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Pedestrian Wayfinding Under Consideration of Visual Impairment, Blindness, and Deafblindness: A Mixed-Method Investigation Into Individual Experiences and Supporting Elements

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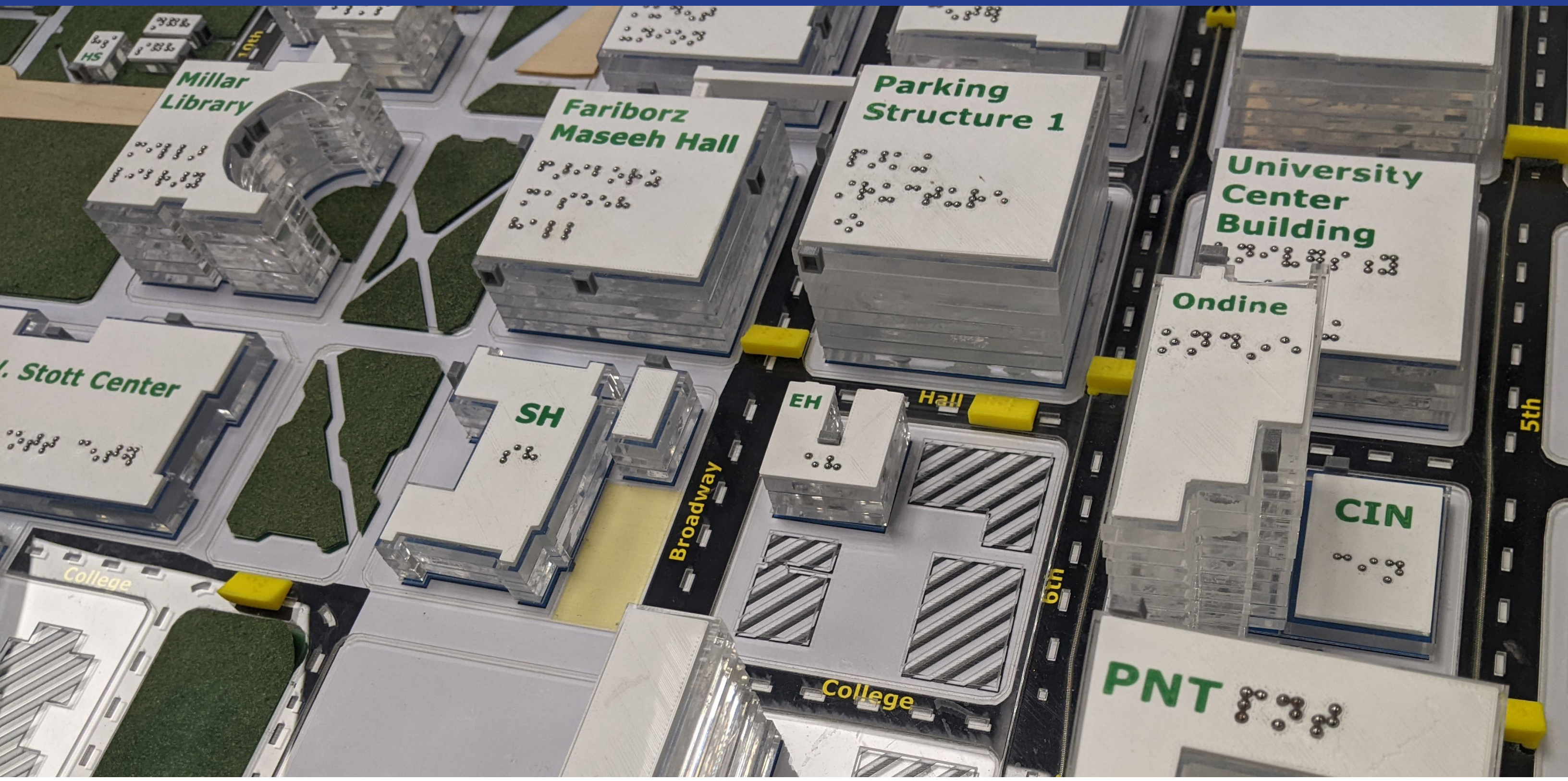

Pedestrian Wayfinding Under Consideration of Visual Impairment, Blindness, and Deafblindness: A Mixed-Method Investigation Into Individual Experiences and Supporting Elements

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Portland State UNIVERSITY

Pedestrian Wayfinding Under Consideration of Visual Impairment, Blindness, And Deafblindness: A Mixed-Method Investigation into Individual Experiences and Supporting Elements

Final Report

NITC-RR-1327

by

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16. Abstract

In this report we discuss to-date findings of a project that aimed at assessing individual and environmental affordances in the context of human pedestrian wayfinding of visually impaired, blind, and deafblind travelers in public spaces. Our project afforded collaboration, co-design, and co-creation of knowledge between the investigators, partners at the American Printing House of the Blind and GoodMaps, the Portland State University Digital City Testbed Center, and members of the disability community. The objective of the project was to better understand how different wayfinding aids, that is, wayfinding apps, tactile maps, and verbal route descriptions, are employed by visually impaired, blind, and deafblind travelers. On that account, we examined individual wayfinding behavior and experiences of visually impaired travelers who were tasked with the completion of a set of unfamiliar outdoor/indoor routes on the campus of Portland State University. Our methodology incorporated both qualitative and quantitative methods to evaluate the efficacy of wayfinding behavior, in general, and specifically route completion performance across a set of three routes and wayfinding aids. We expect that the insights garnered from our project drive forward the development of standards and innovation in mobile wayfinding in relation to best practices for technology-mediated pedestrian wayfinding of visually impaired, blind, and deafblind travelers in public spaces.

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DISCLAIMER

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TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

In this report we discuss a project in which we assessed individual and environmental affordances in the context of human pedestrian wayfinding of visually impaired, blind, and deafblind travelers in public spaces, in general, and a university campus environment, in particular. The objective of the project was to better understand how different wayfinding aids, that is, wayfinding apps, tactile maps, and verbal route descriptions, are employed by visually impaired, blind, and deafblind travelers. On that account, we examined the wayfinding behavior and experiences of visually impaired travelers tasked with completing a set of outdoor and indoor routes on the campus of Portland State University (PSU). Our project afforded close collaboration, co-design, and co-creation of knowledge between the investigators, partners at the American Printing House of the Blind and GoodMaps, the PSU Digital City Testbed Center, and members of the disability community.

Our methodology incorporated both qualitative and quantitative methods to evaluate the efficacy of wayfinding behavior, in general, and specifically route completion performance across a set of up to three preconceived routes and wayfinding aids. Our experimental design fostered a comparative analysis of wayfinding behavior in relation to visual function, age, and wayfinding aid used. In addition, our mixed-method design allowed us to investigate environmental and informational supports that were perceived by travelers to be the most useful for facilitating effective wayfinding. More specifically, by drawing from the academic literature, the technical expertise of the American Printing House for the Blind, and empirical research engagements in the form of empirical experimentation and focus groups with visually impaired individuals ages 14 and older, we captured observed and participant-solicited elements of individual and environmental affordances that support effective wayfinding. In addition to structured travel observations and interviews and focus groups, our methods included survey instruments, digital mapping, and spatial data collection and analysis.

The results from our study improve on the understanding of human wayfinding under consideration of visual impairment and blindness by elucidating pertinent aspects regarding the deployment of wayfinding technology and salient wayfinding features at a large public institution of higher education. We also expect that the insights from our study support the development of standards and innovation in mobile wayfinding as it relates to the integration of indoor and outdoor wayfinding and routing of visually impaired, blind, and deafblind pedestrian travelers.

1.0 INTRODUCTION

People with disabilities, including individuals with blindness, deafblindness, visual impairment, and low vision, as well as those who use wheelchairs, constitute a sizable, growing minority of the general population yet continue to face significant barriers to community inclusion. It is commonly understood that the degree to which humans are able to engage in wayfinding and navigation substantially informs the extent to which individuals are able to lead fulfilling, healthy, and economically sustainable lives.

It has been more than three decades since the passage of the Americans with Disabilities Act (ADA)---one of the most significant policies for promoting accessibility for people with disabilities in public spaces. Irrespective of its broad significance, it may be argued that the ADA provides minimum standards for access, and does not offer specific guidance on the facilitation of indoor to outdoor wayfinding by pedestrians with disabilities. In an analysis of themes from the literature and focus group research, Swobodzinski and Parker (2019) found that only few accessible wayfinding options for people who are visually impaired and deafblind exist and that technologies are not well-integrated, in particular as it comes to supporting seamless transitions between indoor to outdoor spaces.

College campuses are notoriously complex to navigate, particularly for travelers with visual impairments. One of the key barriers for culturally and linguistically diverse people in accessing higher education is seeing themselves as full members of a college campus community. Environmental affordances and wayfinding tools that support safe and confident mobility have been linked with improved employment outcomes, access to higher education, and quality of life (Marcheschi et al., 2020).

As a public university situated in the heart of downtown Portland, the campus of Portland State University (PSU) is a desirable location for the study described in this report as it affords realistic wayfinding scenarios and mobility challenges in a public urban environment. In addition, PSU's strengths in research, scholarship, pedagogy, and community service pertaining to urban planning, transportation, geography, special education, and equity align with the emphasis of our project on community participation, data mapping, and practical evaluation of technologies to promote wayfinding, access, and inclusivity.

1.1 BACKGROUND

Physical, personal, and environmental affordances contribute significantly to possibilities for individual action within an environment. An individual's navigation with complex environments is based on that person's goals, constraints, experiences, and their access to affordances provided by the environment including accessible information, universal design, and navigability. If a major affordance of wayfinding tools is to provide information about the environment, one cannot neglect the idiosyncratic nature in and by which individuals select, process, and store information in different ways. As such, assessing the fit of a technology for a particular task necessitates that special attention is given to intrinsic and extrinsic technology-fit factors, especially when the group is diverse users with different knowledge bases, information needs, expectations, experiences, skill, and abilities.

A confluence of on- and off-campus partner activities provided motivation and leverage for this project. Within the PSU community, in 2017, the College of Education (COE) launched a new program for preparing orientation and mobility (O&M) specialists, which was an outgrowth of its 54-year-old program for preparing teachers of the visually impaired. Drs. Swobodzinski and Parker also began collaborating in 2017, and were funded through a NITC Small-Starts proposal to explore the use of smartphones for wayfinding in urban environments by adults with visual impairment or deafblindness. Their initial data analysis from the focus groups supports the need for research that explores the transition from outdoor to indoor wayfinding, and the need for integrated technologies that provide salient environmental information to travelers.

In 2018 and 2019, in partnership with the Transportation Research and Education Center (TREC), the COE hosted Mobility Matters, an interdisciplinary conference, which brought together transportation planners, educators, regulators, and representatives from the disability communities. Concurrently, Drs. Swobodzinski and Parker were involved in the proposal for the Digital Cities Testbed Center (DCTC) that was funded to leverage interdisciplinary knowledge to create smarter cities. Accessibility and inclusivity for people with disabilities is a prominent theme within the DCTC and has led to meaningful conversations about accessible technologies and design with Microsoft, the American Printing House for the Blind (APH), and multiple university partners.

In March 2019, APH hosted the first indoor navigation symposium, and Dr. Swobodzinski joined an international conversation about the profound need to develop processes, approaches, and standards for indoor wayfinding. APH also published its “Accessible Communities Analysis,” which is based on the documented perceptions and experiences of people with vision loss regarding accessible, livable communities. Collected through 449 in-person interviews (and 522 responses to an online survey), the data concluded that of six categories of accessibility barriers, Transportation and Travel was the highest priority for accessibility improvements with 64% of the in-person interviewees selecting it. Additionally, the qualitative analysis of APH’s data yielded four primary themes: inclusive values, walkability, transportation, and access to information.

1.2 MERIT

Individuals with blindness, deafblindness, visual impairment, and low vision, including those who use wheelchairs, constitute a sizable, growing minority of the general population. These individuals experience disproportionate impediments to their mobility---oftentimes with large ramifications to their access to recreational spaces, communal resources and events, opportunities for social interaction, quality of life, and overall health. Pedestrian wayfinding frameworks and data models have yet to be systematically evaluated regarding the degree to which the experiences, expectations, and informational needs of blind, visually impaired, deafblind and low-vision users are met so that these individuals can reap the same benefits that technology affords the general population as it comes to the navigation of outdoor and indoor spaces.

The project discussed in this report aligns closely with NITC's general theme of *improving the mobility of people and goods to build strong communities*. In the context of transportation equity and diversity, and specifically related to the priority of *developing data, models and tools*, our project theoretically and empirically assesses barriers to accessibility related to the mobility of members of the disability community; employs robust data collection and analysis on the lived wayfinding experiences of members of the disability community in public indoor and outdoor environments; and investigates requirements for the specification of data model and attribution standards, data collection and maintenance procedures, and data and equipment stewardship related to indoor wayfinding, digital mapping, and mobile-based routing of visually impaired, blind, and deafblind travelers. Last, but not least, our project fostered close *collaboration, co-design, and co-creation of knowledge* between the investigators and our external partners of practitioners, developers, and members of the disability community on seamless outdoor/indoor wayfinding. The very objective of the project was to better understand how mobile-based telecommunication and wayfinding technologies can be best employed to enhance the mobility of all members of society, nondisabled and disabled alike.

1.3 RESEARCH QUESTIONS

In terms of functional disability, our project focused on adults and transition-age youth with vision-related disability. More specifically, we systematically assessed the information needs of visually impaired, blind, and deafblind pedestrian travelers in urban indoor/urban spaces. To the extent that prior work has addressed the information needs and route choices of visually impaired travelers in urban environments, our project assessed individual information needs in conjunction with organizational requirements towards sustainable, scalable deployments of smart technology for seamless indoor/outdoor wayfinding. Our project aimed at distilling preference structures of pedestrian travelers towards indoor/outdoor spaces and routes, as well as formulating criteria for the empirical evaluation of technologies for seamless indoor/outdoor wayfinding in terms of their usability and usefulness as perceived by visually impaired users.

The central research questions for our project were:

- What are the preference structures, information needs, and expectations of individuals with visual-impairment, blindness, and deafblindness towards wayfinding in public indoor/outdoor spaces?
- In which way can low-cost wayfinding technology (e.g., digital maps, spatial data, personal telecommunication devices, and low-energy beacons) be leveraged best to allow for the seamless wayfinding of pedestrian travelers with functional disabilities in public urban indoor/outdoor spaces?

- Which wayfinding technologies, data products, and technology platforms afford a sustainable, scalable deployment in a large academic institution?

1.4 EXTERNAL PARTNERS

1.4.1 American Printing House for the Blind

Our close partner, the American Printing House for the Blind (APH), is the world's largest nonprofit organization creating educational, workplace, and independent living products and services for people who are visually impaired. APH has been working on accessibility issues for more than 160 years, and has identified indoor navigation technology to be the new frontier of accessibility. APH is committed to ensuring that navigation technology moves forward in a way that includes everyone through the research and development of products that include wireless Bluetooth and GPS technology and digital mapping methods. APH provides significant research experience and expertise regarding the lived experiences of people who are visually impaired. As a part of their previous work on perceptions on accessibility, APH conducted a national research project on accessibility barriers identified by the blind and visually impaired community. Our project is building on the results of that research in terms of its motivation and objectives in order to make the urban environment more universally accessible and inclusive.

The partnership with APH grew out of a mapping project on the PSU campus. APH had developed an app called Nearby Explorer, which was a navigation app designed especially for users with visual impairments. Nearby Explorer supported outdoor navigation, but they had also begun to expand to support indoor navigation. This indoor navigation support was facilitated through Bluetooth beacons, which were installed in buildings that had been mapped by the Nearby Explorer team.

The APH/Nearby Explorer team mapped the first floor of several buildings on the PSU campus, and they installed Bluetooth beacons in three buildings: the Millar Library, Smith, and Fariborz. This initial technology deployment, complete with the Nearby Explorer app, was intended to be the technology tool utilized for this study. However, in late 2019, APH shifted their focus and created a separate company to continue this navigation technology work, and in 2020 they ceased support of the Nearby Explorer app. Instead, the new company, GoodMaps, developed a new app, GoodMaps Explore. Along with the new app, GoodMaps significantly changed both the mapping process as well as how the technology works to establish indoor locations and provide directions to users. The new mapping process involved taking a Lidar scan of the floor(s) to be mapped, and using that, rather than blueprints/floor plans, as the basis for the indoor map. Instead of relying on Bluetooth beacons, GoodMaps Explore utilizes camera-based positioning, which provides more accurate localization. GoodMaps Explore, and the GoodMaps-generated map of Smith, became the technology chosen for this study.

In addition to technology support, APH employees Elizabeth Schaller and Denise Snow served as key members of the research team. They supported all aspects of the project, from reviewing the literature to selecting routes on campus to providing support during all phases of the route testing with participants. APH team members traveled to campus several times to assist with data collection and focus groups. They met with GoodMaps in order to keep up to date with the latest app developments and deployment status. They participated in regular meetings with the PSU team and helped to get testing back on track after campus COVID restrictions were lifted. They will continue to support this project during the dissemination phase through conference presentations.

1.4.2 GoodMaps

GoodMaps originated out of APH. Founded in 2019 and based out of Louisville, KY, GoodMaps (previously named Access Explorer) was created by APH to further the cause of accessible navigation, given that universal accessible navigation was limited foremost by a lack of indoor digital mapping solutions, fidelity, and data availability. The GoodMaps mission is to improve the accessibility, safety, and productivity of indoor spaces. On that account, GoodMaps creates and maintains detailed 2D and 3D digital maps of indoor spaces, provides indoor positioning capabilities, and offers end users a secure mobile wayfinding experience through their cloud-based wayfinding data platform (GoodMaps Studio) in conjunction with a mobile app (GoodMaps Explorer).

In May 2021, the GoodMaps team began scanning SMSU onsite using Lidar equipment. Over the next several months, GoodMaps engaged in remote and in-person meetings to refine the scans of the building, collaborating with the building administrator to ensure that the digital maps were appropriately labeled in their database. Concurrently, GoodMaps engaged with developers at Intel to refine the accuracy of spatial information, partnering on global projects relating to the accuracy of real-time feedback for travelers. In November, GoodMaps collaborated with the Disability Resource Center to host interested students and staff with visual impairments to informally evaluate the technology installation within SMSU. Students with disabilities met with Mike May and Evelyn Tichnor to share initial feedback, which led to further refinement of the digital maps. During these on-campus visits, Mike May shared insight with PSU O&M graduate students on the steady evolution of indoor wayfinding technologies. In December 2021, the refined version of the GoodMaps installation was ready for research participants to evaluate through the NITC-funded project.

1.4.3 PSU Digital City Testbed Center

The Digital City Testbed Center (DCTC) at Portland State University seeks to maximize the benefits and minimize the risks of deploying technology in cities. DCTC convenes academics with technologists and entrepreneurs to improve the health and safety of buildings and transportation systems, preserve urban trees, and increase accessible options for all, while protecting privacy and security. DCTC works towards establishing a network of campuses in the Pacific Northwest where smart city technologies can be tested before being deployed in communities at large. In that context, DCTC focuses on how technology can help make cities "smarter" by improving sustainability, public health, social well-being, economic viability, and accessibility. DCTC’s support of the project allowed the hiring of a graduate research assistant who substantially facilitated the progression of the project towards the achievement of project milestones and the furnishing of project deliverables.

1.5 PROJECT TIMELINE AND ACTIVITIES

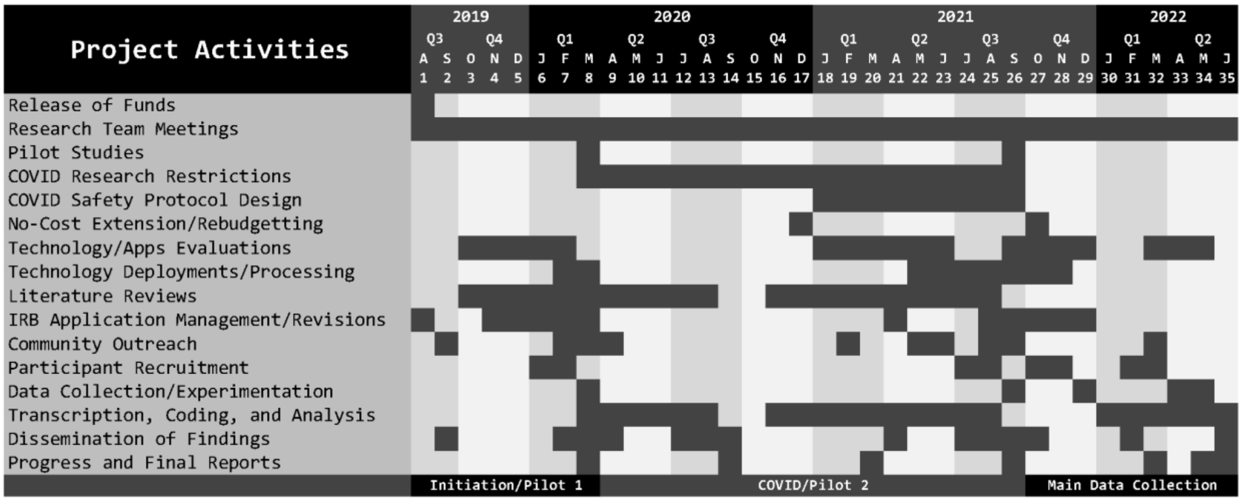

Figure 1: Overview of major project activities by month.

The initial funding period of the project was from September 2019 to December 2020. A major component of our project was experimental research on the wayfinding behavior of human participants with visual impairment or blindness. In that context, the global COVID-19 pandemic resulted in drastic restrictions on human subject research in 2020/2021. Specifically, at Portland State University, from March 2020 to September 2021, human subject research was either suspended institution-wide or limited to human-subject research protocols that could be administered remotely, with no in-person contact between participants and researchers.

Considering the objective of our project pertaining to the assessment of observations of individual pedestrian travel, the structure of our research design, and a prerogative for the safekeeping and well-being of participants in our study, we deemed remote substitutes to the in-person research activities that we devised neither feasible nor practical. As a result of the prominent disruptions to our projected project schedule due to the pandemic, our group filed two no-cost extensions for the project (i.e., 1. January 2021 through December 2021 and 2. January 2022 through June 2022). The final duration of our project was, therefore, the 35-month period from September 2019 through June 2022. Figure 1 provides an overview of the major research activities during that time span.

2.0 METHODOLOGY

We conducted a mixed-method case study that included low-incidence diverse youth and adults. Our participants included people of color, LGBTQIA+ participants, and individuals with varying levels of visual impairments. We have analyzed the travel behaviors by comparing participants' use of wayfinding tools such as tactile maps as well as wayfinding apps. Routes were supported on an urban college campus and conducted in dynamic, typically experienced travel environments. Interactions with participants were naturalistic so that comments or questions asked in route were used to describe what features of the wayfinding tool or environmental elements were useful to the travelers. Data was then gathered using focus groups to further unpack preferences, wayfinding experiences and insights from participants. Qualitative data and quantitative data were analyzed in a convergent manner to describe what supports wayfinding on a complex college campus. Social validity was noted in that participants shared that they enjoyed the experience and that it gave them more confidence about exploring campus environments.

2.1 STUDY LOCATION AND CONTEXT

The campus of Portland State University (PSU) is located in the heart of downtown Portland, OR. The project discussed in this report represents an interdisciplinary research effort across two colleges at PSU, that is, the College of Liberal Arts and Sciences and the College of Education, and involved extensive collaboration with external agency partners. Particularly noteworthy is that the PSU College of Education offers the Visually Impaired Learner (VIL) program, which prepares learners to become teachers of students with visual impairments (TVIs) and/or Orientation and Mobility (O&M) Specialists. The university is the only institute in the Pacific Northwest to offer such programs. Masters and doctoral candidates, led by their university professors, participate in research projects related to the field of visual impairment, both on the PSU campus and using virtual methods of meeting and communication.

The streets around the perimeter of the campus are busy with typical urban city traffic. Visitors to the campus can access public transportation in the form of bus, light rail, or streetcar within a few blocks. Within the campus, however, are the Park Blocks, which offer large green spaces and wide walking paths with no vehicular traffic. There are 48 buildings within the 44-acre campus.

The Smith Student Memorial Union building ("Smith") provided the home-base location for this study. The building is a bustling campus hub, housing the dining hall, coffee and bagel shops, and a market. Most of the university resource centers are located in Smith, including the Veterans Resource Center and Disability Resource Center. Other sought-after locations in this building include the Baby Vikings daycare and a food pantry. Visitors to Smith can navigate through the space using an app called GoodMaps Explore, which provides both visual and voice instructions to particular locations within the building.

2.2 PARTICIPANTS

The research described in this report was conducted under the oversight of the Institutional Review Board (IRB) at Portland State University. Research procedures and materials pertaining to our study were approved under IRB protocol #174312. For all research activities with human subjects, informed assent/consent were provided by the participant or, where applicable, a participant's parent or legal guardian.

In order to capture a wide range of individual perspectives and experiences pertaining to wayfinding, we conceptualized our study to accommodate both adolescent youth as well as adults. Participants underwent a screening process based on an online screening survey. Study-eligible participants self-identified as independent travelers with low vision, blindness, or deafblindness. Each subject who participated in our study activities on the PSU campus received an electronic gift card for their time and effort, ranging in value from $75 to $100.[1] Completion of the screening survey was incentivized by a lottery for a single electronic gift card in the amount of $50.

We opted for the age of 14 as the youngest age for participation (over the exclusion of adolescents) for two reasons. First, 14 is a typical age for underage travelers to engage in independent travel without special supervision needs. Second, youth with visual impairment often benefit from opportunities to participate in college and career exploration. Such opportunities include the task of wayfinding on college campuses, which our study design afforded. Those under the age of 18 years were accompanied by a parent or legal guardian.

Upon conclusion of our data collection for the study, a total of 30 participants completed the experimental protocol. Of the 30 participants, two adult participants partook in the study during pilot data collection activities and 28 during the main data collection phase of our study. Within the main data collection group, 21 participants were adolescents between the age of 14 and 18 and seven were adults.

2.3 METHODS AND MATERIALS

The pilot and main data collection phases of our study consisted of three components: 1. an electronic screening survey to determine eligibility for participation in a follow-up experiment on the PSU campus; 2. an in-person structured wayfinding experience on the PSU campus; and 3. an in-person focus group following the structured wayfinding experience on the PSU campus.

Questions asked in the screening survey included socio-demographics, visual and hearing ability, current mode of mobility, other mobility supports used, frequency of independent travel, comfort level of independent travel, and whether or not the

[1] Our initial allocation in terms of individual incentives for participants in on-campus study activities during the pilot phase of the study was $75. Based on the insights gained from the pilot phase, we subsequently amended our IRB-approved protocol and increased the allocation to $100 for participants in the main data collection phase of the study.

individual had used wayfinding technology, tactile maps, and/or other route previewing resources.

Our collaborative project aimed at distilling preference structures of pedestrian travelers towards indoor/outdoor spaces and routes and empirically evaluating the usefulness of mobile technology (e.g., wayfinding apps, Bluetooth beacons, turn-by-turn route instructions) for seamless indoor/outdoor wayfinding by visually impaired users. Information and written documentation pertaining to informed consent/assent were provided electronically to all participants for preview prior to scheduling for participation on the PSU campus, and signatures were obtained once participants were on the PSU campus prior to participating in the structured travel experience. Minors were asked to furnish completed and signed parental permission forms if a parent was not present in person. All participants who were minors were accompanied by a school professional and/or parent or legal guardian during on-campus research activities.

Participants who self-reported to be independent travelers were invited to partake in a series of wayfinding tasks involving no more than a sequence of three short routes that incorporate both indoor and outdoor elements. The routes were unfamiliar to the participants and resembled common routes from, to, and along points of interest and landmarks on the PSU campus (e.g., Disability Resource Center, library; Smith Hall food court) and points of origin along varying locations on the PSU campus (Appendix A-1, A-2, A-3). Participants were accompanied at all times by an experimenter with professional experience in Orientation and Mobility.

The different routes and collected wayfinding metrics were instrumentalized in a within-subject study design in which all participants completed all routes. Information provisions regarding the routes were, by design, different between the routes in order to assess the interaction between technology-mediated information (e.g., distance and direction to Bluetooth beacons), turn-by-turn instructions, proximal and distal landmarks and the participants' wayfinding performance (e.g., number of turns, time for completion) and self-reported satisfaction. All wayfinding experiences while traveling the routes were video recorded by the researchers for further assessment.

After completion of the routes, participants were debriefed in semi-structured interviews or focus groups about their overall experience with the wayfinding tasks, routes, and information provisions to more holistically capture participants' experiences and perceived information needs that were not captured or observable during the wayfinding experiment. These semi-structured interviews or focus groups were recorded through audio for transcription and further assessment.

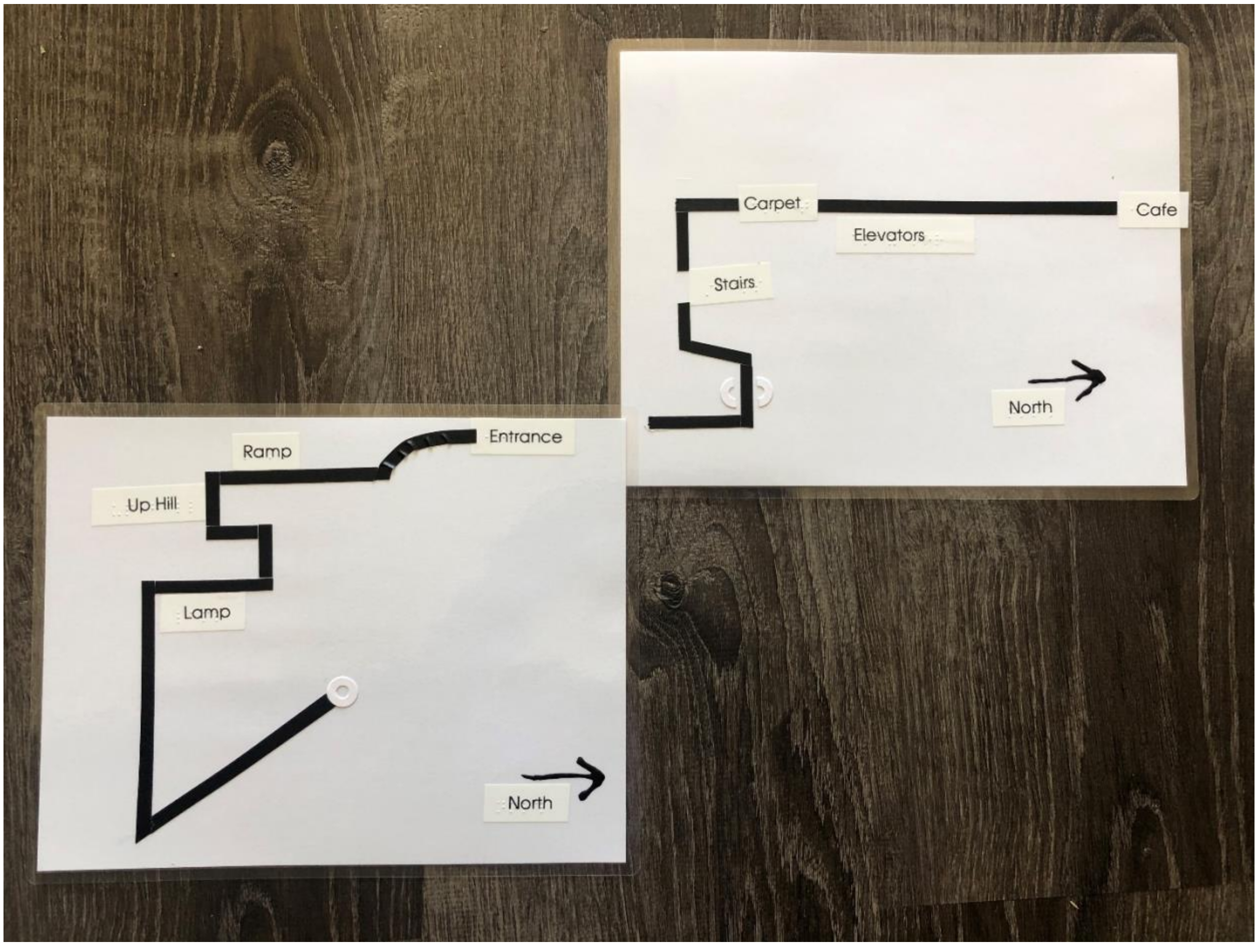

Figure 2: A tactile map capturing indoor and outdoor components of a route in the first phase of our study.

2.4 MAIN DATA COLLECTION PHASE

During our main data collection phase, participants were asked to engage in a structured travel experience on the PSU campus that was comprised of the travel on two routes (across three possible routes) while using one of two possible wayfinding supports (one for each route); that is, a tactile map or a mobile app (i.e., GoodMaps Explore). The lower number of wayfinding supports for the main data collection compared to our pilot phases (from three down to two) was motivated by a) our aspiration to reduce the overall time and energy commitment required of our participants to complete the experimental protocol and, b) the performance of the tactile map and mobile app modalities in our pilot phases---which warranted a focus on these two modalities over the written instructions modality that constituted a third modality during our pilot phases.

To minimize potential risks to participants caused by traffic, no vehicular intersections were considered or crossed. Instead, all crossings were in-block pedestrian crossings only. The length of a single route was no more than three blocks in length on fairly flat terrain with minimal elevation changes. During travel, a researcher, O&M specialist, and/or O&M graduate student were present to monitor participant safety and answer participant questions if addressed. Participants were guided to and from each component of the PSU campus experience components (e.g., structured travel experience locations, focus group meeting room, etc.) and to route origin locations.

After a 30-minute training session on the use of the mobile app and tactile maps, the participants were asked to travel the two routes in subsequent order. All possible routes were conceptualized by the researchers based on best practice in O&M. By design, the routes required travel from an outdoor to an indoor destination. As mentioned above, one of the two different forms of support were given to the traveler before travelling each route. The assignments of wayfinding supports to routes and participants was accomplished through random assignment.

Each respective support was available to the traveler during the route. At all times, a researcher accompanied the participant and assisted them where and when needed. At the end of each route, the participants were asked a few questions about their thoughts and feelings about the route. The travel and responses were recorded using notes, video, and audio. Focus groups/interviews were recorded using an audio recording device for subsequent transcription.

The completion of the pre-screening survey took approximately 30 minutes or less. The structured travel activity took between one and two hours, depending on the participants' comfort, energy levels, abilities, and preferences. Focus groups/interviews were no longer than one hour. Hence, the average overall time commitment for each participant in our study ranged from four to five hours.

3.0 FINDINGS

In the following we discuss the to-date findings from our study. The discussion includes findings that have been published by our group in peer-review publications, all of which are open-access publications and, therefore, freely available to the general public. In these cases, we included an itemized summary of the main findings from the publication as well as the full bibliographic information for the publication. Our selection of a peer-reviewed, open-access publisher for the publications from this study was most deliberate in that the scholarly work that our group placed therein during the duration of the project is interrelated (i.e., continuations and extensions), and the open access model affords greatest access to individuals and organizations in the disability community.

3.1 FINDINGS FROM FOCUS GROUPS

Investigations into the lived experiences of travelers with visual impairments and deafblindness involved structured conversation and engagement with community members about devices they use in real-world contexts. To begin, we employed purposive sampling to recruit adult travelers with blindness, low vision or deafblindness through local agencies and scheduled focus groups at convenient times for interested participants. The communication preferences and needs of individuals were honored.

One of our focus groups included eight blind or visually impaired adults who did not have any hearing loss, and was conducted in spoken English and recorded in an audio format for transcription. Another focus group was conducted with nine deafblind participants who use Tactile American Sign Language or close-range visual American Sign Language. By request, these focus groups were structured with communication facilitators who happened to be deafblind themselves. Facilitators partnered with Dr. Parker as lead researcher to share questions directly with smaller face-to-face groups of participants. With consent, Dr. Parker video recorded the conversations for transcription from ASL to written English, confirming themes from the transcripts with deafblind participants to ensure authenticity and accuracy of transcriptions. Collective themes from the diverse focus groups articulated both the promise of wayfinding apps for offering greater environmental literacy during real-world travel contexts and the limitations of using such apps.

Both groups articulated the need for apps to be designed in collaboration with travelers with visual impairments because of the apps' unique limitations, especially in dynamic travel conditions. A specific theme that emerged amongst visually impaired travelers was the need to use multiple apps to complete one route because each app was useful for a constrained number of wayfinding tasks. For example, a transit app might be helpful during a bus route, but another app would need to be used during a transfer to a different modality, while still another was needed to locate the entrance of a building. For individuals who are deafblind, a theme emerged around the need for real-time, sound-based safety information to be provided, such as the presence of emergency vehicles passing through intersections. For both groups, travelers expressed a need for wayfinding apps on smartphones to interface more seamlessly with braille display devices, especially as many individuals with low vision anticipate progressive vision loss over time leading to a greater need for braille access. For both groups, speech output was difficult or impossible to access in some travel conditions, especially within loud urban environments.

Orientation and mobility specialists are professionals who provide direct assessment and instruction for blind, visually impaired and deafblind travelers of any age to gain knowledge, skills and confidence for safe and efficient travel across multiple environments. As a part of our NITC study, we conducted focus groups with seven O&M professionals on their own experiences in integrating wayfinding apps into their work with students and clients. Themes from these discussions included the challenge for travelers in increasingly complex travel environments to use apps. Both human and environmental factors dynamically interface with the efficacy and utility of wayfinding apps. O&Ms also described the need for travelers to use multiple apps to accomplish one journey and the cognitive load of integrating app skills into global O&M skills. Far from being a panacea, O&Ms described apps as merely one type of support for accomplishing wayfinding tasks.

“Everyone is unique in their own way. Some people adapt to apps very quickly, because they're using their iPhone or using their Android, other people do not adapt quickly because it's foreign. It's not a tool that they've integrated into their tool box.”

“Some experience I've had with one of my clients is some of the apps are not the most compatible with voiceover, it seems like. We were using Apple Maps, and she was trying to right finger flick to scroll through and then sometimes voiceover would get stuck on the map, and calling out these random streets, and she would get really frustrated. And she wouldn't be able to get to the search field to enter in an address.”

“I also think now the changing landscape where you have electric vehicles creeping up on you and you turn around and suddenly there's a Prius behind you. It's like, ‘Where did that car come from?’ It's contextual type of awareness in particular in terms of navigating intersections, I suppose.”

Further description of the findings from our focus group with deafblind participants is provided in the following open-access publication:

Parker, A. T., Swobodzinski, M., Brown-Ogilvie, T., and Beresheim-Kools, J. (2020). The use of wayfinding apps by deafblind travelers in an urban environment: Insights from focus groups; Frontiers in Education – Educational Psychology, 5:572641. DOI: 10.3389/feduc.2020.572641

3.2 FINDINGS FROM LITERATURE REVIEW

The findings from our literature review are provided in the following open-access publication:

Parker, A. T., Swobodzinski, M., Wright, J. D., Hansen, K., Morton, B., and Schaller, E. (2021). Wayfinding tools for people with visual impairments in real-world settings: A literature review of recent studies. Frontiers in Education – Educational Psychology, 6:723816. DOI: 10.3389/feduc.2021.723816

An itemized list with the main elements from this publication is as follows:

- We conducted a structured literature review of peer-reviewed articles that were published between 2016 and 2021.
- Candidate peer-reviewed publications were screened for descriptions of experimental research on wayfinding with blind, visually impaired, or deafblind individuals in indoor/outdoor settings in combination with wayfinding tools or devices, and specifically smart devices/cell phones.
- A total number of 35 peer-reviewed publications fulfilled our selection criteria and were selected for further, in-depth review; 33 of the publications included the use of mobile devices.

- Based on the set of 33 publications, we distilled participant and research characteristics that were employed in the wayfinding research in addition to information on funding agencies and sources.
- Results indicated a large reliance on infrastructure in the form of low-energy Bluetooth beacons for positioning; few studies using Lidar.
- The identified studies included limited description of participants' visual acuities or etiologies, with few exceptions.
- Most studies were concerned with the evaluation of secondary devices in relation to participants' use of a primary mobility device (i.e., long cane or guide dog).
- There was minimal consideration or description of individuals who may have had additional challenges regarding disability or mobility.
- None of the studies specifically included participants with dual sensory loss.
- The placement of a wayfinding device during wayfinding profoundly impacted the perceived usefulness of the device.
- Access to real-time route information generally increased the rate of success among participants, while some individuals reported an increase in cognitive load while using mobile devices.
- Participants greatly valued provisions for structural and functional knowledge of spaces in advance of in-person travel.
- The perceived importance of landmarks varied between participants using different mobility devices and the type of wayfinding task.

3.3 FINDINGS FROM FIRST CASE STUDY

The findings from our first pilot study are comprehensively summarized in the following open-access publication:

Swobodzinski, M., Parker, A. T., Wright, J. D., Hansen, K., and Morton, B. (2021). Seamless wayfinding by a deafblind adult on an urban college campus: A case study on wayfinding performance, information preferences, and technology requirements. Frontiers in Education – Educational Psychology, 6:723098. DOI: 10.3389/feduc.2021.723098

Here, again, we provide an itemized list of the main elements from the publication, as follows:

- Our group conducted an experimental evaluation of the experience, performance, and perception of a deafblind adult participant travelling unfamiliar indoor/outdoor routes.
- The participant self-identified as hard o -hearing who commonly uses a hearing aid.
- The participant completed three routes on the PSU campus using either a mobile app, written directions, or a tactile map as well as a semi-structured interview.
- The routes were designed to resemble real-life travel, each explicitly including indoor and outdoor segments and transitions between them.

- We synthesized observations and responses from a pre-/post-travel survey, video recordings of travel, and post-travel interview.
- Wayfinding performance and confidence differed considerably between the three wayfinding modalities.
- The tactile map afforded highest wayfinding performance, confidence and satisfaction, and afforded the fastest completion time.
- Confidence and wayfinding performance were lowest for the mobile app.
- Longer trip distances and errors occurred during all three modalities.
- Orientation and mobility skills helped the participant negotiate unexpected wayfinding scenarios across all wayfinding modalities.
- Simplicity of use of a wayfinding tool is needed to reduce cognitive load during wayfinding.
- Information that is disjointed from individual information preferences, expectations, and/or needs reduces wayfinding performance.
- Digital representation of spatial data inherently does not account for the complexity of the information needs of visually impaired, blind, and deafblind individuals.
- The selection of landmarks during wayfinding is idiosyncratic.
- Mobile app developers need to better understand, consider, and incorporate the information needs and user interface requirements of deafblind individuals.
- Wayfinding researchers need to consider individual characteristics pertaining to co-occurring impediments and disability, spatial orientation ability, and extent of Orientation and Mobility training and skills.

3.4 PRELIMINARY FINDINGS FROM SECOND CASE STUDY

As a part of our ongoing investigation, we conducted a second pilot study with a participant who was both a traveler with combined vision and hearing loss and who had professional experience as an O&M specialist serving those with visual impairments across multiple states. This participant's occupational and personal experiences were helpful to the research team in describing what may be supportive for different types of travelers as well as in further refining our testing protocol.

Broadly, this expert participant shared that the process of wayfinding is about "asking questions" to make meaning of all available information in the environment. She described her own wayfinding experiences as well as those of her clients to be supported by tools that may change over time. *"Because of my hearing loss, I can't use some wayfinding apps in noisy environments."* When using wayfinding apps, she described: *"I have to remember the number of steps it takes to use the tool."* She also explained that there are certain "tricks" for using tools to get more accurate information, such as asking for location information when the traveler is mid-block rather than at an intersection. She described that her trust in using wayfinding apps is tempered by her own experience in noting that the information offered is sometimes "*ludicrously incorrect."*

In order to further refine our wayfinding protocol, we asked her to participate and offer feedback on the three travel conditions that we offered in our first pilot, the tactile map, verbal directions and using the GoodMaps app. On the wayfinding routes and in the interview, she reflected that the tactile map, particularly the symbols, were useful to her as a confirmation for her location on the route. For a fully blind traveler, she thought the braille along with the symbols on the map would be useful. In response to the GoodMaps app, she reflected: *"I don't have enough experience with the building settings. It doesn't mean it can't be useful in the future. I don't want to give up on it."* The conditions of offering verbal directions was found to be the least useful and because of her insights, we eliminated this testing condition for the next phase of participant testing.

3.5 PRELIMINARY FINDINGS FROM MAIN DATA COLLECTION

Notwithstanding the massive disruptions to the lives of many due to the forceful emergence of the SARS-CoV-2 coronavirus, including but certainly not limited to the prolonged suspension of in-person, human-subject activities at PSU, our group remained diligent and committed to the successful completion of our data collection and the engagement of a robust overall number of participants---which remained our major prerogative through the final period of this project. On that account, our group was able to successfully administer our experimental protocols to and with 30 visually impaired, blind, and deafblind participants across a wide range of individual-level visual function and age.

As stated before, a total of 30 participants completed one of our experimental protocols, 28 of which participated during the main data collection phase of our study. Within the latter group, 21 participants were adolescents between the age of 14 and 18 and seven were adults. Our preliminary analysis of the spatial abilities of the participants based on individual-level responses to the Santa Barbara Sense of Direction scale (Hagarty et al., 2002) revealed significantly lower aggregate spatial ability scores of the adolescent participants compared to the adult participants. If and in which way these differences in self-reported spatial ability inform differences in wayfinding performance has yet to be determined.

The immediate next step for our research group is the full coding and the thorough analysis of the data from our main data collection phase. More specifically, our group is in the process of consolidating individual-level data that we collected for each of the 28 participants in our main data collection, and foremost the coding and analytical assessment of observed wayfinding behavior and performance that we captured through video recordings.

4.0 CONCLUSIONS

In this project we aimed at systematically unpacking the challenges and opportunities that arise from the availability of affordable wayfinding aids in the context of human wayfinding by pedestrian travelers with functional disabilities. More specifically, our project focused on adults and transition-age youth with vision-related impairment, blindness, and deafblindness. Our collaborative research team was comprised of PSU faculty and graduate students (Geography and Special Education) as well as collaborators at the American Printing House for the Blind, and combined professional expertise in the theory and practice of accessibility, human wayfinding, and Orientation and Mobility. The group of collaborators at APH was comprised of both co-investigators and accessible technology experts.

This project contributes to the research base in Orientation & Mobility (O&M) for diverse individuals with visual impairments by including both young and older adults and those who may have additional disabilities, for instance, hearing loss or cognitive impediments to the additional physical challenges. The project leveraged APH's commitment to and investment in propelling forward the integration of indoor and outdoor wayfinding, as showcased by APH's Nearby Explorer app and first Accessible Indoor Navigation Symposium (March 2019). In addition, the project built upon findings from APH's national survey (to date, the largest such study of its kind) on considerations for accessibility by individuals who are blind or visually impaired. Project activities aligned closely, both in terms of schedule and themes, with the activities of our partners at APH and GoodMaps, and served to maximize synergies, collaboration, and effectiveness of our efforts. The assembled research team and the support and involvement of APH and GoodMaps distinguishes this research in the realm of visual impairment and wayfinding.

Our study gave voice to the experience of diverse travelers who use wayfinding technologies to accomplish important life tasks. Despite the proliferation of wayfinding apps that are meant to benefit travelers, the goodness of fit of such tools remains constrained. At the same time, there is a great desire for technologies to be better integrated, more intuitive, and more responsive to individual traveler characteristics and needs. In addition to the findings that we discussed in the report at hand, we expect that the analysis of the remaining data will further the significance and merit of this project and drive forward a better understanding and appreciation of the information needs of visually impaired, blind, and deafblind pedestrian travelers in urban spaces.

Our study focused on individuals with blindness, visual impairments, and deafblindness. We acknowledge that cognitive impairment pertaining to processing and/or memory in the context of wayfinding greatly informs individual experiences. An emphasis on cognitive disability, however, was beyond the scope of our study. In addition, given that visual impairment and blindness are a characteristic with low-incidence rates in the general population, overall numbers of visually impaired and blind participants in non-longitudinal and/or shorter-duration experimental studies such as the one described in this report will remain small. In turn, any statistical analysis of individual-level variables pertaining to wayfinding performance will be limited in terms of power.

As mobile-based wayfinding frameworks and data models evolve, we strongly urge researchers and practitioners to drive forward their systematic and rigorous evaluation, as to make sure that the experiences, expectations, and informational needs of blind, visually impaired, deafblind and low-vision users are met so that these individuals can reap the same benefits that mobile technology affords the general population as it comes to the seamless navigation of outdoor and indoor spaces.

5.0 REFERENCES

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APPENDICES

APPENDIX A-1: PILOT ROUTES DESCRIPTIVE SUMMARY

Route 1: Smith to Fariborz Maseeh Hall (FMH) Student Accounts (Blue Route)

Origin: Just outside Smith Memorial Student Union, East door

Length: 177 Steps (82 outside; 95 indoor)

Number of Outdoor Crossings: 1

Number of Turns: 5-6; 2 outdoors and 3 indoors (4 indoors if counting final turn to face Student Accounts)

Notes: This route starts outside the east door of Smith Memorial Student Union and travels south. It crosses a walkway between Smith and FMH then turns west (right). At mid-block, it turns left (south) to arrive at FMH's north entrance. The route continues south to locate the stairs, then turns right (west) to locate the ramp that reaches the first floor of FMH. Once on the first floor, the route turns right (west) until the end of the building then turns left (south) to locate Student Account Desk. (See indoor route with floorplans on next page).

Route 2: Park Block to Millar Library's Indoor Café (Green Route)

Origin: Park Block between Millar Library and Fariborz Maseeh Hall (FMH)

Length: 184 Steps (112 outside; 72 indoor)

Number of Outdoor Crossings: 1

Number of Turns: 11; 7 outside and 4 indoors

Notes: This route starts close to the center of the Park Block between Millar Library and FMH and travels southeast. It makes a sharp right (west) turn and passes benches. It then turns right (north) for a few steps to find a lamppost (landmark) which indicates where to turn left (west) and cross a walkway. Once the walkway is crossed, the route continues west until the Library ramp is reached. The route turns right (north) to traverse the ramp then turns left (west) to trail the rounded façade of the Library to the south entrance door. Once inside, the routes turns left (west) for a few steps then left (south) for a few more, then right (west) again to trail a wall. After the 2nd wall opening, the route turns right (north) and travels straight to the Library Café, passing elevators along the way. (See indoor route with floorplans on next page)

Route 3: Lamppost Outside Library to Fariborz Rm. 100 (Red Route)

Origin: Lamppost outside Library

Length: 192 Steps (126 outside; 66 indoor)

Number of Outdoor Crossings: 2

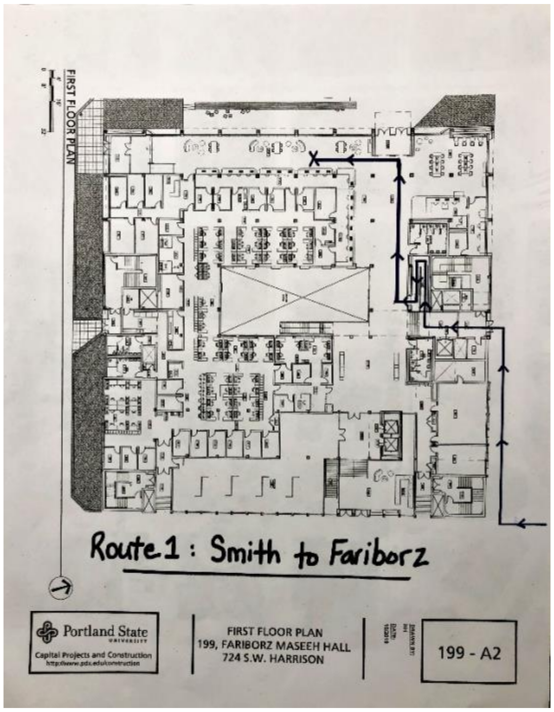
Number of Turns: 10; 6 outside and 4 indoors

Notes: Most challenging of the 4 routes but it does offer great tactile info for shorelining. Start at Lamppost located on ramp side of the Library. Follow brick texture or grassline on right edge as it turns 45-degrees to right (northeast). Continue following brick line until fixed concrete trashcan found, continue straight line for Crossing 1 and pick up continued shoreline until it ends at corner of a triangle. Turn right (south). Square off with this new line on right and make Crossing 2, heading east. Turn right to follow left shoreline to billboard. Find FMH doors behind and parallel to right side of billboard. Enter 2 sets of doors. Continue straight (east) until the perpendicular wall is reached then turn left (north) for a short distance, shorelining wall on right. When it ends, turn right (east). At end of hallway, Conference Room 100 will be found on left (north) side of hallway. (See indoor route with floorplans on next page).

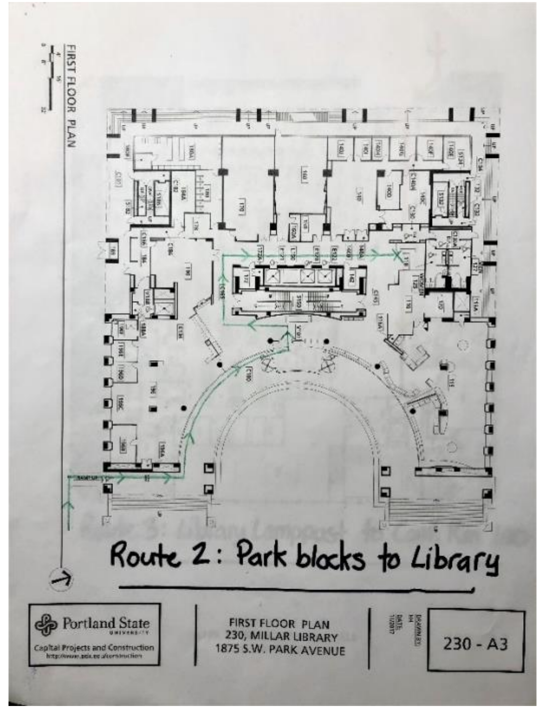
APPENDIX A-2: PILOT OUTDOOR ROUTES MAP

Routes Outdoor Sections

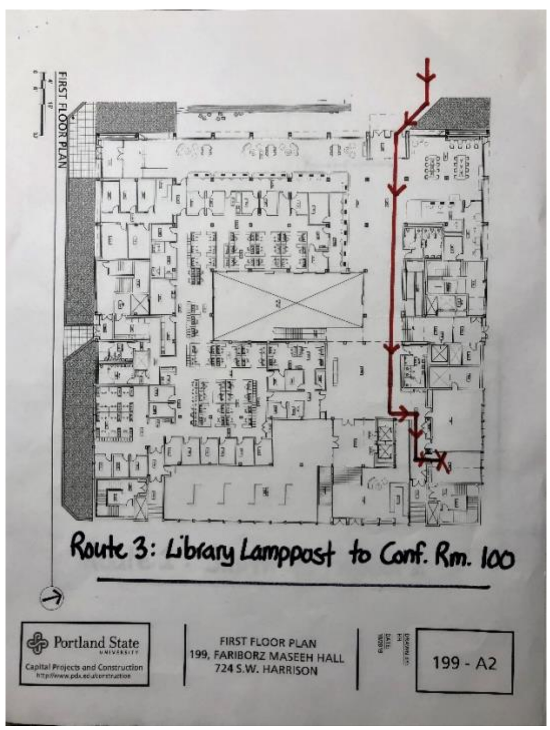
APPENDIX A-3: PILOT INDOOR ROUTE MAPS



Route 1



Route 1



Route 3