigate to their destination.

Motivation For pedestrians with visual impairments, knowing details about the areas they are traversing allows for independent, flexible, and safe wayfinding. 30 percent of people with visual impairments never leave home without a sighted guide, which severely limits their opportunities to travel [2]. Thus, providing environmental details to pedestrians with visual impairments expands the mobility of this population. Currently, however, there are no standards for expressing attributes of the built environment. The existing AccessMap project attempts to remedy these informational gaps by collecting data about sidewalks and footpaths in order to provide custom routing instructions based on a user-defined mobility profile [4]. Using AccessMap as a starting point, this project seeks to mitigate potential risks for people with visual impairments as they navigate the built environment by providing custom walking instructions through an accessible interface. The routing engine takes in certain environmental attributes, such as the safety of a crossing, the presence of stairs, or the presence of landmarks in order to provide the optimal route to the user. Ultimately, this modified version of AccessMap allows for increased mobility for people with visual impairments.

2 Related Work

2.1 Navigation Strategies of Visually Impaired Pedestrians

Landmarks Landmarks can be defined as "conceptually and perceptually distinct locations, built or naturally occurring" [3]. Some examples of landmarks for people with visual impairments include the land use adjacent to a sidewalk (ex. grass, trees, buildings); the corner of a building; a busy street; a bench, trash can, a pole; or a specific tactile marker on a sidewalk (ex. unique surface material, metal utility hole cover) [3]. Auditory cues can also be used as landmarks; for example, public transit sounds such as train whistles or sounds associated with schools, such as children's voices [15]. Following is an explanation of the importance of landmarks to one pedestrian with visual impairments:

> "Whether there is a tree, bushes, a wall, a kind of fence, I don't know, maybe metal, wooden. ... Whether a path is gravel or cobblestone or paved. All these details are extremely important ... Here, let me give you an example, you might laugh, but when I go to the pharmacy, my landmark is a rubber mat. It helps me recognize the pharmacy door ... You might find it funny when I say that manhole covers, edges, and grass are important. But to me, these can be of considerable help. So it is the tiny details, not even details, but tiny details that are important." [15]

Landmarks are typically differentiated from obstacles because they are spatially fixed and detectable using a cane or a dog. Obstacles might include temporary sidewalk furniture, construction equipment, low-hanging tree branches, or bicycle racks [5]. Including landmarks in pedestrian directions is known to increase user confidence and reduce navigation errors [14]. The Route4All project (see subsequent section) prioritizes landmarks as a navigation tool for people with visual impairments. In a user study of Route4All, routes with landmark descriptions resulted in higher route comprehension [2].

Sensory Cues While navigating, visually impaired people rely more on their other senses to understand their environment; for example, they might use the sound of people walking or cars passing by in order to understand the direction of the road/sidewalk [12]. They might also use tactile information such as the texture of the ground in order to ascertain their current location [12]. Finally, they might follow olfactory sensory inputs such as the smell of coffee or clothing to situate themselves in an area [12]. Generally, people with visual impairments navigate well in areas with many boundaries as opposed to wide open spaces because there is more tactile feedback [17].

Challenges There are a few urban situations that are especially challenging and dangerous for people with visual impairments. These include open spaces certain types of crossings, and stairs. In open spaces, visually impaired people are unable to identify straight lines/edges such as the side of a building or the edge of a sidewalk in order to maintain travel in a straight line [12]. Especially wide crossings are challenging for the same reasons as open spaces; there are no tactile guiding lines and thus it is easy to veer off the crosswalk. Wide crossings are often also located at large, complex intersections, which can be perceived as "connected with chaos and noise" [15]. In especially complex intersections, pedestrians with visual impairments can feel as if they are "both blind and deaf" [15]. Additionally, crossings without traffic lights or audible pedestrian signals are difficult to cross because there is no regular traffic pattern to discern and pedestrians with visual impairments do not know when it is safe to cross. Crossings at roundabouts are very difficult to cross because of the irregular traffic pattern and confusing auditory cues [6]. Finally, stairs can be challenging to navigate and dangerous if they are unexpected or if the direction of travel is unknown [16].

2.2 Existing Navigation Tools

Mobile Applications We looked at users' experiences using existing navigation tools in order to inform the modifications we would eventually make to AccessMap. The two main navigational tools we looked at were BlindSquare and NearbyExplorer. Both tools are mobile applications. We looked at the reviews of each application on the App Store, as well as forum posts about them.

BlindSquare is typically used as an exploratory tool, as it will dictate street names or other points of interest to the user as they pass by, but it outsources routing to Google Maps or Apple Maps. One big feature BlindSquare is missing is intersection analysis. Any information about an intersection is added by volunteers, and according to users, the information is often incorrect [10]. Additionally, BlindSquare will give the user the distance to the middle of an upcoming street because it uses road data instead of sidewalk data [9].

NearbyExplorer has more routing features than BlindSquare; the user can optimize for fastest time, shortest distance, or fewest turns [8]. While this customization appears helpful, some users have even more specific preferences, such as Bill Holton, a user who reviewed NearbyExplorer for *AccessWorld*. He writes:

> "The route Nearby Explorer proposed for one trip I make on a fairly regular basis is faster, shorter, and requires fewer turns, but it also requires walking along a busy street with no sidewalks. My preferred route is a bit longer. To travel this way I have to set my destination to a POI about midway along the alternate route, then set my ultimate location from that place to complete the journey" [11].

This sort of route customization is what we are trying to achieve with AccessMap.

Route4All The project that is most similar to what we are trying to achieve is called Route4All and is based out of the Czech Technical University in Prague. When routing for people with visual impairments, their routing engine "focuses on the orientation possibility of the visually impaired" and avoids open spaces, underpasses, and stairs, while prioritizing intersections with sound signals [13] [3]. Navigation instructions consist of the current location (corner/street address/intersection), then direction, action (walk/cross), distance approximation, slope, endpoint, landmarks (crossing type, street shape), land use (keep buildings on left/right) [2]. The application does not use GPS; rather, it provides a list of instructions and users can advance the directions, go back a step, or repeat an instruction [3].

Effective Navigation Aids In order for navigation tools to be effective, they should "stay out of the user's way, only providing information that is not already provided by their navigation aid [cane or dog]" [17]. Most people will abandon assistive technology because of poor device performance, stagnant design, or changes in needs. A good navigation aid should perform to users' expectations and be open to changing design based on user input.

3 Methodology

Overview In order to understand whether the AccessMap model could be used to fill some of the informational gaps experienced by people with visual impairments during wayfinding and navigation, we first conducted an extensive literature review and identified attributes of the built environment that are especially important for people with visual impairments. Then, we evaluated each attribute on how easy it would be to implement into the existing version of AccessMap and selected a features that would be both straightforward to implement and helpful for navigation and routing. We decided on the following attributes: (1) landmarks/obstacles, (2) crossing safety, and (3) stairs. We chose the Microsoft Campus as our pilot region because we have active mappers there who can update OpenStreetMaps (OSM) with more information.

Evaluating Attributes of the Built Environment We compiled a list of 50 attributes of the built environment, and then evaluated each on the following criteria: (1) ease of tagging, (2) ease of collection, (3) ease of crowdsourcing, (4) clarity of nonvisual representation, and (5) ease of obtaining preference. We used a scale from 1 to 5 where 1 means extremely clear/easy, 2 means somewhat clear/easy, 3 means neither clear/easy nor unclear/difficult, 4 means somewhat unclear/difficult, and 5 means extremely unclear/difficult. The full list of attributes with their evaluated criteria is available in the Appendix (Table 1).

Here we describe in more detail each of the 5 criteria we developed, as well as provide various examples of how we evaluated attributes. "Ease of tagging" refers to how well the attribute would align with current OpenStreetMaps (OSM) or AccessMap tag schemas. For example, it would be extremely easy to tag the shape of a sidewalk corner as rounded or pointed, but it would be extremely hard to tag an intersection with the timings of the traffic light patterns. "Ease of collection" refers to how straightforward it would be to collect data about a certain attribute, typically from preexisting data sources such as municipal data. For example, sidewalk surface material might not be stored in city databases whereas transit stops would most definitely be stored and therefore easily collected. "Ease of crowdsourcing" refers to how easy it would be for people to collect data about the attribute and upload it to OSM. For example, it would be very difficult for an average person with a smartphone to figure out the elevation change of a stretch of sidewalk, whereas it would be very easy for this same person to mark whether there is a crossing island at a crosswalk. "Clarity of nonvisual representation" refers to how intuitive a nonvisual representation of a certain attribute would be. For example, representing an "open space" non-visually would be challenging because it would require the boundaries and size of the space to be conveyed, whereas representing a lowered curb non-visually is straightforward. Finally, "ease of obtaining preference" refers to how straightforward it would be to ask a user about their preferences for encountering a certain attribute on their route. For example, it is difficult to conceptualize what sort of "noise level" one might prefer on a route and how to quantify this, whereas it is very straightforward to ask whether someone would prefer a route without stairs.

Modifying AccessMap: Landmarks The first modification we made to the existing AccessMap application was the addition of landmarks. As a reminder, landmarks are "conceptually and perceptually distinct locations, built or naturally occurring" [3]. The specific landmarks we mapped include: benches, trash cans, bollards, street lamps, stop signs, manholes, and pedestrian request button poles. We modified the AccessMap data pipeline in order to extract these features, and then added a point layer to the AccessMap application in order to visualize these point features. Figure 2 contains an example of the information that might be displayed when someone clicks on a point feature. Then, we performed spatial calculations to count how many landmarks are within a certain radius of each pedestrian segment, and added this count as a feature of each segment. In Figure 1, each pedestrian segment is colored based on how many landmarks are along it; the darker blue, the more landmarks. For each landmark, we also calculated its distance along its nearest segment and added these distances as a separate attribute to the segments. This allows us to provide more detailed landmark-centric directions, such as "In 30 meters, there will be a manhole on the sidewalk." Finally, we implemented a landmark priority slider, which allows the user to dictate how important a route with a lot of landmarks is to them. In Figure 3 and Figure 4, the returned route changes depending on how important landmarks are to the user. In Figure 4, the routing engine's cost function returns a longer route with more landmarks along the way.

Modifying AccessMap: Crossing Safety We also modified the crossing data and visualization to reflect the different levels of safety of each crossing. We used satellite and street view imagery to tag crossings with their corresponding traffic control methods. Traffic control methods include traffic lights, stop signs, yield for pedestrian signs, or no traffic control. The crossings are the colored according to their traffic control. As pictured in Figure 5, green crossings are controlled by traffic lights, yellow crossings by stop signs, orange crossings by a pedestrian/yield sign, and red have no formal traffic control method. The routing engine prioritizes crossings with more traffic control. While crossing safety is not currently customizable, we hope to implement a slider similar to the "landmark priority" slider so users can better customize their routes. Additionally, when a crossing is clicked on, all of the data about the crossing is displayed; this data includes the presence of curbramps and/or tactile paving, whether the crossing is marked or not, the type of traffic control at the crossing, whether there is a button operated and/or audible pedestrian signal, and the surface of the crossing. A screenshot of the information displayed when a crossing is clicked on can be seen in Figure 6.

Modifying AccessMap: Stairs Finally, we modified AccessMap to include data about stairs. When a stairway is clicked, the application displays the step count and presence of a handrail. Figure 7 is an example of how steps are represented and what information is displayed. The routing engine will only give routes without stairs, but we hope to implement a slider similar to the “landmark priority” slider so users choose whether they want to avoid stairs or not.

4 Results

Overview Due to the current circumstances around COVID-19 and the remote nature of this research project, user testing was unable to be completed within the DREU timeframe. User testing would be the most robust method for understanding whether the modifications made to AccessMap can be effectively used to fill some of the informational gaps experienced by people with visual disabilities during wayfinding and navigation. We were able to demonstrate, however, that the modifications made to AccessMap result in significantly different routes than those provided by Google Maps. Additionally, we were able to meet with an Orientation & Mobility Specialist, Amy Parker. Amy provided us with valuable feedback and potential future directions.

Google Maps vs. AccessMap: Landmarks In order to prove the utility of our routing engine, we obtained routes from AccessMap and Google Maps for the same pair of start/end points and compared them. Figure 8 shows the AccessMap route and Figure 9 shows the Google Maps route. The AccessMap route passes by 8 landmarks (mostly benches), while the default Google Maps route passes by no landmarks. Though the AccessMap route is longer, a user could adjust the landmark slider to get a shorter route that passed by less landmarks.

Google Maps vs. AccessMap: Crossings and Stairs Figure 10 shows an AccessMap route that involves one crossing at a fully controlled intersection with audible pedestrian signals. Figure 11 shows a Google Maps route for the same start/end points that involves two crossings: one controlled by a stop sign and one controlled by a yield sign. While the AccessMap route is slightly longer, it is much safer for a pedestrian with visual impairments. Figure 12 shows an AccessMap route that involves one crossing controlled by a stop sign and no stairs. Figure 13 shows the corresponding Google Maps route, which involves stairs, as well as two crossings: one with no traffic control and one controlled by a yield sign. Again, while the AccessMap route is slightly longer, it is safer for a pedestrian with visual impairments.

Orientation & Mobility Specialist Feedback Amy Parker, the O & M Specialist we met with, thought that the work we had done so far had great potential for an exploratory tool as well as a routing tool. She pointed us towards UniDescription, a project that two of her colleagues are working on which focuses on translating visual media to audible media. The UniD team has worked with the National Park Service to create audio descriptions of maps, so we might be able to collaborate and ideate with them in order to create a fully accessible AccessMap instance for people with visual impairments! The ultimate goal might be a sort of “narrative map” with a flow from broad information about the space to specific descriptions of a few different routing options. She also talked about potential options for people with both visual and hearing impairments, such as tactile maps, and brought up special routing considerations for people with guide dogs. She reminded us of some especially dangerous situations such as roundabouts, and the importance of having customizable options for any audio-based application.

5 Discussion

Future Work In the near future, we hope to increase the detail on the directions cards to reflect more environmental attributes, such as landmark location, surface material, and other details about crossings. We want to ensure that the directions meet the standards put forth by the Consumer Technology Association for "Inclusive, Audio-based, Network Navigation Systems for All Persons including those who are Blind/Low vision" [1]. Additionally, we hope to add more customization sliders for crossings and stairs, as previously mentioned. We would also like to expand beyond the Microsoft Campus and robustly test our routing engine against Google Maps. After our conversation with Amy Parker, we want to think more about how AccessMap can be used as an exploratory tool for people with visual impairments as opposed to only a routing tool. This might take the form of a narrative map, as previously mentioned. The ultimate goal of an exploratory tool would be imparting spatial awareness through a non-visual modality.

User Testing Once we are finally able to conduct user testing, we hope to learn whether our routing engine gives more optimal routes than Google Maps. This could be achieved by asking our participants to follow a route from Google Maps and a route from AccessMap and comparing their experiences. In order to ensure that we are comparing the routes themselves as opposed to the directions, we would get a route from Google Maps and a route from AccessMap and create directions for the Google Maps route that are just as detailed as those from AccessMap. This experiment would address the safety and quality of the routes from AccessMap as opposed to Google Maps. If we are able to modify AccessMap further in order for it to be a more feasible exploratory tool, we would also like to test users' overall wayfinding confidence and spatial awareness of a location once they have virtually explored the area on AccessMap.

Acknowledgements

This project would not have been possible without the support of my mentor, Dr. Anat Caspi. I would also like to thank Nick Bolten, who created the original AccessMap application and helped me with all sorts of debugging. Thank you to our mappers at Microsoft for providing us with valuable landmark data. Finally, this work was generously supported by the Computing Research Association (CRA) and the Distributed Research Experiences for Undergraduates (DREU) program.

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Figure Captions

Figure 1. *A screenshot of the AccessMap application, with edges colored according to how many landmarks are nearby. The darker blue the edge, the more landmarks nearby.*

Figure 2. *A screenshot of AccessMap with a point clicked on and its corresponding description, manhole.*

Figure 3. *A screenshot of an AccessMap route that does not prioritize landmarks; the landmark priority slider is set to 25 percent.*

Figure 4. *A screenshot of an AccessMap route that prioritizes landmarks; the landmark priority slider is set to 95 percent.*

Figure 5. *A screenshot of crossings in AccessMap; the different colorings reflect the different forms of traffic control present at each crossing. Green crossings are controlled by traffic lights, yellow crossings by stop signs, orange crossings by a pedestrian/yield sign, and red with no formal traffic control method.*

Figure 6. *A screenshot the information displayed when a crossing is clicked on in AccessMap. This information includes whether the crossing is marked/unmarked, how the intersection is controlled, whether the pedestrian signal is auditory and/or button-operated, the surface of the crossing, and whether there is tactile paving/curbramps.*

Figure 7. *A screenshot the information displayed when steps are clicked on in AccessMap. This information includes the step count and the handrail status.*

Figure 8. *An AccessMap route that passes by 8 landmarks. Compare with Figure 9, the Google Maps route for the same start/end points.*

Figure 9. *A Google Maps route that passes by no landmarks. Compare with Figure 8, the AccessMap route for the same start/end points.*

Figure 10. *An AccessMap route that involves one crossing at a fully controlled intersection with audible pedestrian signals. Compare with Figure 11, the Google Maps route for the same start/end points.*

Figure 11. *A Google Maps route that involves two crossings: one controlled by a stop sign and one controlled by a yield sign. Compare with Figure 10, the AccessMap route for the same start/end points.*

Figure 12. *An AccessMap route that involves one crossing controlled by a stop sign and no stairs. Compare with Figure 13, the Google Maps route for the same start/end points.*

Figure 13. *A Google Maps route that involves stairs, as well as two crossings: one with no traffic control and one controlled by a yield sign. Compare with Figure 12, the AccessMap route for the same start/end points.*

Figures

Figure 1: *A screenshot of the AccessMap application, with edges colored according to how many landmarks are nearby. The darker blue the edge, the more landmarks nearby.*

Figure 2: *A screenshot of AccessMap with a point clicked on and its corresponding description, manhole.*

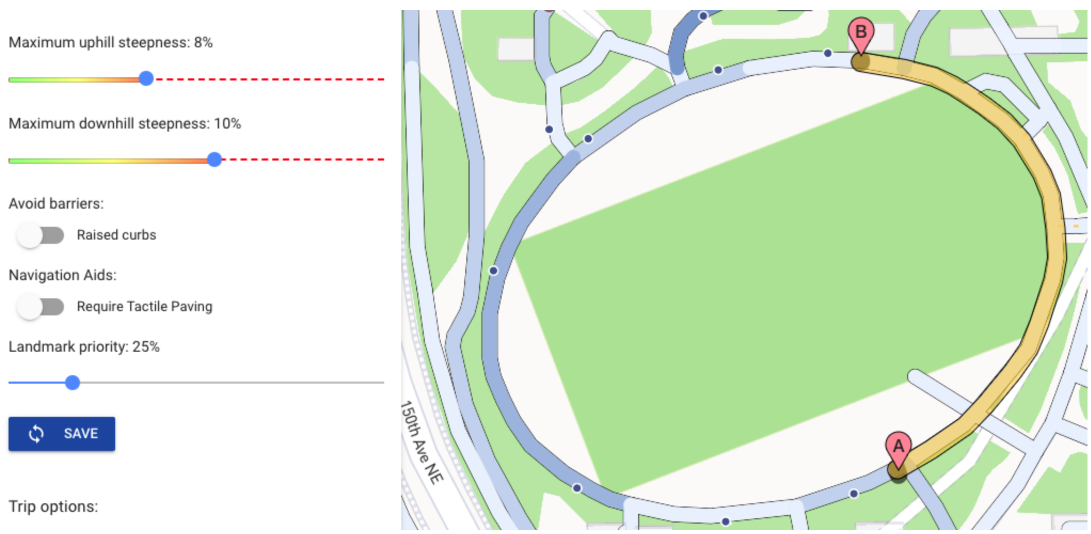

Figure 3: *A screenshot of an AccessMap route that does not prioritize landmarks; the landmark priority slider is set to 25 percent.*

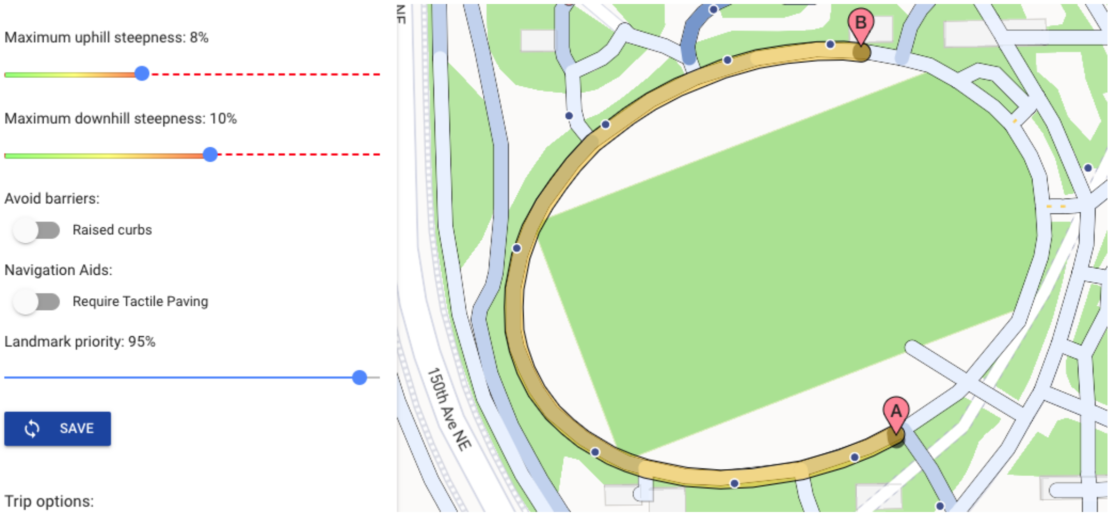

Figure 4: *A screenshot of an AccessMap route that prioritizes landmarks; the landmark priority slider is set to 95 percent.*

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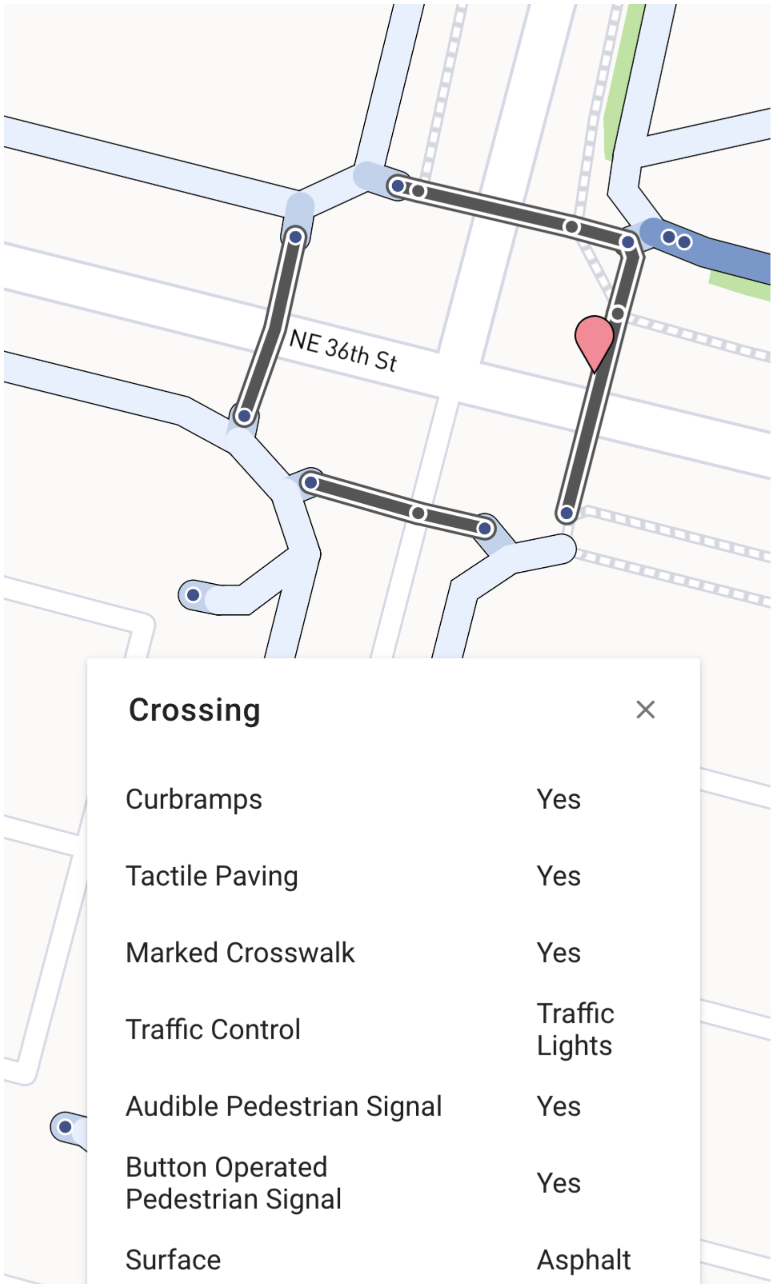


Figure 6: *A screenshot the information displayed when a crossing is clicked on in AccessMap. This information includes whether the crossing is marked/unmarked, how the intersection is controlled, whether the pedestrian signal is auditory and/or button-operated, the surface of the crossing, and whether there is tactile paving/curbramps.*

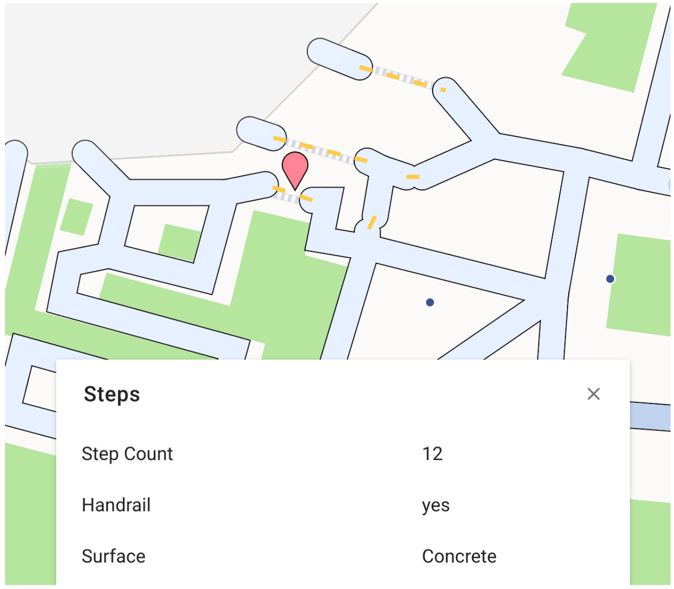


Figure 7: *A screenshot the information displayed when steps are clicked on in AccessMap. This information includes the step count and the handrail status.*

Figure 8: *An AccessMap route that passes by 8 landmarks. Compare with Figure 9, the Google Maps route for the same start/end points.*

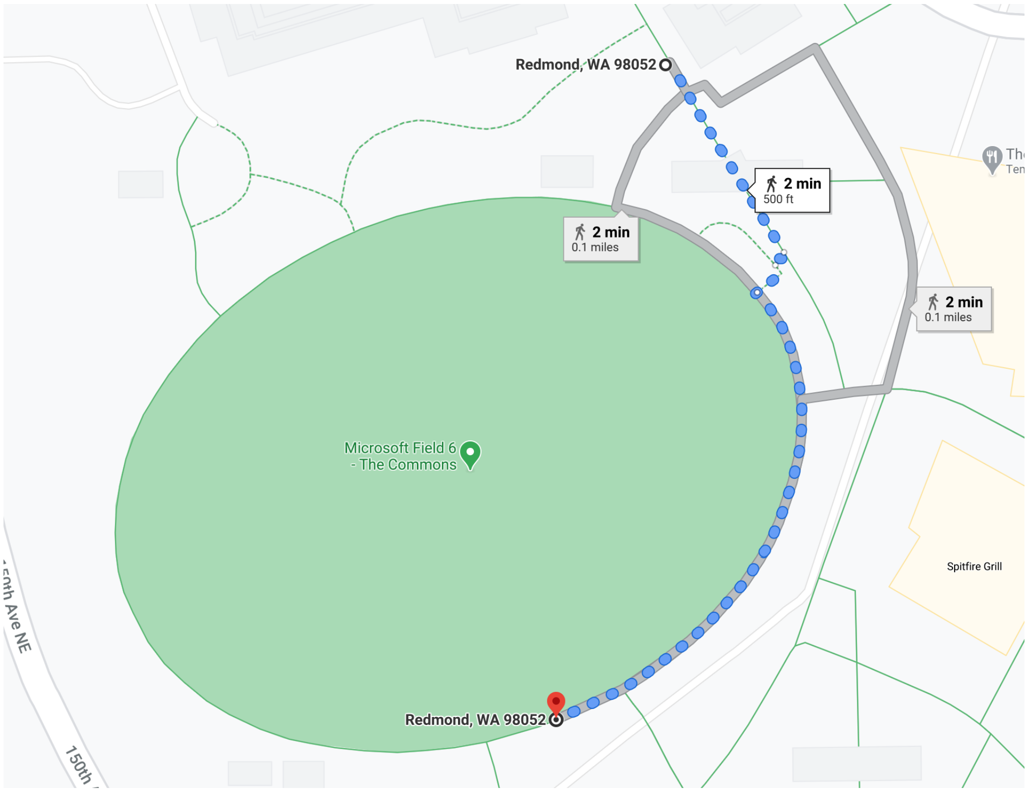
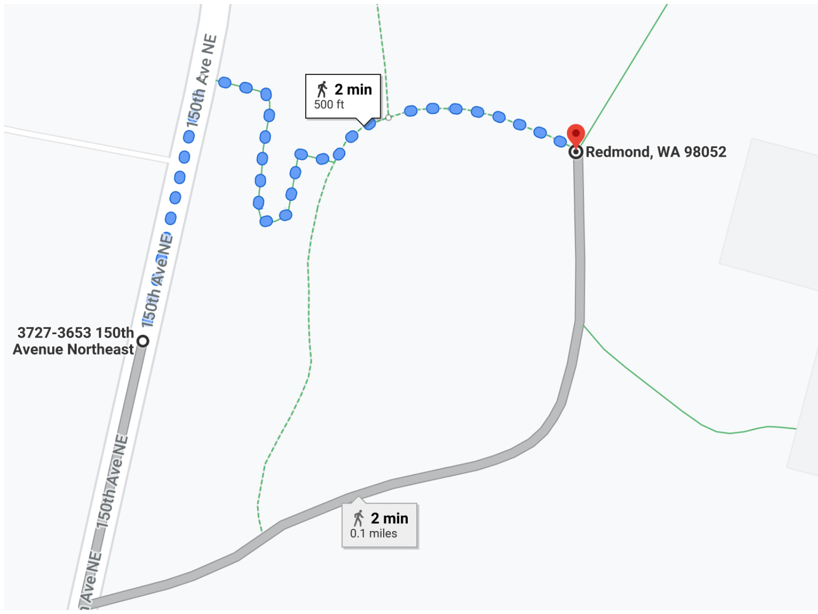


Figure 9: *A Google Maps route that passes by no landmarks. Compare with Figure 8, the AccessMap route for the same start/end points.*

Figure 10: *An AccessMap route that involves one crossing at a fully controlled intersection with audible pedestrian signals. Compare with Figure 11, the Google Maps route for the same start/end points.*



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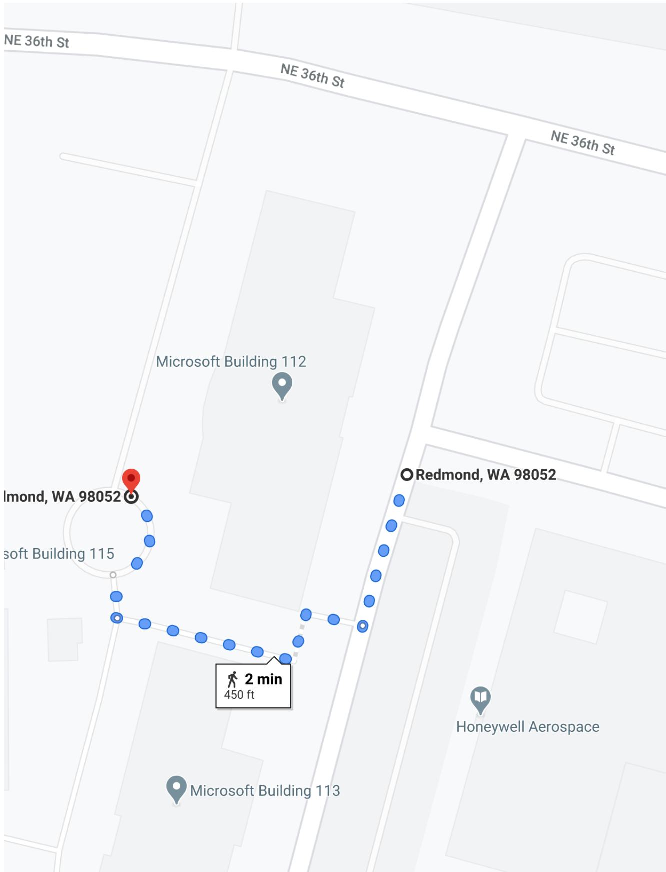

Figure 13: *A Google Maps route that involves stairs, as well as two crossings: one with no traffic control and one controlled by a yield sign. Compare with Figure 12, the AccessMap route for the same start/end points.*

Appendix

Built Environment Features	Ease of Tagging	Ease of Collection	Ease of Crowdsourcing	Clarity of Nonvisual Representation	Ease of Obtaining Preference	Citations
1 = extremely clear; 2 = somewhat clear; 3 = neither clear nor unclear; 4 = somewhat unclear; 5 = extremely unclear						
Sidewalks						
Location	1	1	2	1	1	
Elevation Change	1	1	4	2	4	Balata et al. 2016
Tactile Paving	1	1	1	1	1	Šakaja 2018
Surface Material	2	2	1	1	1	Kan-Kilic et al. 2017
Width	2	3	3	1	1	
Cross Slope	2	5	5	3	3	
Adjacent Land Use	1	1	1	1	2	Balata et al. 2016, Fernandes et al. 2019, Šakaja 2018
Travel Direction	2	3	3	1	1	Williams et al. 2014
Crowdedness	2	3	3	2	1	Balata et al. 2018, Williams et al. 2013
Point-Specific Surface Disruptions	3	2	4	2	1	Šakaja 2018
Lighting	1	1	1	4	1	
Overhangs	1	2	2	1	1	Williams et al. 2013
Obstacles/Landmarks	1	1	1	1	1	Šakaja 2018, Williams et al. 2013
Noise Level	3	3	3	3	2	Fernandes et al. 2019, Šakaja 2018
Transit Stops	1	1	1	1	1	Guerriero et al. 2017, Kan-Kilic et al. 2017
Underpass	1	1	1	1	1	
Overpass	1	1	1	1	1	
Curbs						
Curb Type	1	2	2	1	1	
Curb Ramp	2	1	1	1	1	Wall Emerson 2017
Shoring & Directionality	2	3	2	2	3	Balata et al. 2018
Corner Shape	1	1	1	1	1	Balata et al. 2016
Curb Bulb	1	1	1	1	1	
Intersections						
Street/Rail/Bike Path Configuration	N/A	1	1	1	1	Ahmetovic et al. 2017
Number of Streets Intersecting	N/A	1	1	2	1	
Street Width	1	1	3	1	1	Ahmetovic et al. 2017
Traffic Cycle/Pattern	5	2	5	4	1	Wall Emerson 2017

Roundabout	1	1	1	1	1	Wall Emerson 2017
Uncontrolled Right Turns into Crossing	3	1	2	1	1	
Crosswalks						
Mid-Block Crossing	1	1	1	1	1	
Diagonal Crossing	1	1	1	1	1	Ahmetovic et al. 2017
Marked/Unmarked	1	1	1	1	1	Ahmetovic et al. 2017
Raised	1	1	1	1	1	
Pedestrian Visibility	2	3	3	3	1	Ahmetovic et al. 2017
Traffic Control	1	1	1	1	1	Ahmetovic et al. 2017
Pedestrian Call Button	1	1	1	1	1	Ahmetovic et al. 2017, Balata et al. 2018
Accessible Pedestrian Signal	2	2	1	1	1	
Pedestrian Signal	1	1	1	1	1	Coughlan et al. 2013
Crossing Island	1	1	1	1	1	Ahmetovic et al. 2017
Pedestrian Crossing Bridge/Tunnel	1	1	1	1	1	
Traffic Speed	1	1	1	2	1	Ahmetovic et al. 2017
Cross Slope	1	3	4	2	1	
Stairs						
Number of Steps	1	1	1	1	1	Balata et al. 2018, CTA Recommendations
Walking Direction	1	2	2	1	1	Williams et al. 2014
Handrails	1	1	1	1	1	CTA Recommendations
Length/Width	1	1	2	1	1	CTA Recommendations
Open Rise	1	1	1	1	1	CTA Recommendations
Other						
Open Spaces	1	1	2	3	1	Balata et al. 2018, Kan-Kilic et al. 2017, Williams et al. 2014
Street Names	2	1	1	1	N/A	
Water Features	1	1	1	1	1	
Construction	1	4	4	1	1	Due et al. 2019, Williams et al. 2013

Table 1. *Attributes of the built environment and their corresponding ease of tagging, ease of collection, ease of crowdsourcing, clarity of nonvisual representation, and ease of obtaining preference.*