Tactile MapTile: working towards inclusive cartography

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Abstract

Tactile MapTile: working towards inclusive cartography

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This project presents an alternative approach to understanding the pedestrian experience. Challenging the existing primacy afforded to vision, this work takes a tactile approach. Physical abstractions are used as a means to guide people through the multi-sensory environments encountered everyday. Designed as tools that enhance spatial understanding for people within a large range of visual capacities, three-dimensional maps consider circumstances that influence a full spectrum of experience. The maps produced confront gaps in the cartographic record as it pertains to inclusive design, and considers how that is manifest in the lived experience. The project suggests an approach to strengthening the democratic nature of public landscapes including the infrastructure of sidewalks and streets.

This thesis project models the remarkable potential of significant collaboration between landscape architecture and data science to address a real-time challenge that impacts the daily lives of millions of individuals. Pairing a participatory, data-driven design approach together with interdisciplinary collaboration, these 3D printed, parametrically designed maps allow for user feedback, and ever changing open-data sets to be quickly incorporated. Furthermore, this partnership underscores how a broader vision of design research can catalyze alternative forms of engagement, by designers as well as by associated scientists.

Tactile Map Tile

working towards inclusive cartography

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Critical Stance

The great value of public space has been well established throughout the landscape and urban design discourse. Thought leaders from Jane Jacobs to Jan Gehl point not only to the importance of parks and plazas as public spaces, but also to the critical social infrastructure provided by the space between our buildings (Jacobs 1961, Gehl 2014, Koch and Gehl 2006). In addition to opportunities for engagement, public pedestrian ways facilitate health promoting, low impact mobility (Carver, Timperio, and Crawford 2008, Cutts et al. 2009, Dannenberg, Frumkin, and Jackson 2011). With no fees for use, no licensure or expensive equipment; no age limits or minimums to meet, sidewalks and footpaths make up one of the most inclusive transportation networks available to urban dwellers.

Despite all of this, pedestrian environments are often overlooked and underappreciated. Historically as American cities grew, primacy has been given to vehicular traffic. Even in the most progressive cities, pedestrian ways tend to be treated as addend to the streets, rather than comprising a transportation network of their own right. As a result pedestrian networks remain incomplete and often inaccessible, both physically and digitally, particularly in less affluent areas (Schrader 2017, Maciag 2014). Unfortunately and perhaps unsurprisingly, even in the age of smart cities and Google maps, pedestrian network data is scattered and messy at best (Seattle 2017, Arlington 2017, San Francisco 2017), and in many cases out of date or absent altogether (Savannah 2008, Houston 2017, Chicago 2012).

There are no major digital mapping services to date with a comprehensive sidewalk dataset (Apple 2017 , Microsoft 2017, Google 2017, OpenStreetMap 2017). Many cities have made attempts at collecting this data, willingly or otherwise, but disparate efforts, risk being outdated before they begin and often are done in such an imprecise manner that significant clean up needs to be done before the data can be utilized for routing, or other applications that require a finer granularity of data (Bolten et al. 2016).

This absence of information is not merely a reflection of the auto centric culture from which these tools emerged, but has significant implications for millions of people in terms of their access to useful routing that facilitates safe, independent navigation. Walking directions that route pedestrians down highways, or streets without sidewalks have the potential to frustrate nearly everyone. This frustration is compounded when a more granular set of information is needed. From curb ramps to audible pedestrian signals, built features of the pedestrian environment have a significant impact on the way people move through space, and for millions these features are not merely a convenience but dictate the degree to which an area is independently traversable.

While a sidewalk and its associated curb ramp may seem mundane, the spaces that people are navigating through are the work of landscape architects. The profession prides itself in making public spaces for all people (ASLA 2010), but an incomplete understanding of the existing built environment as it relates to the vast range of experiences precludes us from realizing truly inclusive environments. This incomplete understanding in part stems from an inadequate engagement with the ideas surrounding inclusive design. Beyond this a reticence to embrace the data and digital technologies that have

SDOT Sidewalks after cleaning for AccessMap (TCAT 2016) become ubiquitous in contemporary urban life, present another missed opportunity for understanding the extent of these challenges.

As a landscape architecture graduate student, dialogue relating to accessible design has largely been isolated to discrete sessions within specific courses, or an occasional studio critique suggesting a grading plan need further consideration. Discussions pertaining to accessible design also tend to be overwhelmingly directed towards thinking about use cases involving assistive devices (i.e. wheelchairs). This approach excludes a wide range of other experiences, both permanent and situational that would benefit from a critical integration of universal design thinking.

Lack of engagement with the discourse surrounding universal, inclusive and accessible design lends itself to perpetuating these quiet injustices in the public realm. Rather than approaching inclusion as an inherent design challenge that can enhance an intervention, designers and engineers too often frame access in terms of the requirements outlined in the American Disabilities Act (1990, 2008). Viewing access considerations as mere boxes that need to be checked increases the likelihood of uninspired and ineffective accessibility interventions.

Technology may seem like an odd entrant into the discussion of accessible landscapes. However, over the last few decades personal technologies and their resultant data have had an undeniable impact on the way nearly everyone experiences place. The value of the associated data has been widely accepted, but how to employ it effectively and responsibly is not always so clear (O’Neil 2016).

Resources for development and reticence to engage with new technologies have been two significant barriers to the field of landscape architecture. These barriers are compounded by the fact that students and practitioners are already spread quite thin in terms of fields they are trying to understand. It is frequently pointed out that authority on any one topic is sacrificed for a more holistic systems approach to thinking, leading designers to question what may, or may not be the role of landscape architecture.

As technology and data become ubiquitous in city building and decision making, it is critical that landscape architects integrate these elements into this systems approach to design thinking. Like it or not, the shift towards smart cities is here, so as designers of the spaces between our buildings, it behooves landscape architects to ask: what does big data in landscape architecture actually look like? How do digital tools affect not only analysis and representation, but also the design process and implementation? In what ways could these technologies be folded into the physical landscape, and how can we leverage a data driven design approach to make our cities accommodate more people in an inclusive and effective way?

Over time, neglecting to fully consider this shift in our environments could conceivably surrender the agency of landscape architecture as a profession. This trajectory has the potential to perpetuate an imbalanced data-scape that fails to capture, operationalize and protect experiences and environments that landscape architects have unique insights into and respect for.

The proposals in this thesis will explore ways in which landscape architecture can embrace data driven design not only in analysis, but also in design development and generation. Both big data sets (OpenStreetMap) and small (interviews, surveys and user feedback) are considered as they relate to the human experience, understanding and design of place.

Specifically I will investigate ways in which data and technology can be used together with qualitative research methods to understand pedestrian access in public space, through wayfinding explorations, and a collaborative approach to design. These wayfinding explorations manifest in physical tactile maps that invite iteration and customization, and are intended to be legible for users within a broad spectrum of visual capacities. This attention to meeting the needs of a broader diversity of the public is critical to the call for democratic and equitable access to the urban landscape for all people.

Literature Review

RESEARCH QUESTION

How can a better understanding and design of the pedestrian environment, specifically as it relates to a broad range of visual capacities, be facilitated through the employment of data and technology?

What data is required to meet the informational needs of pedestrians navigating with minimal visual acuity?

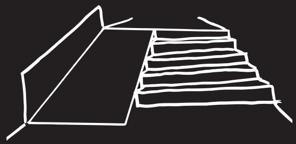
What technologies and cartographic strategies can be used to translate large datasets into accessible tools?

THEORETICAL GROUNDING

Our environmental image is still a fundamental part of our equipment of living, but for most people it is probably much less vivid and particular today. *(Lynch 1960, 124)*

Volumes have been written unpacking Kevin Lynch's *Image of a City*. That is not the intent of this paper. This quote is used to draw attention to the fact that rhetoric of seminal works in the discourse surrounding urban planning and design has for decades hinged on an ocular-centric positioning that ranks visual experience above that of the other senses. How does this influence the decision-making processes that shape our cities? Lynch states, "...[we] can better plan, design and manage the environment for and with people if we know how they image the world." (Lynch 1976, xi), but if our only mode of communication is predicated on the visual, what is being left out of that planning, designing and management? What views and experiences are neglected?

The discourse in landscape architecture surrounding inclusive design as it relates to access and the spectrum of human abilities is largely centered on the Universal Design Principles developed at the North Carolina State Center for Universal Design in 1997. Established by a group including architects, product designers, engineers and environmental design researchers these guidelines were developed to inform the design and evaluation of both environments and products (Connell et al. 1997). These principles advocate for design, which meets the needs of all people, regardless of age, ability, culture, gender, or preference without special accommodation (Connell et al. 1997).

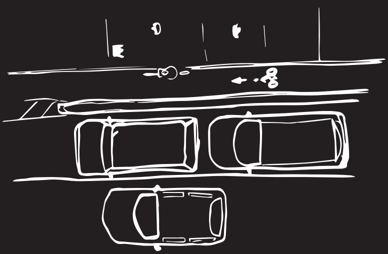


1. equitable use

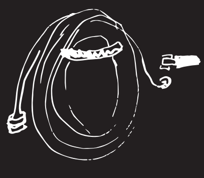
2. flexibility in use

3. simple and intuitive use

4. perceptible information



5. tolerance for error



6. low physical effort

7. size and space for approach and use

PRINCIPLES of UNIVERSAL DESIGN

1. Equitable Use: designs should be useful and marketable to people with diverse abilities.

2. Flexibility in Use: The design accommodates a wide range of individual preferences and abilities.

3. Simple and Intuitive Use: Use of the design is easy to understand regardless of the user's experience, knowledge, language skills or current concentration level.

4. Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

5. Tolerance for Error: minimize hazards and the adverse consequences of accidental or unintended actions

6. Low Physical Effort: Design can be used efficiently and comfortably and with a minimum of fatigue.

7. Size and Space for Approach and Use: Appropriate size and space is provided for approach reach, manipulation and use regardless of user's body size, posture, or mobility.

(Connell et al. 1997)

Universal design discussions are often associated with, the Americans with Disabilities Act (ADA), which was established by the National Council on Disability in 1990, and updated in 2008(ADAAA 2008, National Council on Disability 1990). However, it is important to draw a distinction, the universal design principles propose an approach to design thinking, while the ADA, a part of the federal building code, requires technical specifications be met in order to facilitate accessibility to public spaces for people with vision and motor challenges (Disability 1990, 2008).

Much of the writing on universal design as it relates to landscape architecture has been directed towards applications in therapeutic and educational gardens (Souter-Brown 2015, Wagenfeld and Winterbottom 2015, Balode 2014). While these are worthy areas of focus, people experience environments with a range of abilities and backgrounds, and the breadth of this implication has not been given proportionate attention in landscape design scholarship. This is a crucial point, as inaccessible built environments have been shown to not only fail in meeting the needs of people with disabilities, but can reinforce the disadvantages these populations face (Imrie 1993).

Concepts of inclusive urban design and planning have been subject to intermittent discussion over the past few decades often associated with scholarship dedicated to creating healthier more transit friendly cities (Mitchell and Burton 2006, Goltsman and Iacofano 2007, Kamp 2009, Bright and Sawyer 2014, Christ 2009, Dannenberg, Frumkin, and Jackson 2011). However, much of the writing has been published as general guidelines using broad strokes, rather than a critical investigation of how theses ideas are put into practice. As such there is a significant gap in scholarship surrounding ideas of inclusive and accessible landscape design in the public realm.

Universal design is an excellent starting place for discussions and design thinking concerned with inclusion and accessibility, yet such complex issues cannot be addressed fully without critical engagement. Participatory and human centered approaches that solicit user feedback throughout the design process have been encouraged in fields ranging from software (Henry 2007) to environmental designs (Preiser and Ostroff 2001). However, with the wide breadth of personal circumstances and design applications, countless questions remain unaddressed. From very practical conflicts that arise with feasibility, cost, sustainability and user experience, to more theoretically grounded questions relating to preservation, access and nature. These are not easy questions, but arguably that is what makes them worth asking, particularly in a field that is so proud of its commitment to ethical inclusion (ASLA 2010, Landscape Architecture Foundation 2016). Landscape architecture however, is far from the only field to shy away from these challenging questions.

The cartographic records of our cities reflect the physical manifestations of these absent discussions, and add their own economic and political biases. As a result not only are the navigational needs of millions of pedestrians not being met, but designers and planners that depend on these representations are basing design thinking and decision making on incomplete information. This undermines our efforts to create public landscapes that serve all participants.

Graphic maps have been used as tools for organizing, representing and understanding spatial data for centuries. As a practice landscape architecture reflects this history, in both borrowing from cartographic conventions and contributing to the development of new ones. Geographic Information Systems (GIS) mapping emerged out of Harvard's Graduate School of Design in the 1960s and has had a significant influence on the profession ever since. Theorist and writer Charles Waldheim posits this was first of two paradigm shifts in landscape representation that were “transformative of the culture and commitments of landscape architecture” (Waldheim 2012, 444). Ian McHarg, a forerunner of this movement to operationalize geographic information systems will forever be associated with his iconic layering of geographic information presented in his 1969, *Design with Nature*. This and McHarg’s subsequent work had a resounding impact on how we understood humans’ relationship to the environment in landscape architecture and planning. Though there have been significant technological, and informational advances since this work was identified, in many ways the composition and approach to representation has remained the same. Nearly fifty years later this approach is still featured in foundational readers and mimicked in studio environments.

The second significant paradigm shift that Waldheim cites is that of collage and montage practice. Ironically this is fundamentally an analog technology, but Waldheim suggests the shift towards these more emotive, collaged representations that emerged out of the late 1980s and 1990s allowed studios to move away from more rigid models to more experiential, temporal studies of site articulating seasonal and ecological change (Waldheim 2012). Not only does this approach still limit the communication of transient information to a fixed media, but as is want to happen with all technologies, these paradigm shifting approaches to visual representation are today increasingly stale. This has resulted not only from overexposure and imprecise use but also by the contrast with that of the emerging dynamic and engaging forms being produced with more technologically driven design practices. Despite general technological advances, the challenge of communicating and enhancing temporal and phenomenological experience remains salient in landscape discourse. In their recent publication, *Responsive Landscapes*, Justine Holzman and Bradley Cantrell explore the concept of Elucidate, outlining opportunities for landscape architecture to engage in the spatial design and rendering of extracted and translated information, "using landscape interventions to augment information, build narratives from complexity and activate processes for engaging and unpacking data" providing an alternative approach to the "exhausting ubiquity of data visualizations" (Holzman and Cantrell 2016).

In recent decades landscape architecture has lagged behind its allied disciplines in terms of its embrace of the digital tool and technological opportunity (Rahmann and Walliss 2016). While this hesitancy may seem detrimental, as there is exciting potential embedded in these emerging technologies, there also are advantages to a delayed adoption. Patience gives the field time and space to reflect on the rapidly evolving digital age and adapt accordingly. Architectural historian Mario Carpo posits, "The digital revolution at the end of the 20th century may have been the first self-proclaimed revolution in recent Western history to take place for the most part without, and outside of, any established philosophy of history", as such, "the new nonstandard environment was often seen as a liberation from the ideological straightjackets of modernism - including social and collective responsibility" (Carpo 2011, 107). This is not lost on other scholars reflecting on the implications of data driven cities, "the push toward interdisciplinary computational approaches has the potential to obscure social processes and practices underlying data rather than elucidating them and their intermingling with research methods" (Graham and Shelton 2013, 257). While there is great promise for data to substantiate theories and quantitatively support decision making, these scholars point to the fact that this approach is not implicitly free from bias. Even with careful consideration of where these data are coming from, and how they are being used there is potential to exasperate existing inequity or generate entirely new, potentially more confounding issues.

Heralding the guidelines of urban designer Jan Gehl and theories of the writer and protagonist Jane Jacobs, landscape architects and urban designers have prided themselves in the deliberate attention given to the social qualities of space. In this emerging age of data driven design these conversations remain critical. A collective cognizance seems to have manifest. "Agency, interactivity and participation are the catchwords of the day, and the architectural discourse on these matters is now as intense as the discourse on hyper surfaces, nonstandard, and topological geometries was ten years ago" (Carpo 2011, 114). The challenge however, is not to throw these words around but to address and act on these concerns of agency and inclusion in a meaningful way. Over 40 years ago land artist Agnes Denes grappling with the impact of technological advancement, asked "If we are the results of a development, in what direction is that development moving?" (Heartney et al. 2003, 12). The threat and the potential of this answer still loom today.

Waldheim's view of the technologies' influence on the future risks falling prey to many of the same shortcomings he cited that emerged in the advent of GIS (Waldheim 2012). One cannot exalt the potential of emerging data and technologies; and their related ecological and infrastructural efficiencies, without considering the social and cultural implications – all of which are embedded in urban landscape. While a shift from test-culture appearance to more performative metrics may be more efficient, it is the cultural aspects and access that engage and enable people to occupy and steward a site.

Linking power and privilege to geographic knowledge critical cartography emerged in the early 1990s as a challenge to academic cartographic conventions, asserting that the making of maps is a political act (Kim 2015a, Crampton and Krygier 2005b). Designers and planners have an opportunity to embrace this type of bottom up strategy for information collection and distribution to combat the threat of a soulless city born out of omnipresent big data. Shifting authorship of maps out of the elite/establishments/cities a citizen driven approach to mapmaking has the potential to reveal layers of the human experience that have traditionally been obfuscated by the politically imbued top down maps (Kim 2015a). This shift in authorship, positions the field well to serve in the analysis and approach to addressing some of the shortcomings discussed above related to accessible and inclusive design.

The following literature review was conducted in anticipation of a project that attempts to synthesize some of the broader theoretical discussions addressed up until this point. Rather than explicitly focusing on developing a space that embodies inclusive design; data, parametric design and a user driven approach will be embraced in the development and production of tactile maps. These maps will attempt to convey the non-visual phenomena that impact the way we move through space. The maps created are intended to serve as a tactile tool that enhances a user's experience and understanding of space, ultimately facilitating independent navigation for people with visual impairments.

TACTILE MAPS: Data, Use, Design and Limitations

This review summarizes and makes recommendations for a map project based on the available literature relating to the design, use and production of tactile maps.

METHODS

This literature review was conducted using the following databases: WebofScience, GoogleScholar, Worldcat, Avery Index to Architectural Periodicals

Keywords: Tactile Maps, Wayfinding, Navigation, Cartography AND Visual Impairments, Low Vision OR Blind

Literature was considered from the fields of: geography, urban design and planning, landscape architecture, orientation and mobility (O&M), applied ergonomics, environmental psychology and computer science.

I**nclusion and exclusion criteria:** Articles Published in English between 1990 and 2017, with exceptions made for seminal works.

Studies that included subjects that were not visually impaired required novel technological or cartographic approaches to improved access, design or understanding of urban spaces.

Peer review publications were included in analysis, but non peer-reviewed articles may have provided context.

Reports, guidelines and recommendations were included from nationally recognized organizations related to policy, accessibility and transportation.

PRACTICAL CONSIDERATIONS

Independence and safety are critical factors in any quality of life assessment. Pedestrian and public transportation networks comprise the two primary modes of independent mobility for people with low vision or blindness (Azenkot et al. 2011). With a specific interest in producing tactile abstractions of the built environment that can help facilitate this enhanced sense of independence and safety, the following questions were considered:

- What information is important to pedestrians with visual impairments in the context of mobility and wayfinding?
- How are physical representations of the built environment used as tools?
- What design considerations must be taken into account to ensure legibility?
- And what are the limitations and opportunities in terms of production and access?

DATA

Mental maps, or memorized routes and landmarks learned from experience, O&M trainers, and other visually impaired acquaintances are important tools utilized by pedestrians with low vision or blindness when navigating in familiar settings (Quinones et al. 2011). These mental maps tend to be very detailed, but typically are confined to a particular route. This confinement has obvious limitations when it comes to contextual orientation, and can be particularly problematic if re-routing when faced with an unexpected barrier or trajectory (Quinones et al. 2011).

Studies have shown, for both familiar and unfamiliar environments providing information about an area ahead of time can enhance independence in travelers with low vision and blindness (Quinones et al. 2011, Campbell et al. 2014). More information has been shown to empower public transit riders to attempt unfamiliar trips (Campbell et al. 2014), but inaccurate and incomplete data has been a significant source of frustration in facilitating this kind of independent travel (Bonnar C et al. 2015). Pedestrians that require an assistive mobility device prior to a trip often use digital tools such as Google Street View, in order to get a more complete understanding of the environments that they are planning to traverse and to hopefully identify any unsurpassable obstacles ahead of time (Hara, 2016). However, digital mapping tools are generally not accessible to a broad spectrum of users that would benefit from more a granular understanding of space, prior to entering. Individuals that are vision-impaired require the assistance of a person with sight to utilize Google Street View as a method for gaining insight into an area before experiencing it. Additionally, current tools generally lack the ability to reflect recent changes in the environment, whether those be human induced (construction) or otherwise (weather) (Quinones et al. 2011).

For individuals that are blind or have low vision, adequate pedestrian information not only has the potential to facilitate independent mobility, but also supports residual benefits of increased walking, such as increased exercise (Campbell et al. 2014) and enhanced community connection. Data that may be useful to blind and low vision pedestrians includes but is not limited to: cardinal directions, landmarks, obstacles, auditory and sensory cues, surface and tactile cues, street names, street numbers, traffic patterns, crossing information, sidewalk or footpath presence, transit stop locations and routes, water features, greenspace...the list goes on (Golledge et al. 2004, Azenkot et al. 2011).

Rather than identify every piece of information any individual may find useful, if a baseline of standard, reliable data is made available, both the extent of challenges faced can be better understood, while tools and environments can be designed to better meet a range of needs.

Tool development for low vision and blind populations has ranged from audible navigational aids, to smart canes and wearable technologies that can communicate with instrumented environments providing enhanced information to pedestrians as they travel through a space. Tactile maps provide users with information that facilitates enhanced orientation and navigation (Erin 2009; Espinosa et al. 1998), while also giving form to the pedestrian environments that impact the way everyone moves through space.

USE

The utility of tactile maps in wayfinding and orientation for people with visual impairments is well established (Erin 2009; Espinosa et al. 1998). Tactile maps have been demonstrated to contribute to people's ability to learn new routes, and are an important source of geographical information, particularly when people are learning new environments (Blades, Ungar, and Spencer 1999).

As with graphic maps, there a variety of ways in which tactile maps can be used. When compared to a group that received a verbal description, blind and low vision pedestrians were shown to gain significantly more spatial knowledge by experiencing a new urban environment with a tactile map (Espinosa et al. 1998). Tactile maps provide an opportunity for users to orient in urban and rural environments (Rowell and Ungar 2003c), as well as in more confined spaces such as buildings, conference centers or campuses (Erin 2009). These physical representations of the environment can be used while actively navigating or orienting, but also facilitate learning a route prior to embarking on a journey (Espinosa et

Point Features

Modifiers

flexible

elevation change

Intersection Features

no traffic control

4-way traffic control

one-way control (following cl)

one-way control (following cl)

Passageway Features

general passageway

underpass or tunnel

overpass or bridge

Other

challenging feature

vegetation

entrance

entrance w/ stairs or ramp-up

entrance w/ stairs or ramp-down

Area Features

parking lot

ground

building

water

flexible

park

Line Features

streets

one-way street

one-way street

water

fence

railroad

sidewalk

stairs or ramp in sidewalk

Adapted from "The Use of Environmental Features on Tactile Maps by Navigators Who Are Blind". (Lobben and Lawrence 2012) al. 1998). Due to a lack of experience with tactile maps not all people that are blind or have low vision feel comfortable using this type of navigational aid (Erin 2009). However, tactile graphics are generally accepted as useful for providing contextual information that is not directly related to mobility, such as city's location within a state (Erin 2009).

DESIGN

Directly related to how a tactile map is used, cartographic design and symbology are significant factors in how effective these tools are in enhancing spatial understanding. The majority of tactile mapmakers are orientation and mobility specialists, typically employed through special education programs (Lobben and Lawrence 2012, Rowell and Ungar 2003c). While this implies they are experts in the needs and limitations of people with visual impairments, formal training in cartographic design is limited. There have been some efforts to codify and standardize symbology for tactile maps, however the work has been scattered and there does not yet seem to be a consensus in adoption. Additionally, as illustrated by the annals of graphic map history, there is no guarantee that standardization will result in good maps. Tools produced by mediators limit the agency afforded by the opportunity to dictate one's own priorities and are susceptible to biases in terms of what information is presented and how that is prioritized.

In 2012 researchers from the University of Oregon published a comprehensive set of tactile map graphic symbols (Lobben and Lawrence 2012, 107). This standard was adopted by the Braille Authority of North America (BANA), to be distributed in their tactile graphics publication (Lobben and Lawrence 2012, 107). However, to date, the only documents available on the BANA's website predate Lobben and Lawrence's publication, and thus do not include these proposed standards.

Before considering what features to include or how to render them, two essential questions addressing effective design must be considered and answered: who is the audience? and what is the goal?

Few people are completely without sight. Many people that are legally blind in fact have low vision, and anyone with non-correctable reduced vision is considered visually impaired (WHO 2016). This can be the result of any number of circumstances, and as such manifests in different ways; blurred vision, loss of central vision, and loss of peripheral vision are just a few ways people's visual experiences of the environment differ (AOA 2016).

Based on the literature reviewed the following recommendations for tactile maps accommodate understanding for people with a broad range of visual capacities. High contrast map features and legends facilitate enhanced understanding by people with low vision, while also providing information to sighted people that may be working with or assisting a tactile map user (Rowell and Ungar 2003a). Traditional cartographic best practices should also be adopted, including the incorporation of a braille key and legend, indicators of scale, and an indication of cardinal direction. In place of a north arrow a tactically and visually identifiable north edge is recommended, as it is easier to keep track of when navigating (BANA 2011).

Identifying the goal of a map is equally important. Graphic maps have taken on countless forms and it would be a futile effort to try to categorize them all. The same potential exists for tactile maps. There is an opportunity to present broad context, route finding and place based navigation aids, detailed information for complex sites and everything in between. Natural, built and transient features of the environment could be reimagined, revealing topological relationships that may otherwise be obscured.

Context or area maps, cover a wide spectrum of information and representation styles, but generally provide an understanding of the spatial and topological relationships of a given place, be those internal or external. Orientation and mobility route maps on the other hand are specifically designed to help facilitate navigation through space (BANA 2011). Designed with way finding in mind, mobility route maps typically include landmarks and information points.

Where visual maps depend on lines, color and shading, tactile maps depend on texture and height variation. Simplicity is stressed as essential to a successful, legible tactile map (Rowell and Ungar 2003b). There are several reasons for this; the first commonly cited reason is the lower tactile acuity relative to visual perception (Schiff and Foulke 1982). Symbols closer than 1/8" tend to be perceived as the same symbol (BANA 2011). Additionally when one views a map they are taking in much of the information all at once, on the other hand people with visual impairments experience a tactile map in a more sequential manner through touch (Gual, Puyuelo, and Lloveras 2015).

PARTICIPATORY AND ACCESSIBLE DESIGN

Closely considering the experience of the environment from a disability perspective leads to a seamless natural experience of one's surroundings for a broader public. Not only does that make it the right thing to do, or the law for many architects, but it offers benefits to all users and drives creative solutions to encompass opportunities for many more 'users' - whether chronically or situationally disabled. More accessible design means more access for everyone.

Despite their utility, tactile maps are not readily available. Limited attention to the design and development of these tools as well as high production costs have been significant barriers to adoption (Espinosa et al. 1998). Fields traditionally interested in cartographic representation such as geography, graphic design, urban design and landscape architecture, have largely been absent from the practice. The lack of end user participation in the production of replicable tactile maps also limits the potential for gleaning unique insights that facilitate both an enhanced tool, but also a better understanding of the environments being represented.

The most accessible relatively low-tech method of map production often utilized by orientation and mobility specialists and educators, as well as those they are training, employs a collage style approach (Hudson 2014). This strategy is particularly useful in hands-on learning environments. Using different materials, such as string, cardboard, and sandpaper, individuals are able to recreate their mental maps and customize representations of features important to them. Once constructed these can be reproduced using a vacuum form or thermoform machine, which molds a plastic sheet to take the shape of the original map (BANA 2011). This thermoform reproduction technique can likewise be used with clay or tooled originals, allowing for greater durability and variability in the shape and depth relative to the two relief methods that follow (Rowell and Ungar 2003b). However, hand forged base models are a challenge to standardize, take significant time to produce and vacuum form machines for reproduction can be expensive and are not always readily available.

Braille graphics embossers can be used to reproduce digital files and with a crisp relief familiar to those already comfortable with braille. However, the variation in height of the embossing is limited, thus restricting the amount of information that can be conveyed on a surface. This limitation will be explored in more depth in subsequent sections. Here again machines are expensive, costing about $4,000-$14,000, which significantly reduces potential access (Lobben and Lawrence 2012, 96).

Microcapsule image enhancers are traditionally the least expensive, and most common method of reproducible map production (Rowell and Ungar 2003c, 262). This technique allows for both hand-drawn and digital graphics, first printed on special paper that contains chemical-filled capsules. This special paper is then fed through a tactile image enhancer, which applies heat and creates a reaction between the chemical in the capsules and the ink, resulting in a raised relief. The relief produced using this method is less crisp than that which might be created using a braille embosser, and it again is limited in terms of a symbol height variation. Both methods are limited to a binary 'raised' or 'not' state, comparable to a representation that contains only black or white, with no gray in between.

To date tactile map standards and guidelines have been developed with the aforementioned modes of map production, and their inherent limitations in mind. "Effect of Volumetric (3D) Tactile Symbols Within Inclusive Tactile Maps" explores the potential in 3D printing technology to produce a more volumetrically varied symbology (Gual, Puyuelo, and Lloveras 2015). Ultimately, all types of participants, braille and non braille readers, people with low vision, blind and sighted were able to distinguish more unique features with the inclusion of a greater variety of tactile attributes, in this case, a higher contrast in symbol heights (Gual, Puyuelo, and Lloveras 2015). Gual et al's findings imply that 3D printing techniques present an opportunity to represent more information in a smaller area than current techniques allow. Ultimately this suggests that while map production limitations have been a limiting factor in the availability of tactile maps, the primary issue today boils down to data and design.

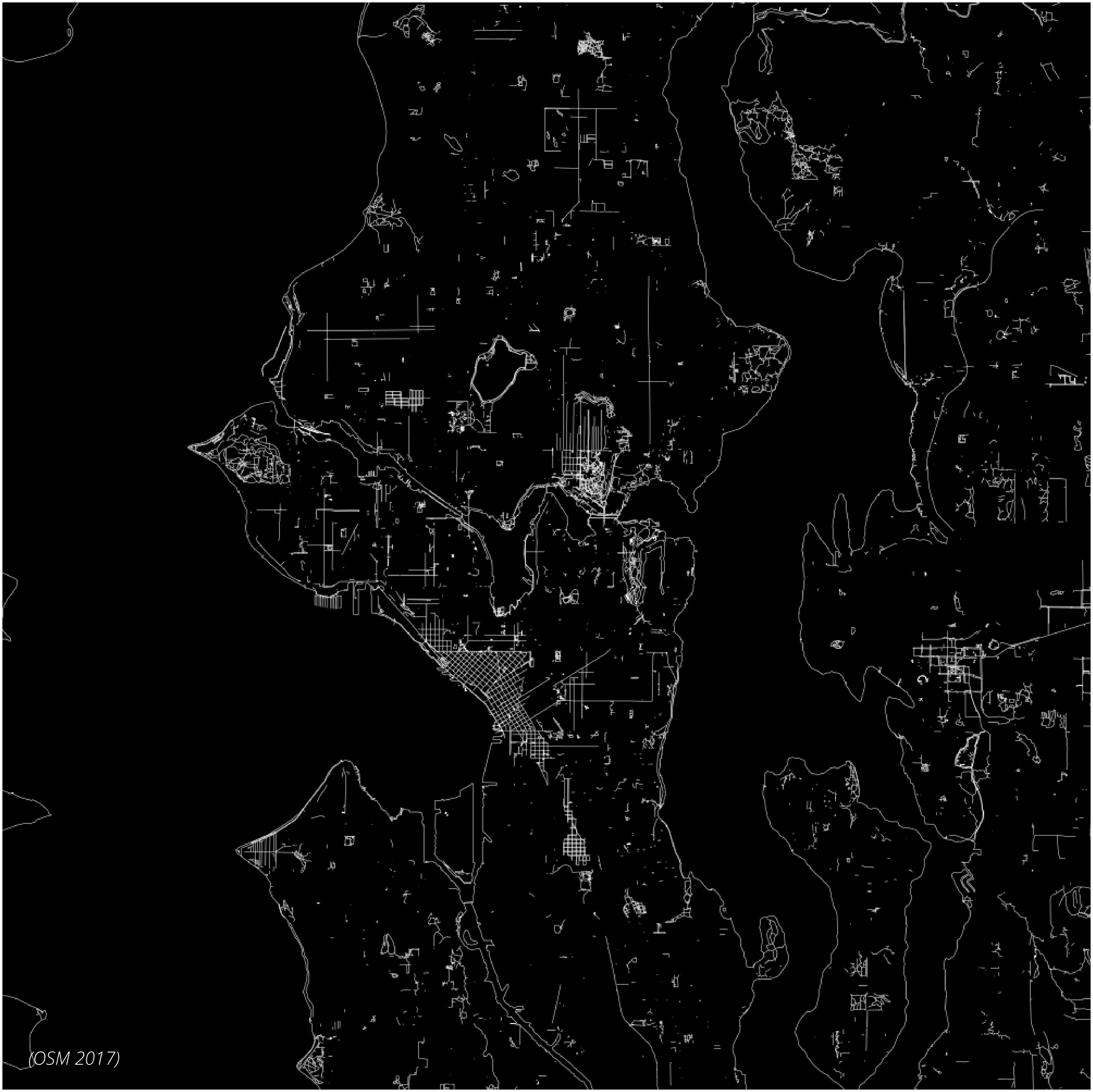
LIMITATIONS, QUESTIONS AND OPPORTUNITIES

"Effect of Volumetric (3D) Tactile Symbols Within Inclusive Tactile Maps" (Gual, Puyuelo, and Lloveras 2015) appears to be the only peer-reviewed paper to date explicitly investigating the comprehension and usability of 3D printed tactile maps by a range of users. As such, there is ample room for further research in this area. Understanding what levels of variation are perceptible could be used to generate a dense symbol set that is legible to a broad population, or to lay the groundwork for customized symbols designed to accommodate finger size and acuity.

Data availability is perhaps the more pressing constraint. This has implications for a wide range of tools and applications as well as broader planning and urban design. Based on the discussions of symbology (Blades, Ungar, and Spencer 1999, Rowell and Ungar 2003c, Lobben and Lawrence 2012, Gual, Puyuelo, and Lloveras 2015), tactile map production thus far has been fairly limited in the type of information that has been conveyed, and largely a reflection of standards put forth by O&M specialists and traditional cartographers. The field of critical cartography has begun to push this traditional definition of map data in an effort to 'make the invisible visible', decolonizing imposed political values (Crampton and Krygier 2005a). Yet, this 'radical' approach still largely operates within an ocular-centric framework, excluding millions of people without sight. Such an ocular-centric approach is reflected in Annette Miae Kim's *Sidewalk City* which uses critical cartography to re-define sidewalks in Ho Chi Minh City as distinctive geographical areas that constitute critical public space (Kim 2015b). Kim's team used a mixed method, ethnographic approach to collecting their map data, which included interviews and field surveys, as well as newspaper, photo and video analysis (Kim 2015b). Despite this mixed methods approach, the products of the work are reduced down to two-dimensional visualizations that blend Waldheim's paradigms of representation, incorporating both formalized GIS data, with more emotive collaged images.

Given recent advances in algorithmic form generation dictated by data inputs, there is great potential for an alternative approach to map generation that expands cartography beyond the two-dimensional and provides a more immersive and inclusive tactile experience. This may eventually take into account more ephemeral or transient information, political and historic narratives, environmental and ecological considerations; the list of potential combinations is limitless. Understanding what these data feel like, not only has the potential to situate, but also to reflect qualities of the human experience of that place. This could manifest in a very conceptual study, but also may unlock clues to alternative perspectives and experiences that traditional 2D cartographic representations have not been able to capture or accommodate. Topography for example has been a notoriously challenging feature of the environment to convey to untrained map-readers. Even if the scale is abstracted, relief would provide additional intuitive information.

Inclusive Pedestrian Environments



(OSM 2017)

INTRODUCTION TO THE PROJECT and AUDIENCE

"There are those with disabilities, and there are those that haven't quite found theirs yet." *(Downey 2013)*

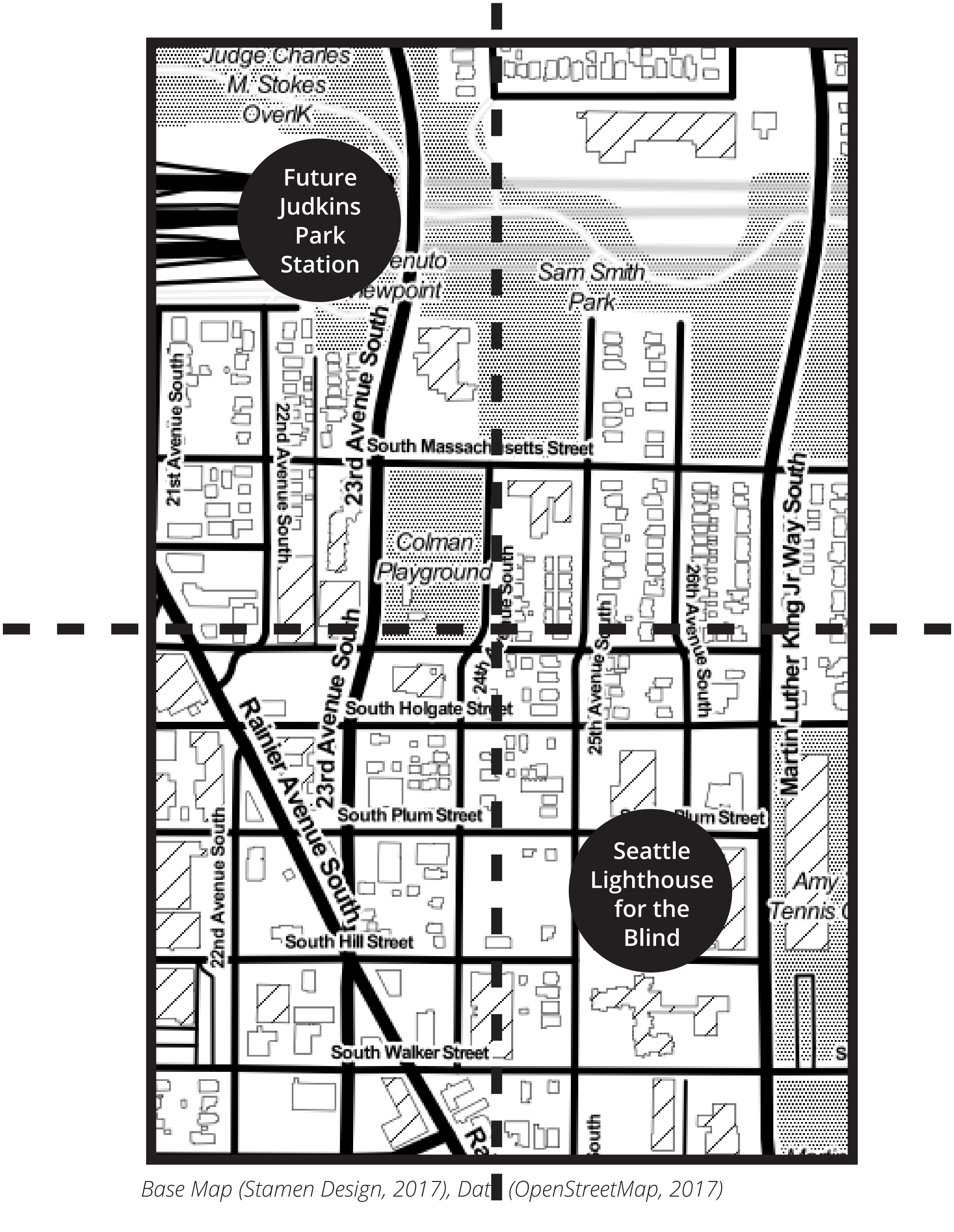
Abstracting nonvisual cues from the pedestrian environment and considering circumstances that influence a full spectrum of experience, the maps created for this project were designed as tools that enhance spatial understanding for people within a large range of visual capacities.

Undertaken in collaboration with a group of computer science students, this project addresses the development of a web application that would allow users to customize and automatically generate a 3D map model of any given area. The end product, a customized 3D printable map tile, using form and relief rather than the traditional flat cartographic representation, provides users with geographic information related to their defined area of interest. This application is intended to allow end users to co-design by making personal choices about the location, scope, and selection of features important to them. This user driven approach democratizes the making of these maps, and the data associated with this co-design asserts preferences and priorities from a user group that may not otherwise be revealed.

Parametrically designed, through the establishment of rules and adjustable parameters, rather than predefined geometries that dictate the representation of datasets, these maps allow for user feedback, and ever changing open-data sets to be quickly incorporated. Approaching the map design through the establishment of parameters rather than fixed geometries, allows for adjustments in size and shape to easily be made and applied to all of the data that relate to the OpenStreetMap (OSM) key value pairs of interest. As such if something is not legible to a user, modifications to the feature of interest can easily be made and applied to all subsequent maps. Applying parameters to key value pairs rather than static cartographic features facilitates scaling. Scaling in this context can be considered both in terms of the granularity of data available at a given locale, and in the representation of spatial information from a multitude of localities.

As a case study a series of maps were produced that intend to provide enough context and detail for low vision and blind pedestrians to determine their own routes through an area. These case study maps focused on representing pedestrian infrastructure in the walk-shed surrounding the Seattle Lighthouse for the Blind and the forthcoming Judkins Park Lightrail Station. The relationship of this area with Seattle's blind and deaf-blind communities has resulted in the installation of several features specifically designed to facilitate mobility for this group. At the same time, in many ways this relatively working class, residential neighborhood is representative of other similarly situated areas, with incomplete pedestrian networks. Located in what are now the I-90 express lanes, the proposed transit station presents its own unique set of challenges in terms of wayfinding, pedestrian safety and accessibility. Specifically, the station is planned to be located above Rainier Avenue South, with a street level entrance below the platform from Rainier, which will require multi-level navigation. Another entrance, located to the east at 23rd Ave, will require pedestrians cross the light rail tracks to reach the station.

Expert user interviews throughout the design process were used to guide the establishment and design of atomic symbols associated with critical pedestrian information, which could serve as the foundation for a pedestrian base map. Not only does this expert user input



Base Map (Stamen Design, 2017), Data (OpenStreetMap, 2017) have implications for the maps specific to this project, but it more broadly works towards elevating pedestrian infrastructures in the context of our digital landscape. Representation of pedestrian infrastructures in digital cartography is important not only from a navigational perspective, but is also a reflection of the information designers, planners, and policy makers depend on to make significant decisions that affect our urban fabric. Informed decisions based on incomplete data are not only difficult but also more prone to error and bias. As we move rapidly towards sensor laced smart cities, it is critical these data gaps be identified and understood in order to account for the influence their absence has on design and decision-making. As such, this work is meant to take an accessible approach to data as it relates to pedestrian design and experience.

This project employed open source, crowd contributed, geospatial data from OpenStreetMap. OpenStreetMap was chosen for its extensive global coverage and easily extensible data schema. This platform allows for the project to easily pull from a large existing data pool, while also making contribution simple, so that informational gaps as they pertain to pedestrians could be filled in.

Illustrative documentation of both the process and analysis that went into making these maps is directed more squarely at the design community. This thesis work re-examines the pedestrian environment, with a focus on the specific needs of the low vision and blind communities. The goal of this work is to persuade designers to consider a broader spectrum of experience, and engage more critically in what it means to design inclusive cities.

The research and designed materials are meant to bring attention to the deficiencies of the system currently place, in which accessibility checklists too often are accepted in lieu of truly inclusive design. The straightforward approach is intended to remind designers that accessible design is good design, and if we want to build more equitable cities we must first understand that there is vast spectrum of experiences we need to address fully.

METHODS

Multiple methods were used in developing this thesis project. These methods drew on the interdisciplinary nature of the project by using methods within design practice and research as well as those within data science research.

IRB Study: STUDY00000851

Expert User Interviews

Expert user feedback was solicited throughout the tactile map design process. Four adults of varying ages, three females and one male that use white canes while traveling were consulted, as well as a sighted orientation and mobility specialist employed by the Seattle Lighthouse for the Blind and accessibility managers from both the City of Seattle and Puget Sound Transit.

Informal Group Interview

The initial informal interview was conducted as an open conversation between three expert users, an O&M specialist, and accessibility managers from both the City of Seattle and Puget Sound Transit. A first iteration, 3D printed map which only had extruded buildings and the street network, as well as a sample of 3D printed texture swatches, were presented to provide context for the conversation. Questions to guide the conversation included:

- Would this type of tool be useful to you in terms of enhancing your understanding of an area?
- In what context would a tool like this be most useful?
- What information would be useful to have represented on a tactile map?
- What kind of barriers or frustrations do you run into while traveling as a pedestrian?

Field Interview

Following the production of several prototypes, an extended informal interview with the O&M specialist was conducted while walking along the recommended travel route from the Seattle Lighthouse for the Blind to the forthcoming Judkins Park Transit Station. During this walk the O&M specialist pointed out specific pedestrian infrastructure elements that had been designed to facilitate navigation for low vision and blind pedestrians in the area. He also provided information on non-pedestrian specific features of the environment, which impact his route designing and recommendations, such as traffic speed, directionality and visibility for motorists.

Map Legibility

Individual experts, one male and one female were consulted independently after the maps had been modified to incorporate feedback from the initial informal interviews and the field interview with the O&M specialist. Experts were asked to respond to whether they could easily distinguish map features, and whether the braille key could be easily read and related back to the printed map

Both users reported that the braille was legible, but suggested that the map features be more clearly articulated through higher contrast and greater symbol variation.

Limitations

The limited number of expert users interviewed does not constitute a representative sample of the blind and low vision population. All were from the Seattle area, implying that they may have more of a vested interest in urban pedestrian maps than the blind and low vision community at large. Prototypes were used to facilitate conversation, but may have also biased the direction of conversations pertaining to both map features, and aspects of the pedestrian environment that impacted the interviewees' ability to safely and confidently navigate.

Survey: challenges / process

The features ultimately selected for inclusion on the map tiles were established through relevant literature and conversations conducted needs experts. Several attempts were made at putting together a survey to get feedback from a broader sample population. However, unfortunately time constraints prohibited the distribution of a satisfactory survey. Some of survey considerations included:

Self-selection: Each iteration of this survey began with questions that allowed respondents to categorize their visual experience. Initially a likert scale was used in association with a number of scenarios describing situations in which various features of the pedestrian environment may be visible to the respondent. As the survey became more complex, this question was simplified, to eventually capture what type of assistive devices or accessibility features respondents used.

Survey scope: Initially the survey was designed to explore experiential qualities of a low vision or blind pedestrian experience. These multiple-choice likert based questions focused largely on temporal features of the environment that would fall into non-traditional, transient map data such as audio and olfactory cues for orientation and navigation in the built environment. Perceived barriers and route planning strategies were also to be assessed through scenario based short answer questions. While these inquiries were interesting, it quickly became clear, that baseline set of information was necessary for the tactile maps to be effective. This was easier said than done. While pedestrian environments, sidewalks if you will, seem straight forward enough, research, informal interviews, and brainstorming revealed over 80 potential features, or variations as candidates for representation. To assess the importance of representing each of these features in different scenarios was quickly overwhelming and made the survey unwieldy. One iteration of the survey broke up the features into categories according to Lynch's paths, edges, nodes, landmarks and districts, which helped narrow down some of the questions but this still proved to be too many questions to reasonably expect respondents to answer. Moving forward, grouping potential features to satisfy potential use cases may be an effective strategy for organizing the survey.

Technological constraints: developing and testing the survey to be compatible with a range of screen readers and other assistive devices proved to be a challenge. Google Forms was the primary tool tested for this study, however had the survey been pursued further it would have been worthwhile to test other survey applications. One issue that arose through preliminary user testing had to do with pagination, and unnecessary tag information at the top of each page. This issue constrained the survey design to a single page.

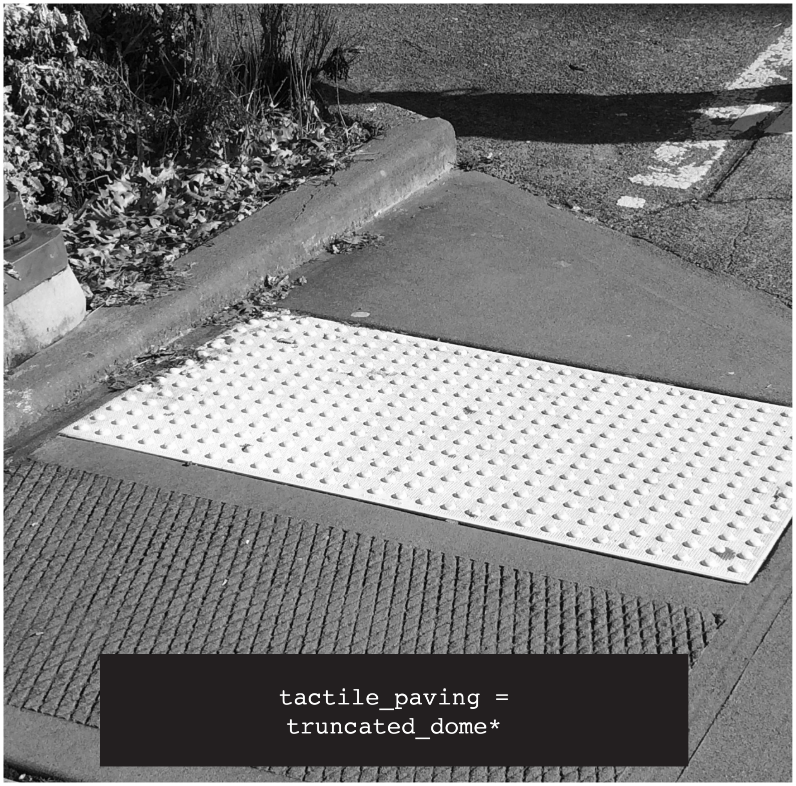
A sample survey is included in Appendix A

CRITICAL PEDESTRIAN FEATURES

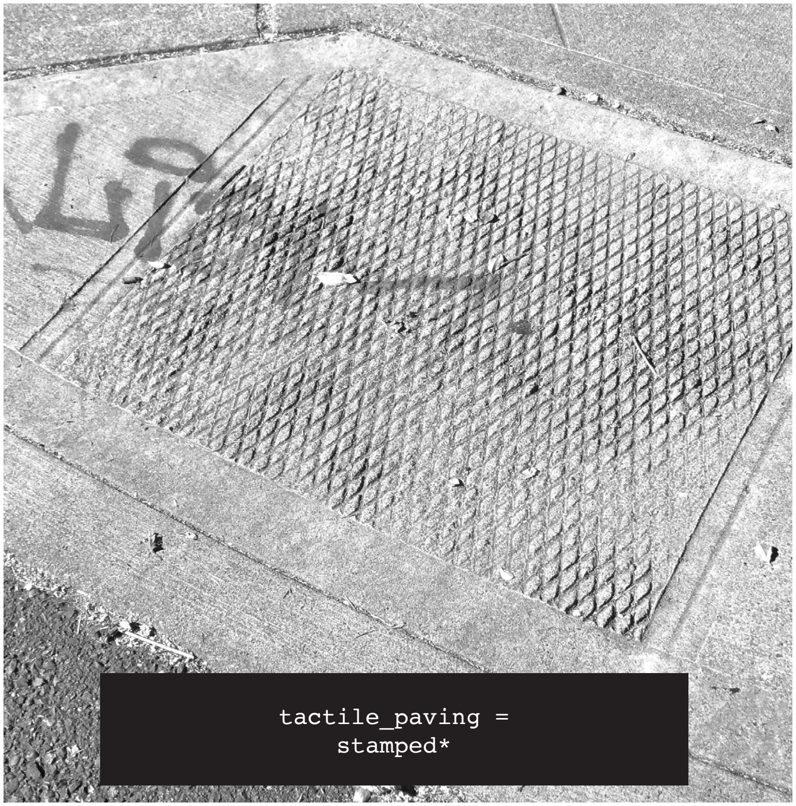
Based on the aforementioned interviews and their ubiquity in urban pedestrian environments, surfaces, topography and street interfaces were explored further as critical features relating to wayfinding, mobility and safety for people with a wide range of visual capacities.

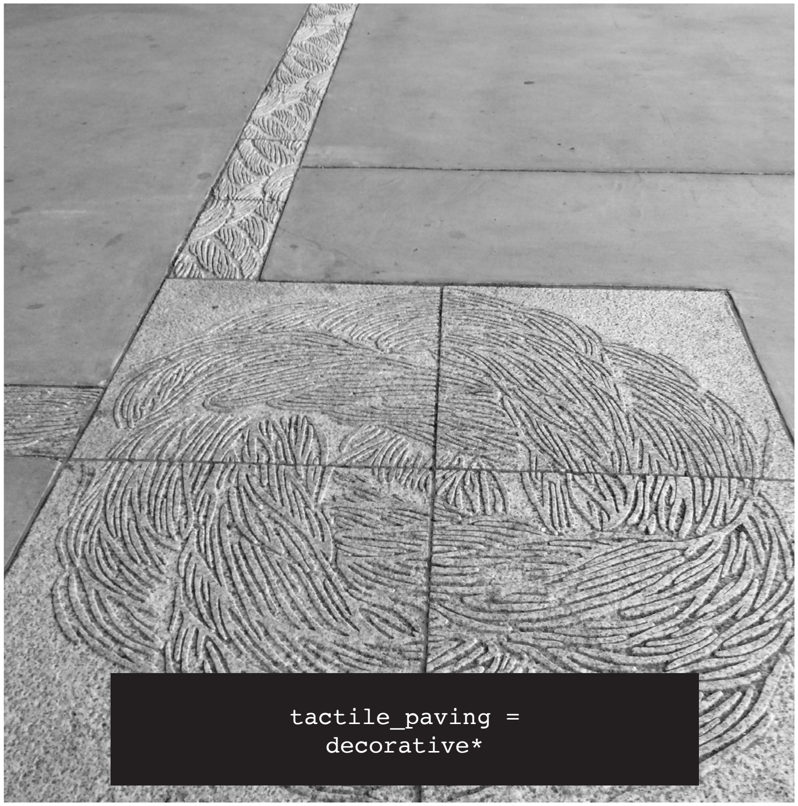
The following section illustrates aspects of the pedestrian environment considered for inclusion on the case study map tiles. The features outlined may not be appropriate at all map scales, likewise there are many potential features not covered. Some of the following surface features have been studied in relationship to the experience of visually impaired pedestrian (Secchi, Lauria, and Cellai 2017), however there is certainly room for further research relating to all categories. The following exploration is not intended to be a comprehensive examination of public space. Instead, the considerations outlined are meant to facilitate a more comprehensive approach to pedestrian mapping as well as encourage design thinking with a low vision or blind experience in mind.

Where appropriate, images have been annotated with OSM key value pairs. Those marked with an asterisk are suggested value pairs and do not yet exist. It is also worth noting, due to OSM's European origins, British-English is used for the majority of tags. Requisite features of pedestrian environment surfaces are first explored, followed by topography, which is nearly as ubiquitous. Street interfaces, while occupying less space in a pedestrian environment, arguably have the most impact on pedestrian safety and well-being, are the third feature set considered. This section concludes with a brief overview of additional feature information, namely transit stops, barriers, landmarks and points of interest which were outside of the scope of this illustrated feature guide but warrant further study in the context of mapping and design to enhance independence, mobility and safety for pedestrians that are blind or have low vision.


tactile_paving =
truncated_dome*


tactile_paving = corduroy*


tactile_paving =
stamped*


tactile_paving =
decorative*

SURFACES

Surface materials have many distinct traits that are perceptible through the various senses. There are several significant non-visual characteristics that impact a pedestrian's experience, visually impaired or otherwise.

Heat: Anyone that has sought relief in the cool grass after running barefoot across a hot parking lot has experienced first hand what a dramatic difference surface material makes when it comes to heat. The urban heat island effect is another manifestation of this property that is experienced through the skin, rather than the eyes.

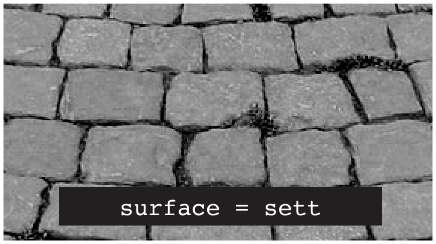
Noise: Distinguished through both footfalls and the tapping of a cane, the acoustic contrast between paths and surrounding materials can be useful in way finding, and maintaining a heading in both urban and rural settings (Secchi, Lauria, and Cellai 2017, Gardiner and Perkins 2005).

Smoothness: Haptic canes make apparent even relatively minor changes in texture (like that found in stamped concrete). Smoother surfaces require less effort to navigate with a cane.

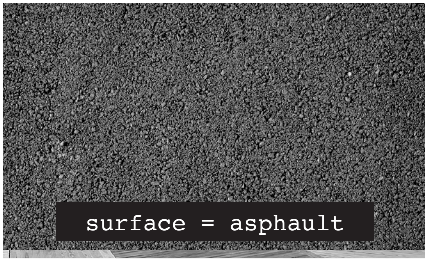
Evenness: Similar to smoothness, evenness can have an impact on ease of navigation with a cane. In addition, uneven surfaces have a higher potential to be a tripping hazard.

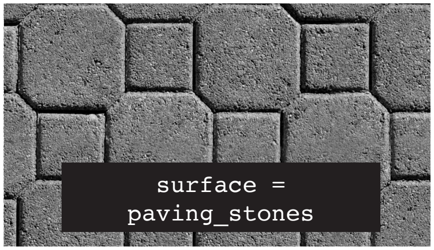
Traction: Some surfaces are more prone to being slippery than others. This can be a permanent feature of a material, for example a metal plate is generally going to provide less traction than a gravel path, but can also be a transient property, determined by seasonal (fallen leaves) or weather conditions (sleet).

heat	● ● ●
noise	● ●
traction	● ●
evenness	● ●
infiltration	● ●
smoothness	●



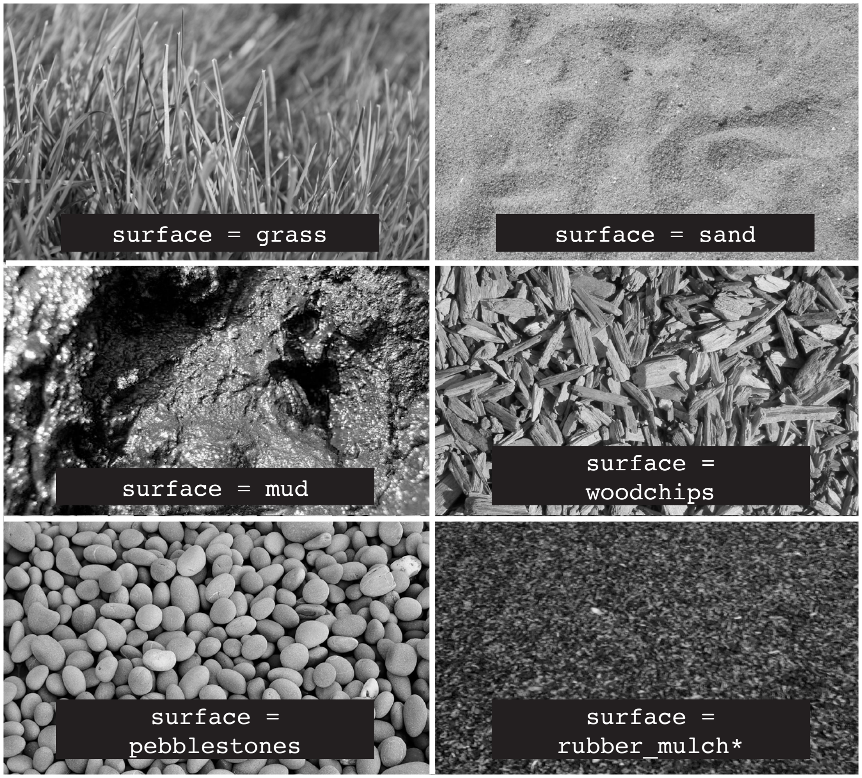
heat	● ● ● ● ●
noise	● ● ●
traction	● ● ●
evenness	● ● ● ● ●
infiltration	
smoothness	● ● ● ● ●





heat	● ●
noise	● ● ● ●
traction	● ● ● ● ●
evenness	● ●
infiltration	● ●
smoothness	●

heat	●
noise	● ●
traction	● ● ● ● ●
evenness	
infiltration	● ● ● ● ●
smoothness	



Infiltration: An unanticipated puddle can ruin anyone's day. Without being able to identify potential water hazards in advance and determine an alternate route, the odds of inadvertently ending up with soggy socks increases.

Tactile Paving: High-contrast truncated dome tactile paving is the most common found in the United States, typically found on curb-ramps, stairs, and transit platforms. A variety of other textures including cones, bars and decorative paving can also be used for way finding or to alert pedestrians to a potential hazard.

Width: Wide (min 6'-12') unobstructed paths are one of most straightforward ways to address access in a pedestrian environment (Goltsman and Iacofano 2007, Mitchell and Burton 2006). This allows enough room for navigation with a haptic cane, or assistive device, and provides a buffer to adjacent traffic.

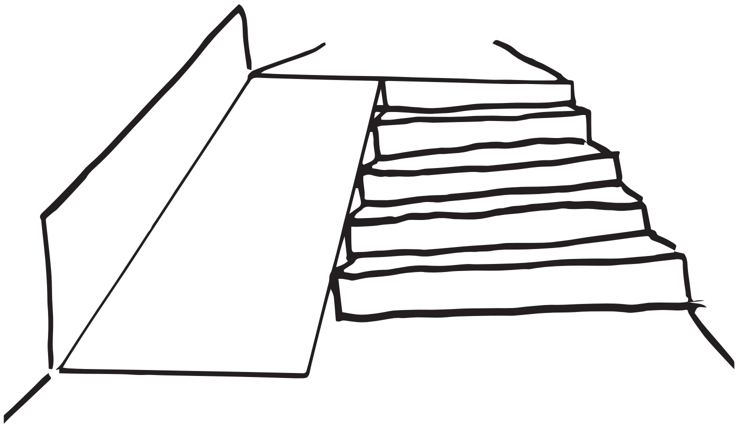
Ultimately surface materials should be determined based on a path's intended use. To facilitate mobility relatively smooth, unobstructed surfaces that are easy to navigate and provide decent traction are best. Textures can support spaces that are meant to do something other than simply move people through. Material changes and texture can be used to slow pedestrians down, as well as inform people of transitions, hazards, or other circumstances that warrant attention.

TOPOGRAPHY

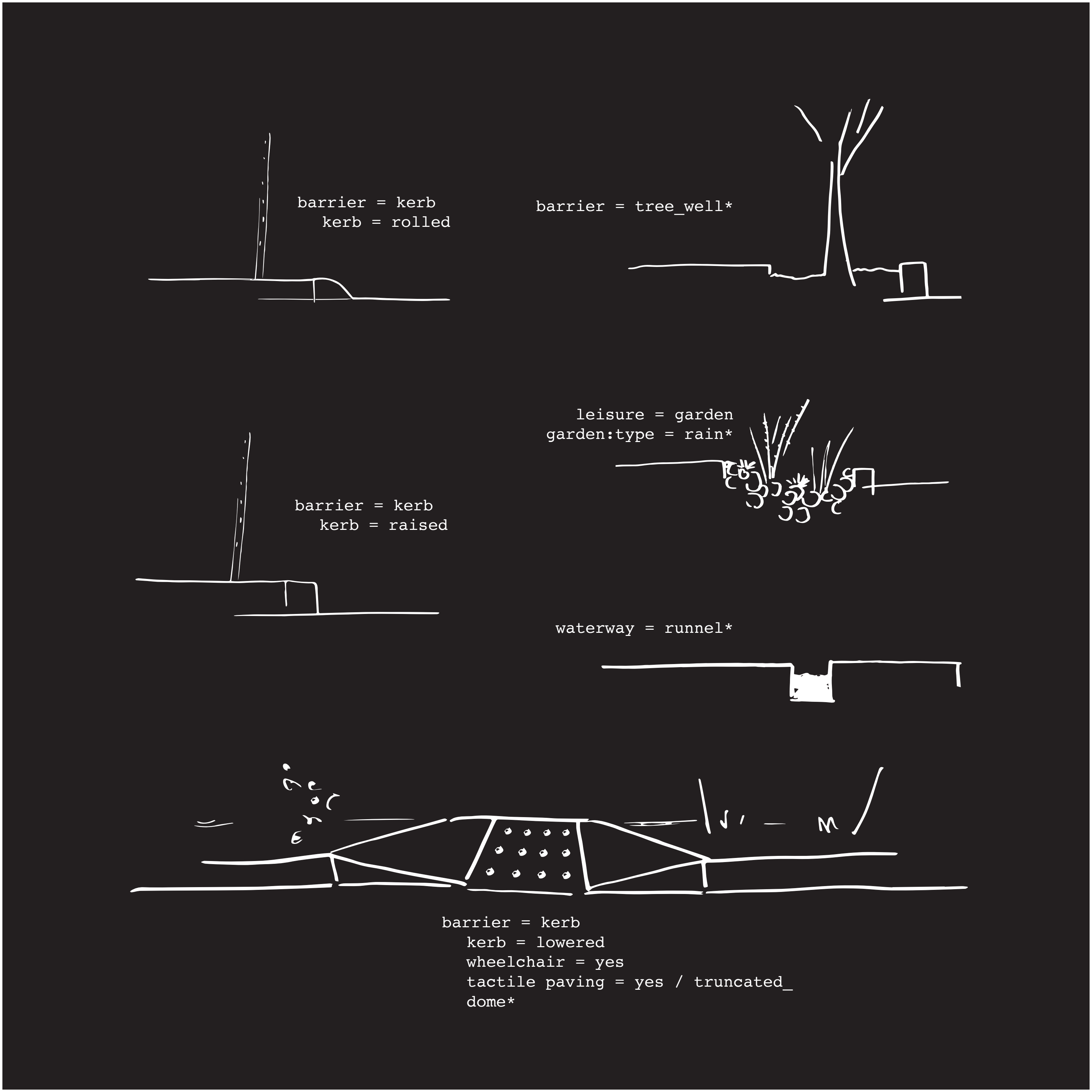
Grade change is something experienced by everyone in even the flattest of cities on the flattest of blocks. This work encourages designers to think about how topography impacts the pedestrian experience at multiple scales.

Micro: Curb heights, tree wells, planting beds, all of these features reflect minor grade changes in urban environments. While these may be empirically minor relative to a steep slope or staircase, they are no less significant when it comes to navigating as a pedestrian. Edge detection, heading and orientation should be considered anytime a grade change is introduced. If an unintuitive change can't be avoided, signals through texture change or other means may be employed to minimize conflict and sprained ankles.

Transitional: Stairs and ramps are used to negotiate site scale macro topography in addition to being common transitional elements to entrances for buildings and other sites of interest. Handrails and raised edges facilitate safe navigation and mitigate misplaced steps, which could lead to sprained ankles or worse.

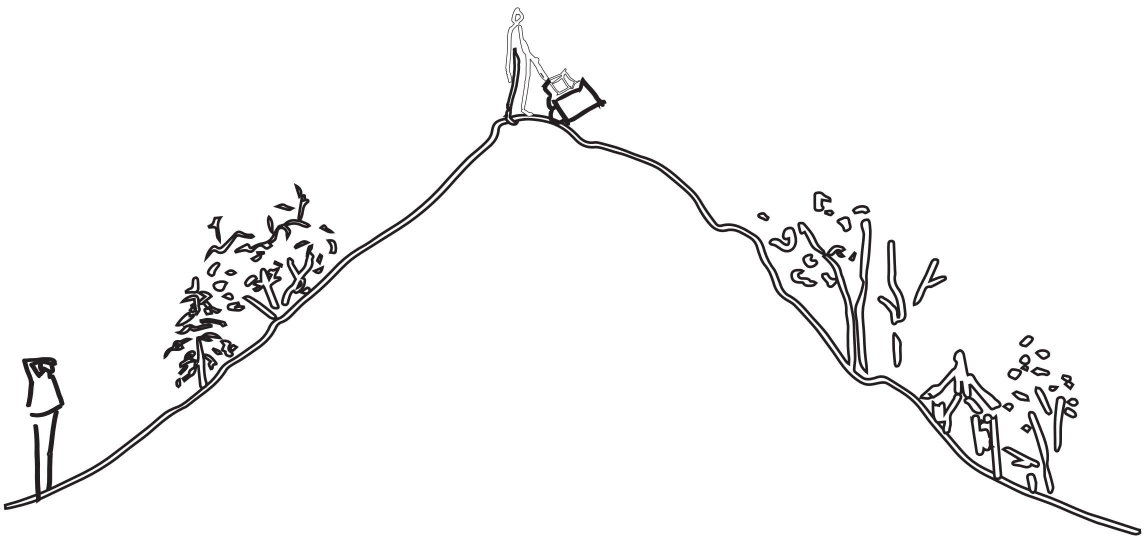


```
highway = steps                                highway = steps
     steps = ramp
```


barrier = kerb
kerb = rolled
barrier = tree_well*
leisure = garden
garden:type = rain*
barrier = kerb
kerb = raised
waterway = runnel*
barrier = kerb
kerb = lowered
wheelchair = yes
tactile paving = yes / truncated_
dome*

Macro: Despite the best efforts of some engineers (Klingle 2007), steep hills are often unavoidable in the urban fabric. Significant topography can enhance spatial understanding (Gardiner and Perkins 2005), but nonetheless may be a barrier to mobility. Instead of simply cursing the topographic fortunes of a place, it is useful to consider ways in which the extent of this burden might be mitigated. This could be through textured pavement, a well-placed bench, facilitating access to a public elevator or strategic design of transportation stops.

Topography often presents a challenge for designers, but accommodating grade change can also be an opportunity to provide information to pedestrians as they move through space. Edge detection is particularly important when designing with blind or low vision pedestrians in mind. Potential signals that an edge is near may include the presence of railings, curbs and plantings, or a change in surface material.



STREET INTERFACES

Street interfaces are among the most dangerous spaces in the pedestrian built environment. Advance knowledge facilitates safety, particularly for people that are blind or have low vision.

Curb Ramps: Well-designed curb ramps provide access not only to pedestrians that rely on assistive devices, but also facilitate mobility for parents with strollers, cyclists, workers navigating with carts and countless other people with a vast range of circumstances and gear. Newly constructed curb ramps are typically outfitted with tactile pavement that alerts pedestrians to the transition into a vehicle-designated space.

Directionality: Curb ramp directionality provides pedestrians heading information as they exit the protected pedestrian area. As such it is important that a curb ramp guide the pedestrian into a safe crossing area. Single curb ramps placed on a corner, or only one edge of the sidewalk, risk directing pedestrians into traffic.

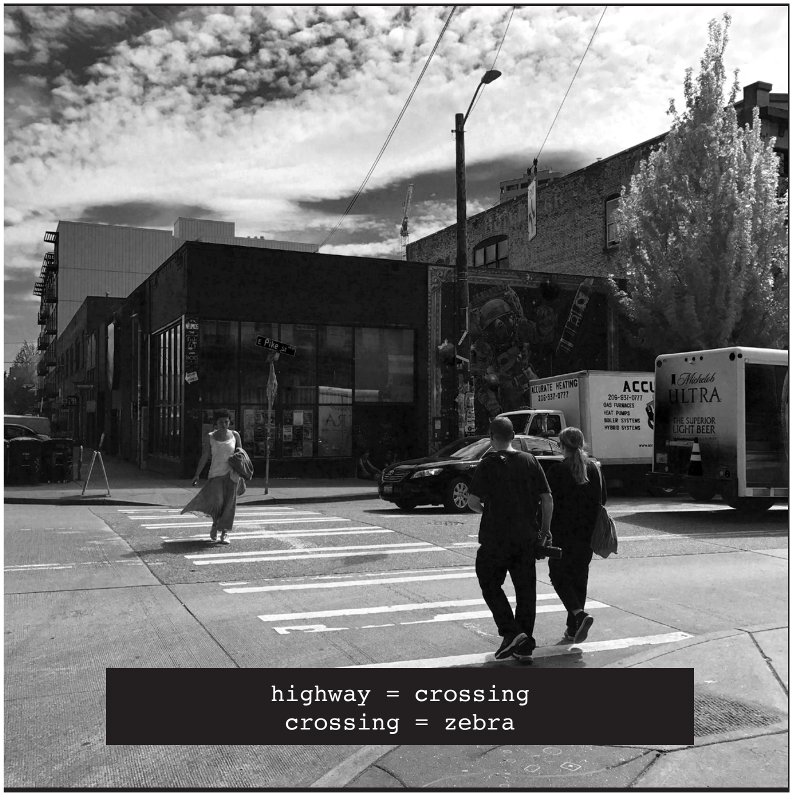
Shoring: Shoring, or a curb ramp's raised edge goes a step further by explicitly providing a safe heading pedestrians that use a white cane for assistance in navigating.

Crossings: Much like surface types, variations of crossing types could be dissected ad nauseam. For the sake of clarity and simplicity, crossing

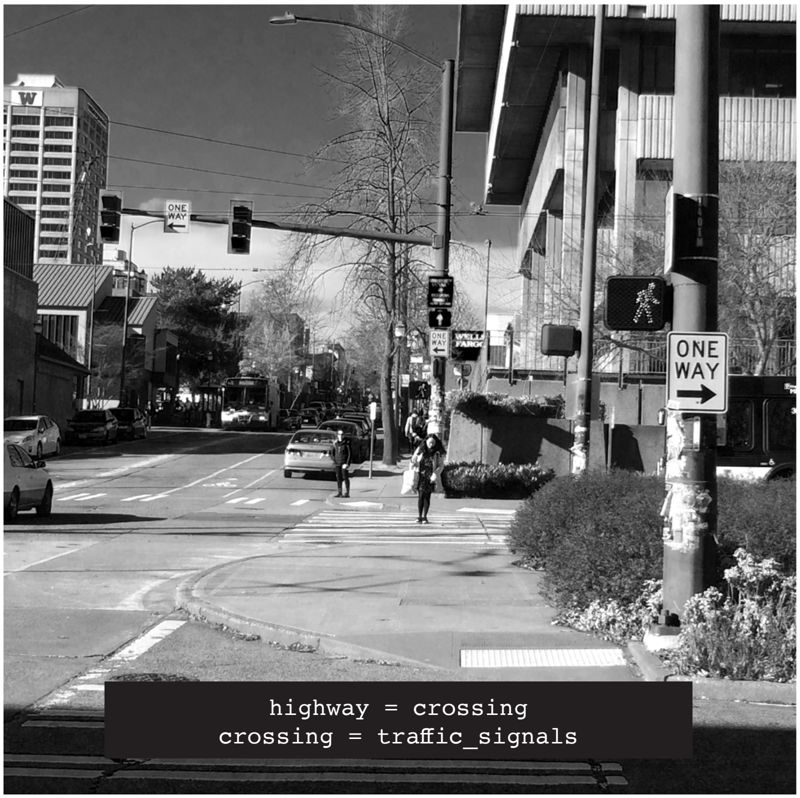
Existing

Proposed

highway = crossing
crossing = unmarked



highway = crossing
crossing = zebra



highway = crossing
crossing = traffic_signals

highway = crossing
crossing = zebra

types have been grouped according to the following eight characteristics. While these characteristics may exist independently, they are not mutually exclusive. It is also important these crossing features be considered in context with the street environment (e.g. number of traffic lanes, round-abouts, non-perpendicular intersections etc.).

Unmarked Crossings: By far the most common crossing type is that which is not marked at all. Any two sidewalk ends or corners separated by a street could be considered an unmarked crossing in certain locales. The majority of intersections in residential and industrial neighborhoods fall into this category. Additionally paint doesn't last forever, in many places throughout Seattle marked crossings have all but disappeared as a result of weathering and traffic.

Marked Crossings: This term encompasses several crossing types that are characterized by a visual cue designed to inform both pedestrians and motorists that a person may be entering the street area at a given point. Line styles may have different meanings depending on location, however as a general rule, high contrast markings with greater surface area are easier to detect for both pedestrians and motorists alike.

Pedestrian Light Signals: This style of crossing signal provides pedestrians with a visual indicator of when it is safe to cross and is typically associated with a corresponding traffic light. Some of these lights cycle automatically, while others require activation with a button. In the City of Seattle, the buttons associated with this type of signal are typically rounded and require greater force to push than newer Accessible Pedestrian Signals (APS).

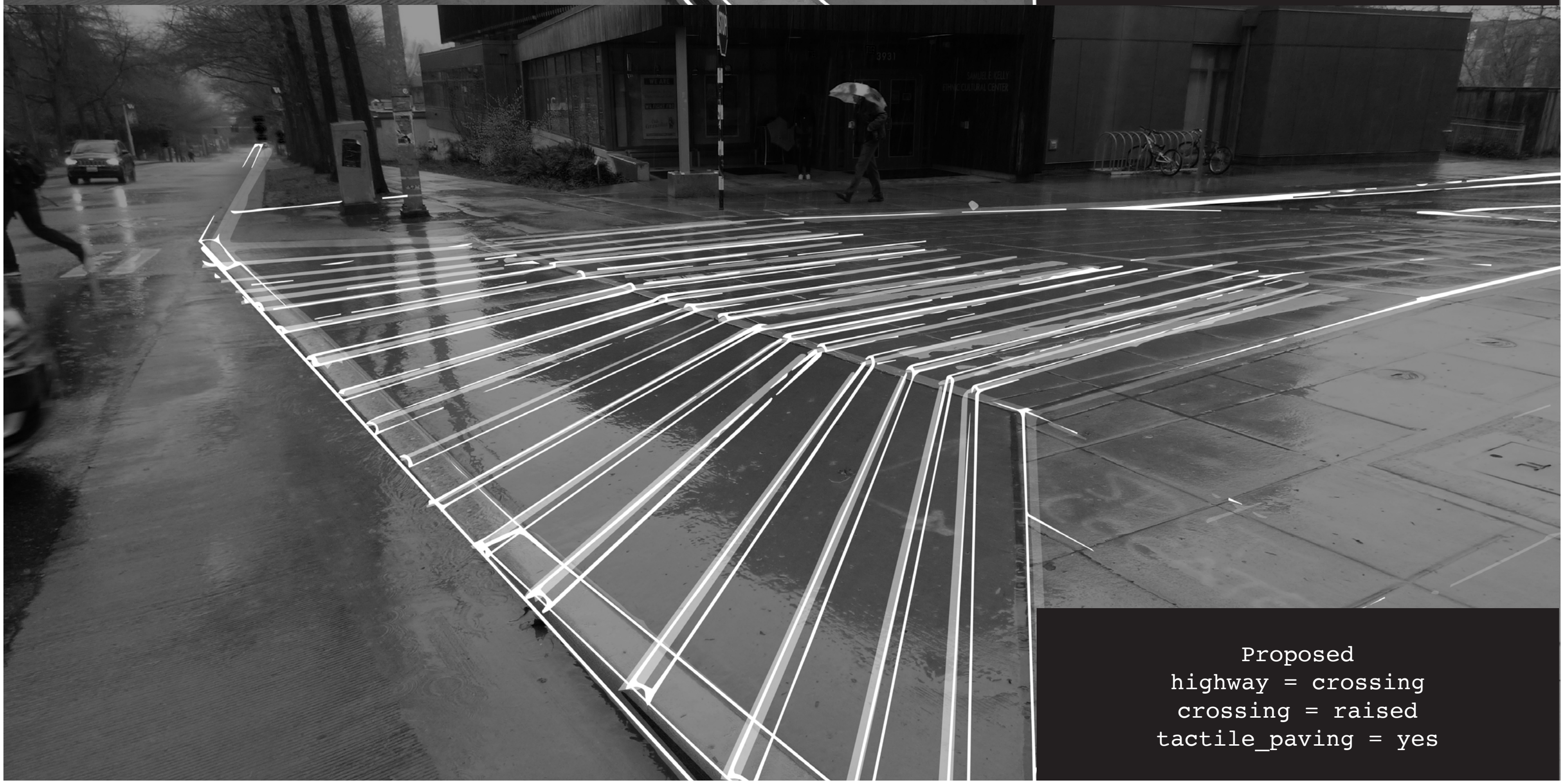
Audible Signals: Audible pedestrian signals communicate the state of a crossing interval. Modern signals are typically associated with a rapid ticking, or verbal cue such as "walk sign is on" or "wait". Older "cuckoo-chirp" signals also fall into this category. Here a "cuckoo" sound is associated with safe north-south crossing, while "chirps" indicate an east-west pedestrian signal. Cuckoo-chirp style signals are no longer recommended for installation, as they tend to be confusing for pedestrians (Harkey et al. 2010).

Audio-Tactile (Vibrating) Signals: Modern accessible pedestrian signals include a haptic indicator embedded in the crossing signals push button. This type of signal is particularly useful for the deaf-blind community, but also provides a clearer indication of what direction is safe to cross for pedestrians that are blind or have low vision, as directionality for audible overhead signals has been shown in some cases to cause confusion (Harkey et al. 2010). In Seattle audio-tactile APS systems are typically associated with flat pushbuttons that require less force than the older systems to activate.

Raised Pedestrian (Tabled) Crossings: This increasingly popular type of crosswalk kept at grade with the sidewalk encouraging cars to slow down and giving pedestrians priority. However, in the absence of the grade change that typically signals to pedestrians that they are entering a car dominant area, it is important to provide a tactile cue through a surface change or warning strips to pedestrians that are blind or have low vision.

Traffic (Refuge) Islands: These painted or raised areas can be located between large traffic lanes, or at the junction of multiple streets intersecting in a non-perpendicular fashion. Ideally these features are accompanied by additional pedestrian safety features such as: high contrast tactile paving, shoring edges to provide heading, signage and pedestrian signals.


Existing
highway = crossing
crossing = raised
tactile_paving = no


Proposed
highway = crossing
crossing = raised
tactile_paving = yes

Pedestrian Bridges and Tunnels: Pedestrian bridges and tunnels mitigate traffic conflicts by routing pedestrians on a separate plane or z-level. Care must be taken to make these features accessible to people that use assistive devices, and to make clear their presence and the locations of their entrances and exits, if separate from the path itself.

A pedestrian's experience of any street interface is going to depend significantly on the vehicular environment. Designers should consider ways to facilitate safety and mobility from both the pedestrian and motorist's perspective. Traffic calming strategies vary depending on street conditions and context, but as a general rule, the more attention that can be brought to a potential pedestrian conflict the better. Visual, audible or tactile cues all can be employed to achieve this aim.

Transit: Public transit provides access to the city for millions of riders each year. Predictable, far side bus stops are preferred in Seattle (Seattle 2005). However these are not ubiquitous. Being aware of alternative situations enables designers to better accommodate these inconsistencies in the urban fabric and facilitate understanding for riders. With more information made available, travelers are more likely to attempt unfamiliar trips on public transportation (Campbell et al. 2014).

Given the importance of transit information cited by both the needs experts interviewed and relevant literature, the maps produced represent transit stop locations, however spatial constraints restricted the granularity of data that could be associated with these stops. Ideally critical information would be available through a linked app that could read bus numbers, and location details to the user. At the very least this more detailed information should be available at the bus stops. Unfortunately, braille is notably absent from a vast majority of informational signage at transit stations.

Barriers, Landmarks and Points of Interest: Barriers (construction sites, low hanging branches, sandwich boards, pavement cracks...), landmarks (fountains, play fields, churches...) and points of interest (retail, food, services...) are additional categories that should be considered in relation to wayfinding, mobility and the pedestrian experience. The vast range of potential features, as well as their subjective nature precluded them from an in depth investigation in this study. However, there is precedent and opportunity to explore these features in future work.

Making and Evaluating

MAKING AND EVALUATING

Giving form to the considerations discussed in previous sections, prototypes of 3D printed map tiles representing urban pedestrian environments were produced. The critical approach taken in these maps re-prioritizes transportation infrastructure focusing not on the street networks but instead on the pedestrian ways. Re-imagining the representation of this network to go beyond the two dimensional and take a physical shape pushed the design to consider not only external factors that impact the way people with low vision and blindness navigate through space, but also the experience of trying to understand and negotiate these factors. The maps produced serve as prototypes of tools that can facilitate understanding for a specific group of people that has been underserved by current cartographic practices. For people with sight they are intended to challenge assumptions and illustrate experiences that often go under appreciated.

Web Application Incorporation

One goal for this project was to facilitate access to tactile maps by designing tiles that could be printed at home, brought to a local library, or sent to a 3D printing service for relatively quick and inexpensive map production. Beyond customizable map locations, ultimately users would be able to specify different scales and map features that are important to them, democratizing the map making process.

Three computer science (CS) students from CSE481H: Accessibility Capstone, helped establish an open source pipeline so that customizable maps could be made available through an accessible web application. Due to the proprietary nature of Rhino 3D, an alternate workflow to the one used for the design development, was established for the web application based on the open source, Touch Mapper (http://touch-mapper.org/) project.

Begin with OpenStreetMap data.

Elk an open-source plug-in for grasshopper is used to read the .osm file, providing easy access to OSM's point and line geometry through the associated key tag pairs.

OSM2World is a small Java application that translates OSM point and line data into mesh surfaces on designated layers in an .obj file.

Rhino is a proprietary 3D modeling software, developed for professional design applications , including architectural, mechanical and automotive design work.

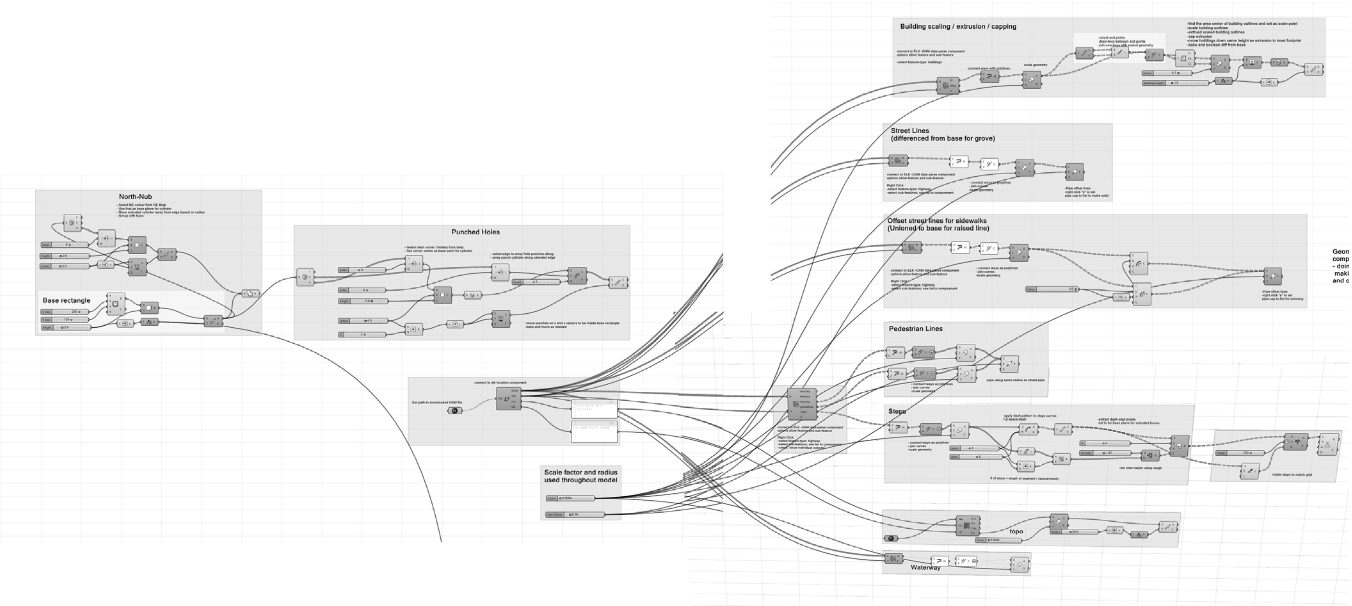
Blender is a free and open-source 3D modeling program, well suited for video and game modeling.

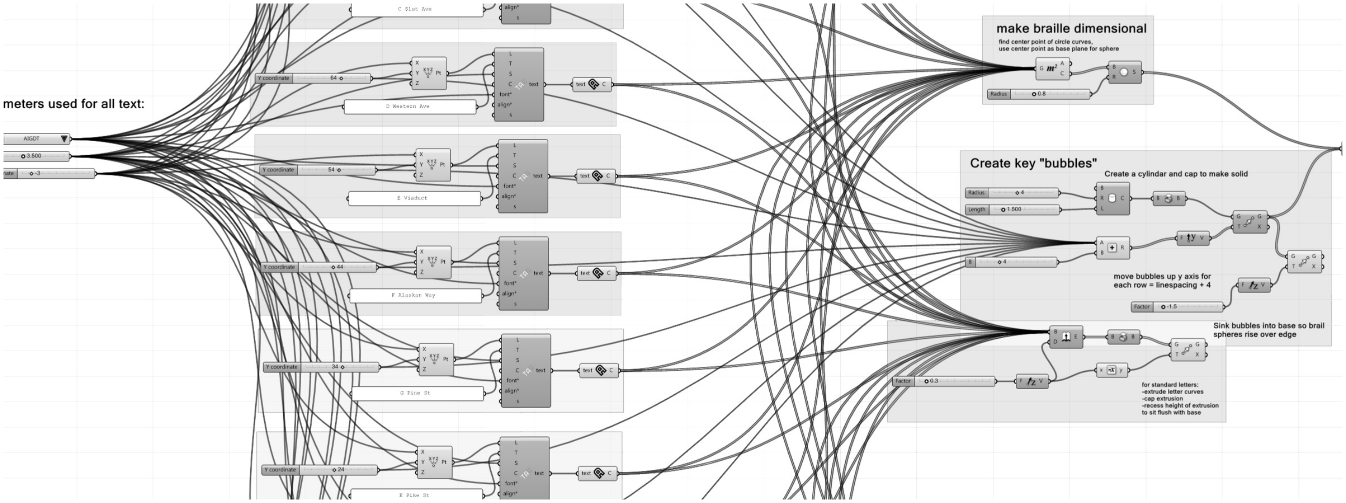
Grasshopper, an open-source visual scripting Rhino add-on, uses components to apply design rules to designated geometry defined by OSM key pairs, extracted in Elk.

Python, a general use programming language is used to script the surface mesh manipulations using the Blender API.

Compared to traditional tactile graphic production methods, 3D printing allows for a greater range of symbols and textures, and is more widely available at a lower cost.

Forked from the TouchMapper project Tactile MapTile is a screen reader accessible web application that automatically generates a .stl file of a designated area ready to be 3D printed





Grasshopper script modeling map data downloaded from OSM (above), and braille key (below)

The CS team enhanced Touch Mapper's web interface to be more accessible to its target user group, and laid the groundwork for incorporating the atomic symbol set designed in this thesis work.

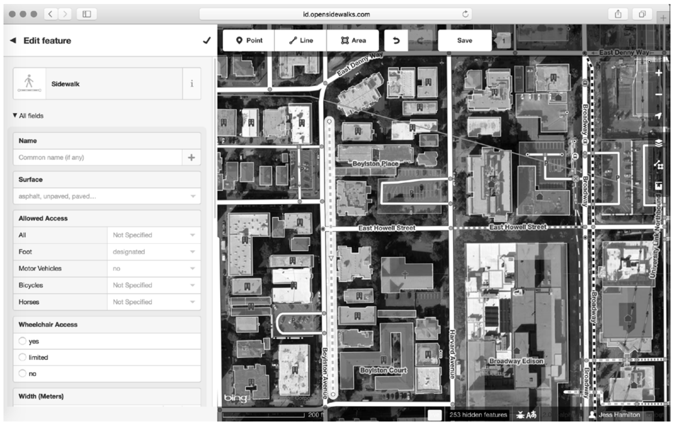
Parametric Modeling

Using the Elk plug-in, OpenStreetMap data was pulled into Grasshopper to create parametrically designed maps allowing for the rapid iterations, based on changing data sets and user preferences discussed earlier. The 'sketchbook' included in the appendix of this document contains annotated scripts that served as the foundation for each map tile produced in both the Pike Place and Judkins Park area case studies. While the majority of the modeling was done parametrically through Grasshopper, the geometry produced subsequently underwent manual cleaning prior to being printed. In order to achieve a watertight 3D model, stray independent surfaces had to be identified and discarded, and features had to be manually unioned and differenced due to computational constraints that prevented these processes being done automatically in Grasshopper.

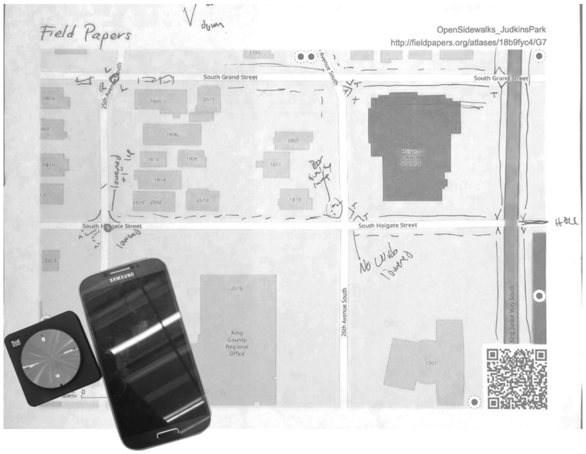
Appendix ## contains the Grasshopper scripts used to create both the map tiles and the brialle keys that accompany them. Along with the annotated documentation in Appendix ##, and tables outlining the parameters used for each iteration the maps created will be replicable. These can serve as a starting point for representing different urban areas or, to facilitate further research and development.

Filling Data Gaps

To fill in the data gaps for the Judkins Park Station area of interest, base maps were printed from fieldpapers.org and manually annotated. After, using the associated QR code, they were scanned to the OpenSidewalks iD editor and digitally mapped. Passive data collection techniques were also tested which paired an android device with a GPS unit to enhance the accuracy of the GPS traces collected. Still under development at the time of writing, the GPS trace collection application was outfitted with two buttons which allow the user to mark the location of significant features they wish to map, while also recording the device's accelerometer data. If affixed to a bike or other wheeled mount, this would allow for a reading of the surface smoothness for the path traveled.



OpenSidewalks iD editor



Field Papers

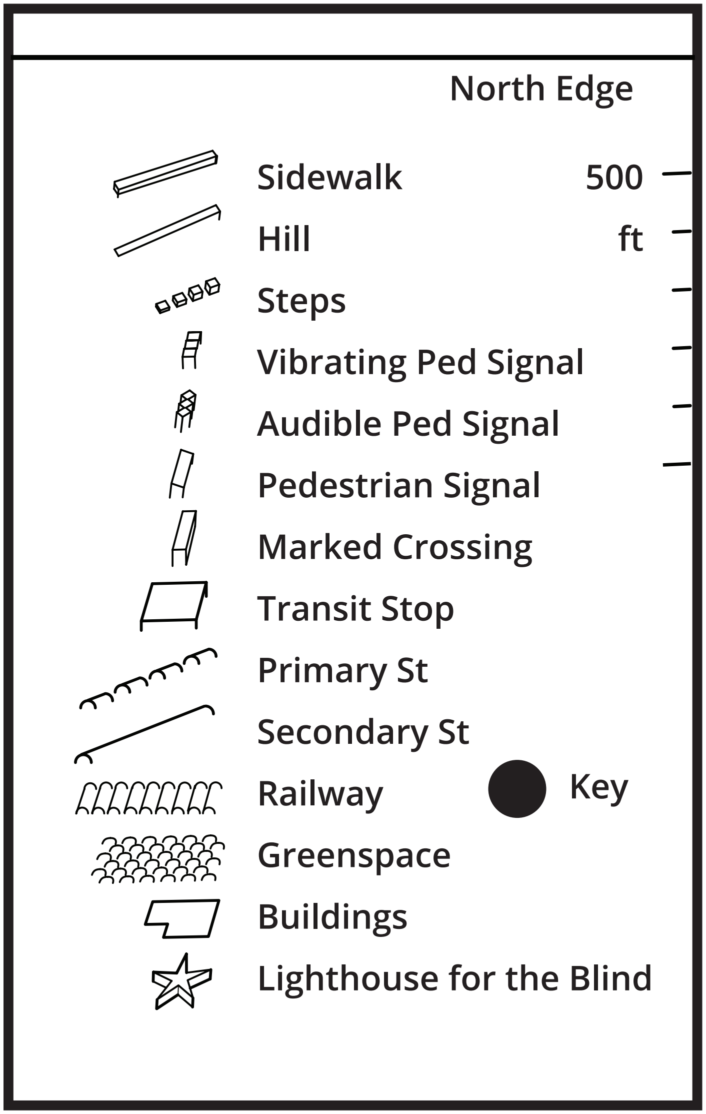
Scope and Scale

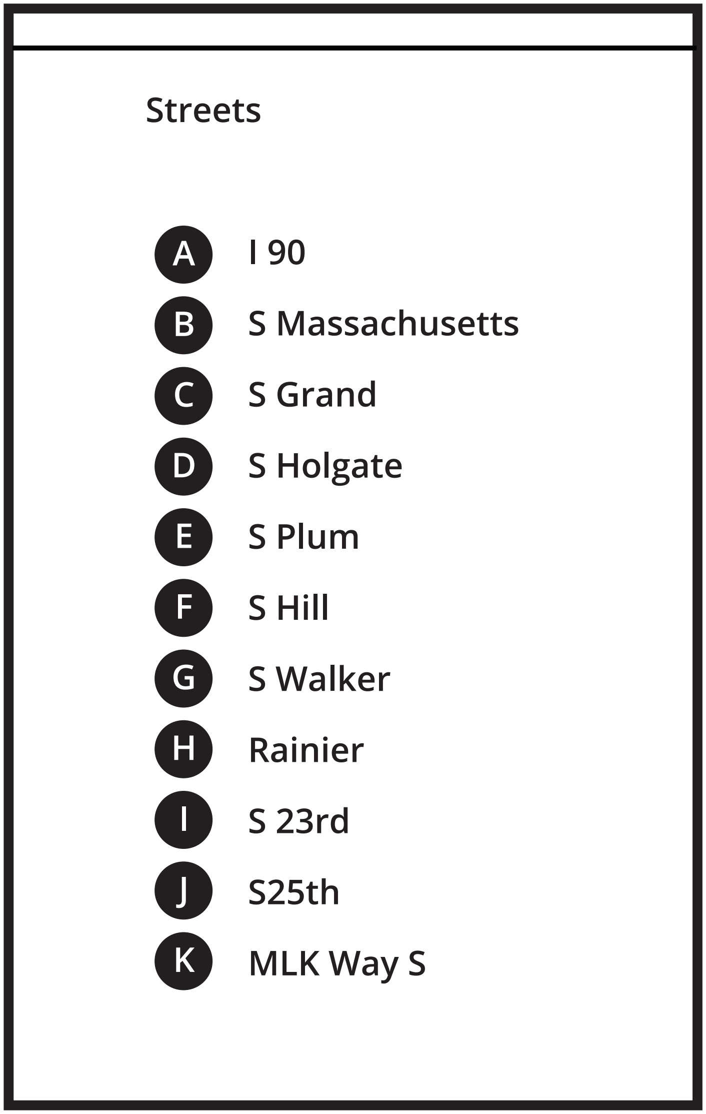
This thesis research has focused specifically on urban environments. It is important to note however that urban environments vary considerably. Moving from the highly developed neighborhood surrounding Pike Place Market, which was used for initial map prototypes, to the more residential Judkins Park area reflected a significant variation in terms of the investment in and completeness of pedestrian infrastructure. The cartographic language and parametric definitions established were elastic enough to function in each of these contexts fairly well. However, different typologies from suburban and rural areas, to campuses and sprawling green spaces warrant further examination in terms of what features should be prioritized for representation and what scale and density of information is appropriate.

The map tiles produced for the Judkins Park Station case study were scaled such that 1”=200’ (1mm=2.4m). This scale accommodated an area roughly 3x4 blocks. Rather than being direct 1:1 models of the environments they examine, these maps abstracted some features and omitted others in order to emphasize the information deemed important to the project. More space for the pedestrian information of interest was created through the reduction of buildings and using footprints rather than an extrusion.

Due to 3D print bed constraints, map tiles were limited to ~8” x 5.5”. In order to capture an area that includes both the forthcoming Judkins Park Transit Station, and Seattle Lighthouse for the Blind at this scale 3 tiles were needed.

Based on preliminary feedback from expert users, basic features of the urban pedestrian environment were legible at this scale. Further usability testing and symbol development must be conducted in order to confidently say if this scale is appropriate as a navigational



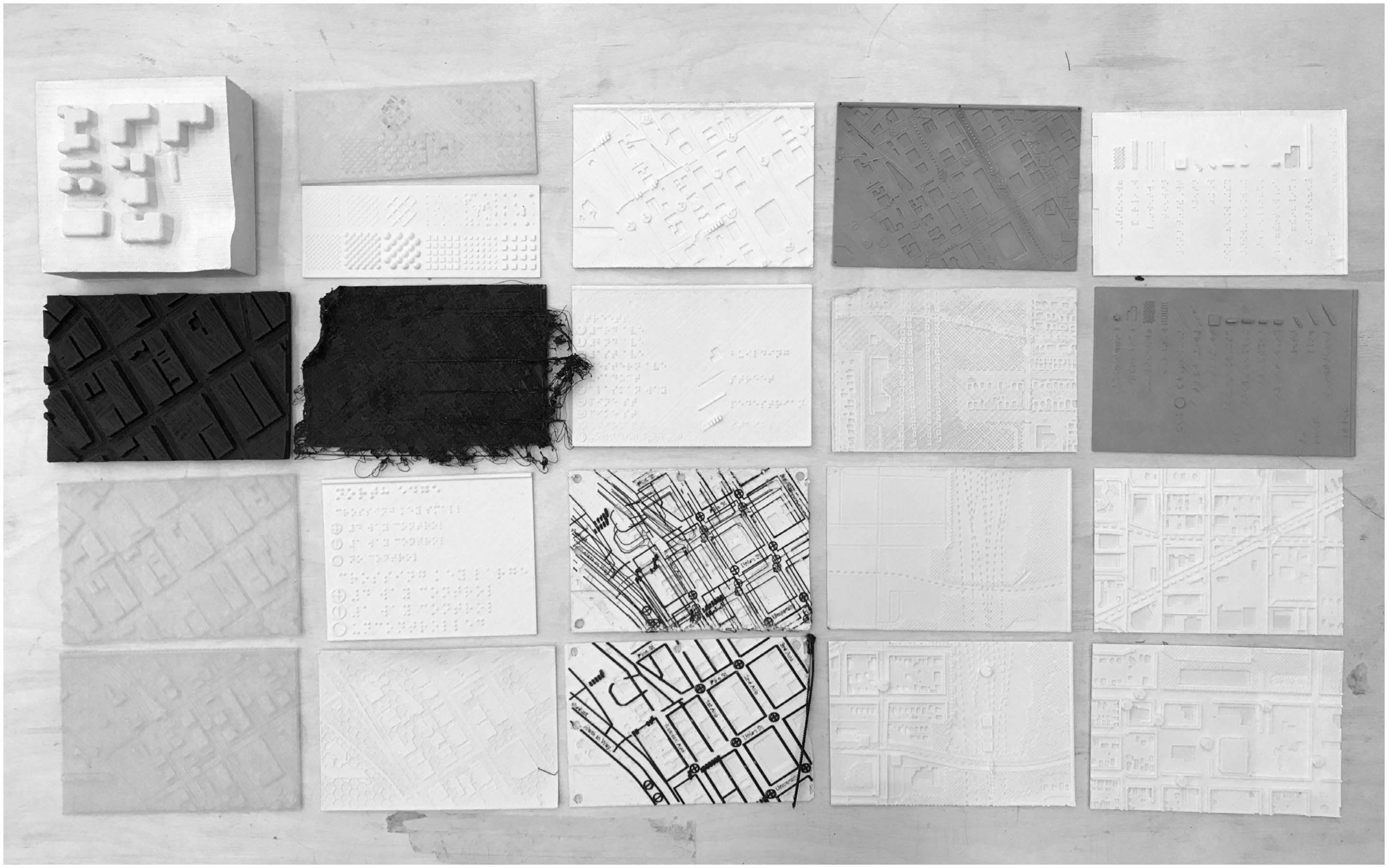


Graphic representations of keys produced in braille aid. The case study map series was printed with slight variation in symbol style and size on each tile in anticipation of user testing, however it seems likely that the variations produced were not adequately different and should be exaggerated more for future testing.

In order to establish a starting point for future research into optimal symbol sizing Appendix ### contains a table outlining these map features and their measurements.

Experts interviewed indicated a more detailed tactile representation of smaller sites might also be valuable. Potential areas cited that would benefit from the availability of detailed maps include transit stations, and complex intersections, particularly non-perpendicular intersections and those involving the junction of three or more streets. Additional interviews or a survey distributed more broadly would be useful in identifying other areas of interest, and what features of these spaces should be prioritized for representation.

There is an additional opportunity to apply the approach used in this project to developing maps that convey different types of information. Zoomed way out, it would be relatively easy to create maps that are more reflective of the broader context of an area or district. Here again there is an opportunity to create a basic symbol set for features that would be desirable in order to better understand how an area is situated in place. In addition to the standard cartographic information such as scale and cardinal direction, this may include green spaces, water bodies, arterials, district lines, etc.



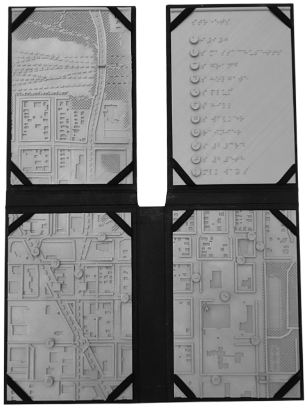
Object Making and Craft

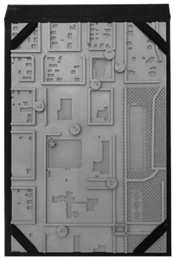
3D printers allow the opportunity to iterate with a speed and precision previously unattainable. Despite the benefits there are also unique challenges in terms of both design and product life cycle.

Prototypes were printed throughout the process to test legibility with needs experts and to better understand the technical and material constraints associated with 3D printing. With access and affordability key goals of this project, all maps were printed using Flashforge Creator Pro-Dual Extrusion 3D Printers. While higher quality prints may have been achieved from other hardware, this relatively affordable device ($900 at the time of writing) was readily available, and has been widely adopted in the maker community (3D Hubs 2017).

Several filament types were tested. Ultimately Hatchbox brand PLA and wood PLA were the preferred filaments used. Wood PLA is a composite filament that combines 10-15% wood particles with a corn-based PLA plastic. During the print process wood PLA proved to be less susceptible to warping, and had better adhesion the 3D print bed resulting in fewer misprints than the standard PLA filament. Additionally the wood PLA can be sanded after printing, resulting in softer map features that are more comfortable to read. Legibility and comfort were both critical concerns raised by the orientation and mobility specialist interviewed. In theory both materials are plant based and could be considered compostable, however the life cycles of these materials warrants further research.

The print settings for use with Flashforge Creator Pro-Dual Extrusion 3D Printers along with a table tracking print the settings tested, with notes on results, filament combinations and print tips can can be found in Appendix E.





Folio

Usability and organization were key concerns identified by needs experts as well as critics that provided feedback throughout the project's development. The primary use case for the maps printed in this case study was to facilitate the studying an environment prior to entering it, however a form was sought that would not exclude users from referring to the maps while actively navigating. With these uses in mind, keeping track of the map tiles in terms of their orientation and relationship to each other was a key concern. Additionally usability issues had to be addressed, regarding how the maps could be carried around if accompanying other navigational facilitators that require the use of one hand such as haptic canes or seeing eye dog.

The tile size limitations inherent in 3D print bed constraints presented a further challenge in terms of organization. For any area printed at the scale of the case study, at least two tiles are going to be required if a braille key is to be used, and more tiles may be added for any given area. The case study area required a minimum of four tiles to cover the walk from the Seattle Lighthouse for the Blind to the new Judkins Park Station with a key. Multiple solutions were considered and prototyped including a spiral binding, fitted edges, and wearable fasteners. The spiral binding and fitted edges were cumbersome and did not fit multiple use cases, i.e. spiral bindings did not facilitate spreading tiles out next to each other, and fitted edges were distracting when tiles were used independently or in small groups. There is ample opportunity for wearable technology to assist this community. However, this approach warrants its own dedicated project.

Ultimately a custom folio that allows users to slip tiles in and out as needed emerged as the preferred solution. This simple approach rooted in book-making craft further enables the tiles' folding and unfolding, similar to a paper map.

Reflections

REFLECTIONS

The future directions that could be taken with this project feel limitless. First and foremost formal user testing of the case study maps printed would inform future development and refinement of the atomic symbol set intended to provide a foundation for the web application discussed in earlier chapters. Similarly a survey of pedestrians that represent a range of visual capacities would facilitate the development of a human centered digital mapping standard, and has the potential to support countless other applications directed at facilitating navigation for people with and without visual impairments.

Both the user testing, and a dedicated survey also has implications for contributing to the body of knowledge landscape architects have at their disposal when designing, whether universally or not, to meet the needs of pedestrians that are blind or have low vision. It is worth noting at this point that the maps produced for this case study do not actually conform to universal design principles. They were designed to meet the needs of a very specific user group that is able to read braille. However, with the addition of high contrast labels these maps could become something that enhances nearly everyone's understanding of a place. Even without the labels though, it is hard to deny the utility of the type of tactile map. This raises interesting questions about the limitations universal design is as one of the few guiding theories for accessible design in a human centered field like landscape architecture.

If there is an opportunity to design to meet the needs of a specific group, and then extend that to benefit the many, does that warrant less consideration than an approach that is universal from the beginning? Is there always a universal design solution available? What is the best approach when there is not? And why aren't more landscape architects asking questions like this?

It seems the lack of critical engagement with the full breadth of accessibility for people with multiple and diverse capabilities from a design perspective is, at least in part, a self-perpetuating issue. The lack of attention from designers has resulted in not only uninspired design solutions, but also uninspired research and educational materials. Dense technical reports (ADA 1990) and twenty year old posters (Connell et al. 1997) are not effective in motivating creative design thinking. Accessible design approaches need to be thought of as way to not only make spaces easier to navigate for people using wheelchairs and white canes, but also for the people listening to podcasts and texting while floating on their hover-boards. None of these circumstances describe an ideal way of moving through space, but that doesn't mean designers can or should ignore them. For this designer the lure of a socially oriented challenge that engaged data and technology provided enough of a spark to inspire nearly ten months' work. Not until the project was fully underway did I really begin to grasp how much better I would forever be as a designer, dedicating so much time and energy trying to understand circumstances completely outside of my own experiences.

That said there are ample opportunities to further the digital fabrication, modeling, and data driven design strategies for inclusion explored in this thesis work. Different scales of map tiles to be customized and printed at home as discussed in earlier sections area a start, but there is also an opportunity for different scales of production. Richer signage at transit stations or complex intersections would require different materials and data input, but could be a fairly straightforward application of the approach used. Similarly models routed and cast or treated could be used in settings ranging from parks and airports to campuses and neighborhoods providing visitors of any age and visual circumstance with an opportunity to enhance their understanding of and interact with, the area's key spatial features and relationships. Pushing further and breaking the frame of typical wayfinding strategies, surfaces, from light posts and trash cans to paving materials and guardrails, all have the potential to act as information rich surfaces throughout the environment.

Beyond static representations, articulated models hold the potential to change shape, taking on the form of multiple spaces, or responding to different conditions. Embedded sensors and haptic feedback could be used to represent any range of data points, manifesting in material temperature variations or vibrations. Audible information could be embedded in the maps or strategically placed throughout the environment to report a more granular or transient pieces of information such as construction site disruptions or poor sidewalk conditions due to weather.

As cities and tech companies embed sensors to monitor traffic, carbon emissions and countless other aspect of urban life, landscape architects and urban designers should be thinking about ways similar technologies can be used to provide safer, more human friendly environments. The same installations that communicate train times via a monitor could also alert pedestrians with low vision through an app, or wearable devices which to train is arriving at what track. Instead of simply triggering a light change, instrumented street environments could alert drivers to pedestrians in their vicinity.

The possibilities are endless for algorithmically driven, and data laced approaches to urban design. Despite reliably taking longer than expected to develop and implement, the challenge is no longer so much in the technology, but in the implementation. However, as tempting as it may be to believe, algorithms don't tell the future; instead built on existing data, by bias prone humans, they often reinforce the past. As such in order to prevent existing injustices and harmful practices from being perpetuated, it is critical we find ways to ensure every voice is heard, not just those donning smart phones and traffic data. Both designers and citizens need to participate in shaping our future cities, failure to do so risks sacrificing not only our intentions, but our autonomy.

Embracing data is not just about making better tools; it also facilitates more informed decision-making. This idea isn't new, designers and planners have been digging through GIS archives for decades trying to get their hands on data to inform their work for decades. If data can be used to support theories on public space and ecosystem services it enhances designers' ability to sell designs and has the potential to quantifiably justify the costs for long-term investments in accessible public spaces and ecological infrastructure.

The application that was put forth as a future goal of this work, gives voice its users by inviting them into the making process. Through participating in the making of their own maps, users are not only are provided with a custom tool, but they are leaving data that asserts their priorities and concerns. In the same way, conversations and informal interviews can be used to glean an understanding of an experience outside of their own, designers can use these data traces to better understand the needs of populations that may otherwise go unmet. The open source approach facilitates collective action on solving problems that can't yet always be accommodated in the public sector and likely shouldn't be left to only to the private.

Ultimately, from exacerbating equity and privacy violations, to extractive consumption and the breakdown of social networks, I think there is a lot that could go very wrong in the pursuit of making our cities smarter and more convenient. However, it is for exactly these reasons, and the equally possible progress on all of these fronts that landscape architects must engage, and pursue understandings outside of their own experience. It will make us better designers, and make the world more hospitable place.

REFERENCES

2008. ADA Amendments Act of 2008 (ADAAA). edited by 110th United States Congress.

2010. "UNIVERSAL DESIGN (1986, R1994, R2000, R2001, R2010)." American Society of Landsacpe Architects. https://www.asla.org/uploadedFiles/CMS/Government_Affairs/Public_Policies/Universal_Design 2010.pdf.

Anderson, Chris. 2012. *Makers : the new industrial revolution.* 1st ed. ed. New York: New York : Crown Business.

AOA. 2016. "Common Types of Low Vision." American Optometric Association.

Apple. "Apple Maps." Apple. https://www.apple.com/ios/maps/. 2017.

Arlington, County of. 2017. Roads. edited by VA Arlington County.

Azenkot, Shiri, Sanjana Prasain, Alan Borning, Emily Fortuna, Richard Ladner, and Jacob Wobbrock. 2011. Enhancing independence and safety for blind and deaf-blind public transit riders.

Balode, Linda. 2014. "The Social Aspect Of Open Space In Rehabilitation Gardens And Parks." ***Mokslas : Lietuvos Ateitis*** 6 (3):310-322-322. doi: 10.3846/mla.2014.043.

BANA. 2011. "Guidelines and Standards for Tactile Graphics." Braille Authority of North America and the Canadian Braille Authority, accessed 12/13/16.

Blades, Mark, Simon Ungar, and Christopher Spencer. 1999. "Map use by adults with visual impairments." *The Professional Geographer* 51 (4):539-553.

Bonnar C, Campbell M, Drapeau R, Bennett C, and Borning A. 2015. Contributing During the Commute: Why Transit Riders Submit Information About Bus Stops with StopInfo. University of Washington.

Bright, Keith, and Ann Sawyer. 2014. *The Access Manual Designing, Auditing and Managing Inclusive Built Environments.* Edited by Keith Bright. 3rd ed. ed, *Access Manual*. Hoboken: Hoboken : Wiley.

Campbell, Megan, Cynthia Bennett, Caitlin Bonnar, and Alan Borning. 2014. Where's my bus stop?: supporting independence of blind transit riders with StopInfo.

Carpo, Mario. 2011. *The Alphabet and the Algorithm*. Cambridge, Mass.: Cambridge, Mass. : MIT Press.

Carver, Alison, Anna Timperio, and David Crawford. 2008. "Neighborhood Road Environments and Physical Activity Among Youth: The CLAN Study." *Journal of Urban Health* 85 (4):532-544. doi: 10.1007/s11524-008-9284-9.

Celani, G., V. Zattera, M. F. De Oliveira, and J. V. L. Da Silva. 2013. Seeing with the hands: Teaching architecture for the visually-impaired with digitally-fabricated scale models.

Chicago, City of. 2012. Sidewalks. edited by City of Chicago.

Christ, Wolfgang. 2009. *Access for All : approaches to the built environment, Approaches to the built environment*. Basel [Switzerland] ; Boston: Basel Switzerland ; Boston : Birkhäuser.

Connell, Bettye Rose , Mike Jones, Ron Mace, Jim Mueller, Abir Mullick, Elaine Ostroff, Jon Sanford, Ed Steinfeld, Molly Story, and Gregg Vanderheiden. 1997. "The Principles of Universal Design ". North Carolina State University, The Center for Universal Design https://www.ncsu.edu/ncsu/design/cud/.

Crampton, Jeremy W, and John Krygier. 2005a. "An introduction to critical cartography." *ACME: An International Journal for Critical Geographies* 4 (1):11-33.

Crampton, Jeremy W, and John Krygier. 2005b. "An introduction to critical cartography." *ACME: an International E-journal for Critical Geographies* 4 (1):11-33.

Cutts, Bethany B., Kate J. Darby, Christopher G. Boone, and Alexandra Brewis. 2009. "City structure, obesity, and environmental justice: An integrated analysis of physical and social barriers to walkable streets and park access." *Social Science & Medicine* 69 (9):1314-1322. doi: 10.1016/j.socscimed.2009.08.020.

Dannenberg, Andrew L., Howard Frumkin, and Richard Jackson. 2011. *Making Healthy Places : designing and building for health, well-being, and sustainability.* Edited by Andrew L. Dannenberg, Howard Frumkin and Richard Jackson. Washington, D.C.: Washington, D.C. : Island Press.

Disability, National Council on. 1990. Americans with Disabilities Act (ADA). 108th Congress, 2nd Session.

Downey, Chris. 2013. *Design with the blind in mind*: TED.

Erin, J. N. 2009. "Traveling by touch: how useful are tactile maps?" *Journal of Visual Impairment & Blindness* 103 (5):265-266.

Espinosa, M. Angeles, Simon Ungar, Esperanza Ochaíta, Mark Blades, and Christopher Spencer. 1998. "Comparing Methods for Introducing Blind and Visually Impaired People to Unfamiliar Urban Environments." *Journal of Environmental Psychology* 18 (3):277-287. doi: 10.1006/jevp.1998.0097.

Foundation, Landscape Architecture. 2016. The New Landscape Decloration. Philadelphia, PA.

Franscisco, City of San. 2017. DPW Street & Sidewalk Evaluation Results, 7-1-2013 to Present. edited by City of San Francisco.

Gardiner, A., and C. Perkins. 2002. "Best practice guidelines for the design, production and presentation of vacuum formed tactile maps. ." Tactile Book Advancement Group (TBAG), accessed December. http://www.tactilebooks.org/tactileguidelines/ page1.htm, .

Gardiner, Ann, and Chris Perkins. 2005. ""It's a Sort of Echo...": Sensory Perception of the Environment as an Aid to Tactile Map Design." *British Journal of Visual Impairment* 23 (2):84-91. doi: 10.1177/0264619605054780.

Gehl, Jan. 2014. *Life Between Buildings Using Public Space*. Washington DC: Washington DC : Island Press.

Golledge, Reginald G., James R. Marston, Jack M. Loomis, and Roberta L. Klatzky. 2004. "Stated Preferences for Components of a Personal Guidance System for Nonvisual Navigation." *Journal of Visual Impairment and Blindness* 98 (3):135-147.

Goltsman, Susan M., and Daniel S. Iacofano. 2007. *The Inclusive City : design solutions for buildings, neighborhoods and urban spaces*. Berkeley, Calif.: Berkeley, Calif. : MIG Communications.

Google. "Google Maps." Google. https://www.google.com/maps. 2017.

Graham, Mark, and Taylor Shelton. 2013. "Geography and the future of big data, big data and the future of geography." *Dialogues in Human Geography* 3 (3):255-261.

Gual, Jaume, Marina Puyuelo, and Joaquim Lloveras. 2015. "The effect of volumetric (3D) tactile symbols within inclusive tactile maps." *Applied Ergonomics* 48:1-10. doi: http://dx.doi.org/10.1016/j.apergo.2014.10.018.

Hanzl, Malgorzata. 2007. "Information technology as a tool for public participation in urban planning: a review of experiments and potentials." *Design Studies* 28 (3):289-307. doi: http://dx.doi.org/10.1016/j.destud.2007.02.003.

Harkey, David, Daniel Carter, Billie Bentzen, and Janet Barlow. 2010. *Accessible Pedestrian Signals: A Guide to Best Practices.*

Heartney, Eleanor, Dan Mills, Gallery Samek Art, and Agnes Denes. 2003. *Agnes Denes : projects for public spaces : a retrospective.* Edited by Eleanor Heartney, Dan Mills and Gallery Samek Art, Projects for public spaces : a retrospective. Lewisburg, PA: Lewisburg, PA : Samek Art Gallery, Bucknell University.

Henry, Shawn Lawton. 2007. *Just Ask : integrating accessibility throughout design.* United States?]: United States? : Lulu.com.

Holzman, Justine, and Bradley Cantrell. 2016. *Responsive Landscapes : strategies for responsive technologies in landscape architecture.* Edited by Justine Holzman. [First edition] ed. Abingdon, Oxon

Houston, City of. "Houston Open Data Portal." City of Houston. http://data.ohouston.org/.

Hubs, 3D. "3D Hubs Best 3D Printer Guide." https://www.3dhubs.com/best-3d-printer-guide.

Imrie, R. F. and Wells P. E. 1993. "Disablism, planning, and the built environment." *Environment and Planning* 11:213--231.

Hudson, Laurie 2014. “O & M Literacy: Creating a Tactile-Map.” Paths to Literacy May. http://www.pathstoliteracy.org/blog/creating-tactile-map.

Jacobs, Jane. 1961. *The death and life of great American cities*. New York: New York : Random House.

Kamp, David. 2009. “Restorative commons : creating health and well-being through urban landscapes.” *Restorative commons : creating health and well-being through urban landscapes*, edited by Lindsay K. Campbell, Anne Wiesen, Meristem, Service United States. Forest and Station United States. Forest Service. Northern Research, 111-123. Newtown Square, PA: Newtown Square, PA : USDA Forest Service.

Kim, Annette M. 2015. “Critical cartography 2.0: From “participatory mapping” to authored visualizations of power and people.” *Landscape and Urban Planning* 142:215-225. doi: 10.1016/j.landurbplan.2015.07.012.

Kim, Annette Miae. 2015. *Sidewalk city : remapping public space in Ho Chi Minh City*. Chicago London: The University of Chicago Press.

Klingle, Matthew W. 2007. *Emerald City : an environmental history of Seattle*. New Haven: New Haven : Yale University Press.

Koch, Jo, and Jan Gehl. 2006. *Life between buildings : using public space*. Edited by Jo Koch. 6th ed. ed. Copenhagen : The Danish Architectural Press.

Lange, Eckart. 2011. “99 volumes later: We can visualise. Now what?” *Landscape and Urban Planning* 100 (4):403-406. doi: http://dx.doi.org/10.1016/j.landurbplan.2011.02.016.

Lobben, Amy, and Megan Lawrence. 2012. “The Use of Environmental Features on Tactile Maps by Navigators Who Are Blind.” *Professional Geographer* 64 (1):95-108. doi: 10.1080/00330124.2011.595619.

Lynch, Kevin. 1960. *The Image of the City.* Cambridge, Mass.: Cambridge, Mass. : MIT Press.

Lynch, Kevin 1976. *Environmental Knowing*. G. T. Moore & R. G. Golledge, Eds., ed. Stroudsberg, PA: Dowden, Hutchinson & Ross.

Maciag, Mike. 2014. “Pedestrians Dying at Disproportionate Rates in America’s Poorer Neighborhoods “ *Governing,* August 2014.

Microsoft. “Bing Maps.” Microsoft. https://www.bing.com/maps/. 2017.

Mitchell, Lynne, and Elizabeth Burton. 2006. *Inclusive Urban Design : streets for life*. Edited by Lynne Mitchell. Oxford: Oxford : Architectural.

OpenStreetMap. “OpenStreetMap.” http://www.openstreetmap.org/ 2017.

Preiser, Wolfgang F. E., and Elaine Ostroff. 2001. *Universal Design Handbook.* Edited by Wolfgang F. E. Preiser and Elaine Ostroff. New York: New York : McGraw-Hill.

Quinones, Pablo-Alejandro, Tammy Greene, Rayoung Yang, and Mark Newman. 2011. Supporting visually impaired navigation: a needs-finding study.

Rahmann, Heike, and Jillian Walliss. 2016. *Landscape Architecture and Digital Technologies : re-conceptualizing design and making.* Edited by Heike Rahmann. Abingdon, Oxon [UK]

New York: Abingdon, Oxon UK

Rowell, J., and S. Ungar. 2003a. "A taxonomy for tactile symbols: Creating a useable database for tactile map designers." *Cartographic Journal* 40 (3):273-276. doi: 10.1179/000870403225012998.

Rowell, J., and S. Ungar. 2003b. "The world of touch: an international survey of tactile maps. Part 1: production." *British Journal of Visual Impairment* 21 (3):98-104. doi: 10.1177/026461960302100303.

Rowell, Jonathan, and Simon Ungar. 2003c. "The world of touch: Results of an international survey of tactile maps and symbols." *Cartographic Journal* 40 (3):259-263. doi: 10.1179/000870403225012961.

Savannah, City fo. 2008. Savannah Facility Maintenance - Sidewalks. edited by City of Savannah. data-sagis.opendata.arcgis.com.

Schiff, W., and E. Foulke. 1982. *Tactual Perception: a Sourcebook.*: Cambridge Univ.. Pr.

Schrader, Megan 2017. "Where the sidewalk ends: In Denver, too many places." *The Denver Post,* February 14, 2017. http://www.denverpost.com/2017/02/14/where-the-sidewalk-ends-in-denver-too-many-places/.

Seattle, City of. Seattle Right-of-Way Improvement Manual.

Seattle, City of. 2017. SDOT Sidewalks edited by City of Seattle. data.seattle.gov: City of Seattle.

Secchi, S., A. Lauria, and G. Cellai. 2017. "Acoustic wayfinding: A method to measure the acoustic contrast of different paving materials for blind people." *Applied Ergonomics* 58:435-445. doi: 10.1016/j.apergo.2016.08.004.

Souter-Brown, Gayle. 2015. *Landscape and Urban Design for Health and Well-Being : using healing, sensory and therapeutic gardens*. Abingdon, Oxon: Abingdon, Oxon : Routledge.

Voženílek, Vít, Magdaléna Kozáková, Zuzana Šťávová, Libuše Ludíková, Veronika Růžičková, and Dita Finková. 2009. "3D Printing technology in tactile maps compiling." Proceedings of 24th International Cartographic Conference, International Cartographic Association, Santiago de Chile, Chile.

Wagenfeld, Amy, and Daniel M. Winterbottom. 2015. *Therapeutic Gardens : design for healing spaces.* Edited by Amy

Wagenfeld. First edition. ed. Portland, Oregon: Portland, Oregon : Timber Press.

Waldheim, Charles. 2012. “Digital Landscape 3.0 (2013-2037).” In *Instigations : engaging architecture landscape and the city : GSD075, Harvard University Graduate School of Design*, edited by Mohsen Mostafavi, Peter Christensen and sponsoring body Harvard University. Graduate School of Design. Zürich, Switzerland: Zürich, Switzerland : Lars Müller Publishers.

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APPENDIX CONTENTS

Appendix A: PEDESTRIAN EXPERIENCE SURVEY

This survey has been developed at the University of Washington for study on pedestrian experiences for people with visual impairments. You have been recommended as a potential needs expert. Obtaining feedback from people with a range of experiences is vital, and your taking the time to complete the following survey would be greatly appreciated. It should only take about 7 minutes.

Your participation is voluntary and will be confidential. Responses will not be identified by individual, and you are free to leave any question unanswered. All responses will be compiled and analyzed as a group. If you choose to provide us with your name and email address, for your participation you will be entered into a raffle for one $15 gift card to Starbucks.

If you have any questions or concerns please contact me Jess Hamilton at 646-369-9015 or jesshami@uw.edu or Anat Caspi, Director of the Taskar Center for Accessible Technology at caspian@cs.washington.edu.

You may contact the UW Institutional Review Board at 206-543-0098 or by email at hsdinfo@uw.edu if you have questions about your rights as a research subject.

About You

I am able to see a digital map with no additional accessibility features:

Mark only one oval.
Strongly agree
Agree
Neither agree nor disagree
Disagree
Strongly disagree

Digital accessibility features I use include (please select all that apply):

Check all that apply.
Screen Reader
Zoom i.e. magnifying screen content
Magnifier i.e. using your device's camera to magnify things
Inverted Screen Colors
Color Filters

None of the Above
Other:

Navigational aides I use when walking include:

Check all that apply.
White cane
Dog
GPS unit
Asking passersby for assistance
Smart phone applications

Which of the following activities do you consider most challenging to you

Finding the sidewalk
Finding mid-block turning points
Finding the crosswalk
Aligning to cross a crosswalk
Starting during the walk interval in a signaled crossing
Ending the crossing within the crosswalk

Age:

Section 2: Consider the following four scenarios

Scenario 1: Contextual Understanding

You are moving to an unfamiliar city. If you could have a general map of that city what information would you want that map to include?

Scenario 2: Orientation

You exited an underground rail station at a mid-block stairwell. Your destination is several blocks away. You know what route you need to take, you just need to orient and figure out in which direction to head. What information would help orient you?

Scenario 3: Local Wayfinding

Your You will be visiting a new city for a vacation. You want to get from your hotel to a restaurant. If your hotel concierge was able to provide you with detailed information on a map of the area and point you to the location of the hotel on the map, what would you want that map to include?

Scenario 4: Route Preference

A new transit station has opened, you are planning your transfer from the light rail to your bus station. You will have to cross a busy intersection. What information would impact your decision about which paths and crossings to use?

For each scenario please rate the features below as information that is:

absolutely essential
very important
moderately important
of little importance
not important at all

Please rate the importance of including the following paths, or routes along which people move:

Footpaths
Stairs
Ramps
Pedestrian tunnels
Pedestrian bridges
Footpath surface type
Footpath width
Streets
Street names
Street directionality
Primary or secondary street differentiation

Please rate the importance of including the following edges, or breaks in continuity

Crossings
Unmarked Crossings
Visually Marked crossings (zebra etc)

Crossings with Stop Signs or Stop Lights
Audible Accessible Pedestrian Signals
Tactile Accessible Pedestrian Signals
Crossings with exclusive pedestrian intervals (crossing 4 ways at once)
Crossings offset from the corner
Tactile Paving
Curb Ramps
Curb ramp with guiding edge
Curb Ramp Direction
Railings
Parking Strips (typically grass or other low planting)

Please rate the importance of including the following district features, or areas characterized by common traits

Hills
Greenspace
Plazas
Parking lots
Beaches
Water bodies
Noisy areas

Please rate the importance of including the following nodes, focus points, hubs and junctions

Transit stations
Transit stop shelters
Transit stop numbers
Elevators
Benches
Street furniture (trash cans, mailboxes, bike racks...etc)
Construction sites

Please rate the importance of including the following landmarks, identifiable features in the urban landscape

Buildings
Entrances

Restaurants
Retail stores
Services
Water features
Trees
Shrubs
Utility poles
Recreation fields and courts

Are there any other features of the environment that facilitate local wayfinding? Please explain.

Tactile Map Specific Questions

I use tactile maps:

Mark only one oval.
Always
Frequently
Occasionally
Rarely
Never

I prefer to use digital maps over tactile maps (when both are available):

Mark only one oval.
Strongly agree
Agree
Neither agree nor disagree
Disagree
Strongly disagree

If available, I would use a tactile map:

Mark only one oval.
Strongly agree
Agree
Neither agree nor disagree
Disagree
Strongly disagree

I find tactile maps helpful when (select all that apply):

planning for a trip, prior to departure
used while navigating with turn by turn directions
actively navigating without other aides
in areas I am already familiar with
in areas I have never visited
not at all
other____

Final Questions

Is there anything else regarding your experience as a pedestrian you would like to share?

Would you be willing to participate in an in person design review at the University of Washington for a $15 gift card to evaluate tactile map designs?

Mark only one oval.

Yes
No
Maybe

Name (only required if you would like to be entered to win a gift card, or would like to participate in a design review):

Email (only required if you would like to be entered to win a gift card, or would like to participate in a design review):

Appendix B: OPENSTREETMAP PEDESTRIAN TAGS

Complete list of OSM Map features: http://wiki.openstreetmap.org/wiki/Map_Features

Feature Group	Feature Key	Key Value	Geometry
Buildings	building	*	indented area
Buildings	entrance	yes/no	point
Pedestrian Way	highway	living_street	Line
Pedestrian Way	highway	pedestrian	Line
Pedestrian Way	highway	footway	Line
Pedestrian Way	highway	path	Line
Pedestrian Way	highway	*	Line
Pedestrian Way	highway	sidewalk	Line
Pedestrian Way	highway	steps	steped line
Pedestrian Way	highway	elevator	point
Pedestrian Way	highway	crossing	dashed line
Pedestrian Way	railway	crossing	dashed line
Pedestrian Way	highway	mini_roundabout	line
Pedestrian Way	traffic_calming	table	raised line
Pedestrian Way	highway	table	raised line
Pedestrian Way	bridge	*	raised line
Pedestrian Way	tunnel	yes/no	sunken line
Pedestrian Combo	kerb	*	affects line style ^
Pedestrian Combo	incline	*	relates to line height
Pedestrian Combo	wheelchair	yes/no/limited	symbol
Pedestrian Combo	smoothness	*	texture
Pedestrian Combo	surface	paved / asphault / concrete	texture
Pedestrian Combo	surface	unpaved / gravel / pebblestone / grass / ground / earth / dirt / mud / sand	texture

Feature Group	Feature Key	Key Value	Geometry
Pedestrian Combo	surface	paving_stones/cobblestone/grass_paver	texture
Pedestrian Combo	surface	metal/wood	
Pedestrian Combo	tactile_paving	yes/no	texture
Pedestrian Combo	width = *	*	line width
Pedestrian Combo	est_width = *	*	line width
Pedestrian Combo	lit = yes/no	yes/no	symbol
Pedestrian Combo	barrier	kerb	line style
Pedestrian Combo	crossing	traffic_signals	point symbol
Pedestrian Combo	traffic_signals:sound	yes/no	point symbol
Pedestrian Combo	traffic_signals:vibration	yes/no	point symbol
Pedestrian Combo	traffic_signals:floor_vibration	yes/no	point symbol
Pedestrian Combo	handraill	yes/no/left/right/center	line
Pedestrian Combo	covered	yes/no	line style
Pedestrian Combo	narrow	yes/no	line width
Pedestrian Combo	landuse	construction	point symbol
Public Transport	public_transport	stop_position	point symbol
Public Transport	public_transport	platform	point symbol
Public Transport	public_transport	station	area
Public Transport	public_transport	stop_area	point symbol
Public Transport	amenity	bus_station	area
Public Transport	amenity	ferry_terminal	area
Public Transport	amenity	taxi	point symbol
Public Transport	highway	bus_guideway	line
Public Transport	railway	funicular	line
Public Transport	railway	light_rail	line
Public Transport	railway	monorail	line
Public Transport	railway	subway	line
Public Transport	railway	tram	line
Public Transport	railway	*	line

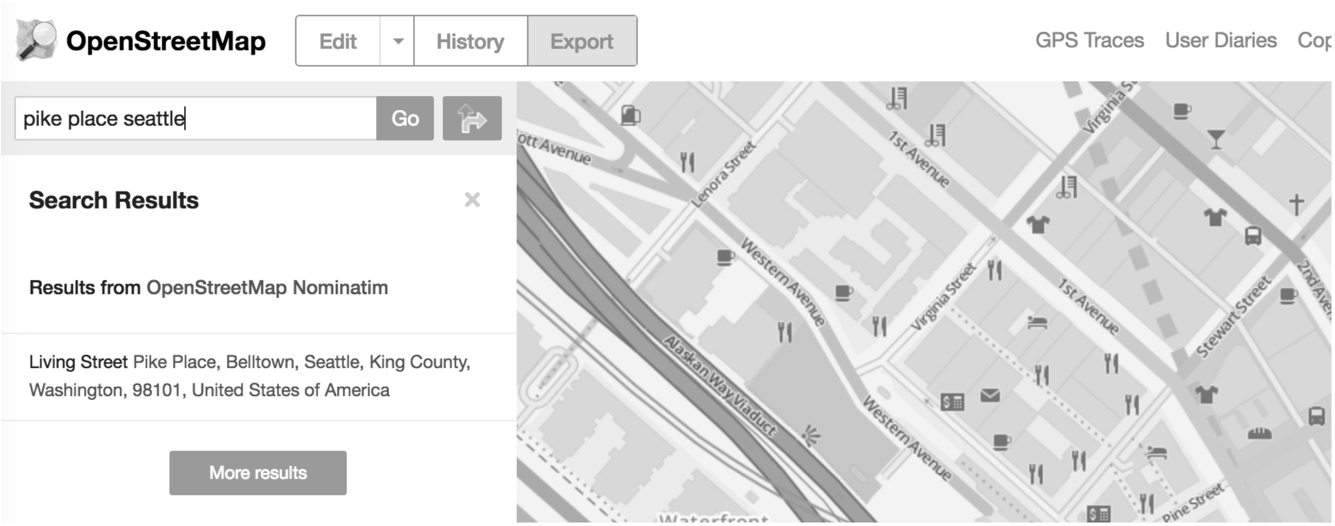
Feature Group	Feature Key	Key Value	Geometry
Public Transport	railway	platform	point symbol
Public Transport	trailway	station	area
Public Transport	railway	subway_entrance	point symbol
Public Transport	railway	trainstop	point
Public Transport	route	bus	line
Public Transport	route	ferry	line
Public Transport	route	fitness_trail	line
Public Transport	route	hiking	line
Public Transport	route	light_rail	line
Public Transport	route	railway	line
Public Transport	route	running	line
Public Transport	route	train	line
Public Transport	route	tram	line
Public Transport	aeroway	terminal	area
Emergency	emergency	assembly_point	point
Street Furniture	amenity	bench	point
Street Furniture	amenity	post_box	point
Street Furniture	highway	street_lamp	point
Street Furniture	emergency	fire_hydrant	point
Street Furniture	amenity	waste_basket	point
Street Furniture	amenity	recycling	point
Barriers	barrier	ditch	line
Barriers	waterway	ditch	line
Barriers	barrier	fence	line
Barriers	barrier	handrail	line
Barriers	barrier	wall	line
Barriers	barrier	block	line
Barriers	barrier	blollard	line
Barriers	barrier	chain	line
Barriers	barrier	rope	line

Feature Group	Feature Key	Key Value	Geometry
Barriers	barrier	entrance	point
Barriers	barrier	gate	point
Barriers	barrier	yes/*	
Water	waterway	river	line
Water	waterway	stream	line
Water	waterway	canal	line
Water	waterway	drain	point
Water	leisure	swimming_pool	area
Water	leisure	swimming_area	area
Water	natural	water	area
Water	natural	bay	area
Water	natural	coastline	line
Destinations	amenity	*	point
Motorways (busy)	highway	motorway	line
Motorways (busy)	highway	motorway_link	line
Motorways (busy)	highway	trunk	line
Motorways (busy)	highway	trunk_link	line
Motorways (busy)	highway	primary	line
Motorways (busy)	highway	primary_link	line
Motorways (busy)	highway	unclassified	line
Motorways (busy)	highway	road	line
Motorways (calm)	highway	secondary	line
Motorways (calm)	highway	secondary_link tertiary	line
Motorways (calm)	highway	teriary_link	line
Motorways (calm)	highway	residential	line
Motorways (calm)	highway	service	line
Cycleways	highway	cycleway	line
Green Space	amenity	grave_yard	area
Green Space	landuse	cemetary	area
Green Space	landuse	forest	area

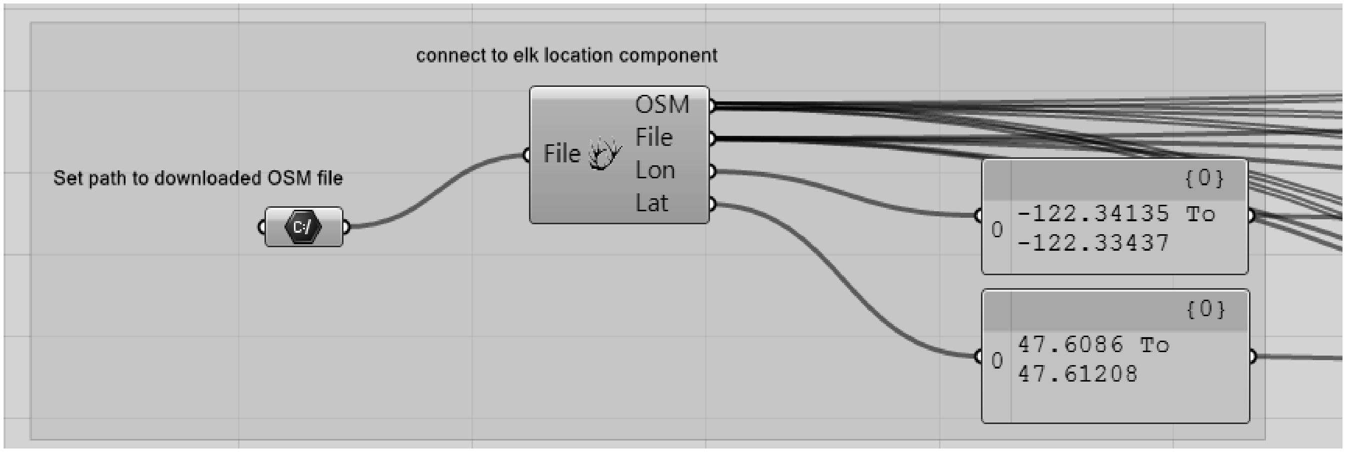
Feature Group	Feature Key	Key Value	Geometry
Green Space	landuse	grass	area
Green Space	landuse	recreation_ground	area
Green Space	leisure	dog_park	area
Green Space	leisure	garden	area
Green Space	leisure	golf_course	area
Green Space	leisure	nature_reserve	area
Green Space	leisure	park	area
Green Space	leisure	pitch	area
Green Space	leisure	playground	area
Green Space	leisure	wildlife_hide	area
Green Space	natural	wood	area
Green Space	natural	tree_row	area
Green Space	natural	tree_row	point
Natural	natural	sand	area
Natural	natural	mud	area
Natural	natural	beach	area
Boundary	boundary	administrative	area
Boundary	place	neighborhood	area or point

Appendix C: Modeling Scripts and Resources

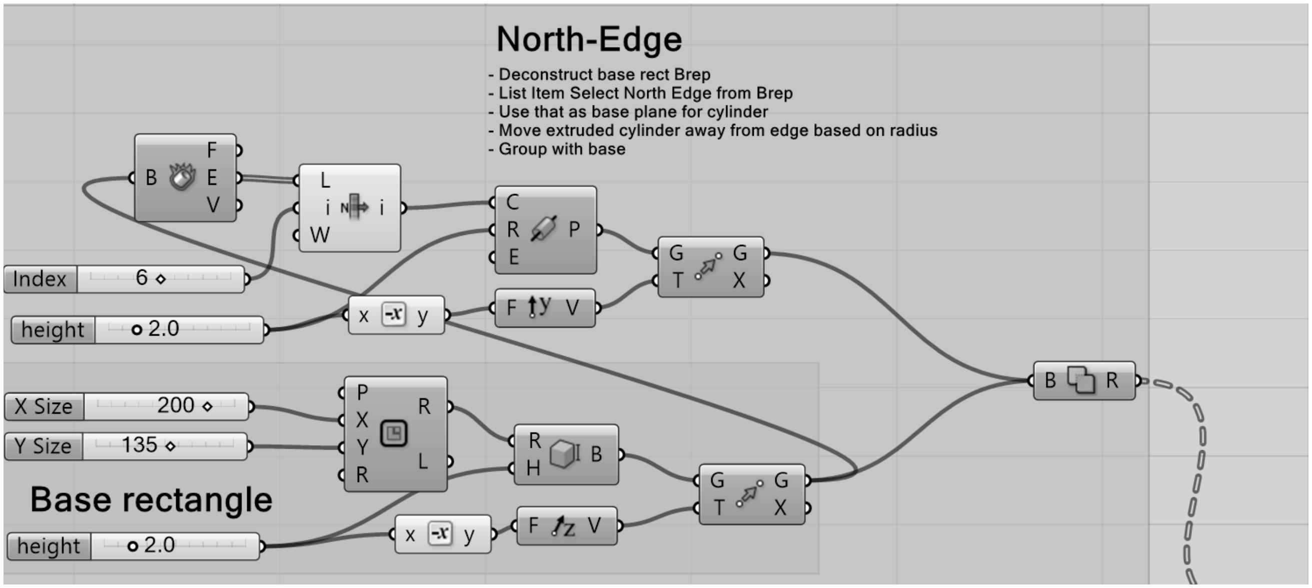
Export OSM Data
http://OpenStreetMap.org



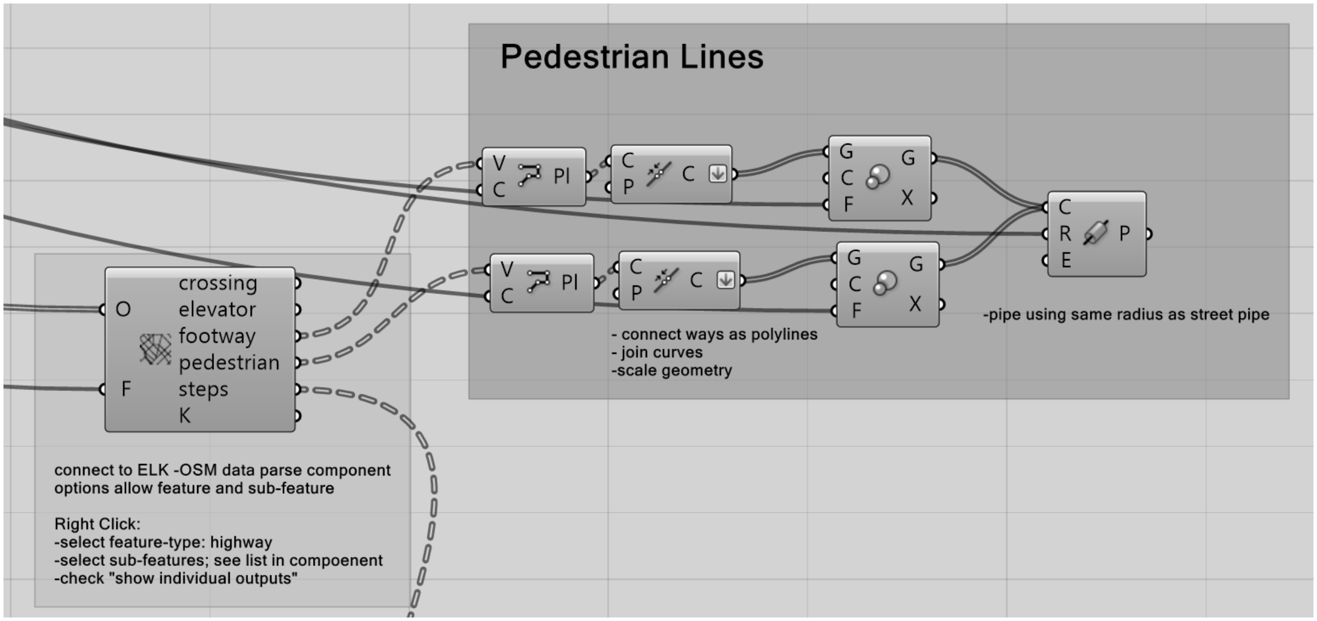
Read OSM File with Elk
http://www.food4rhino.com/app/elk



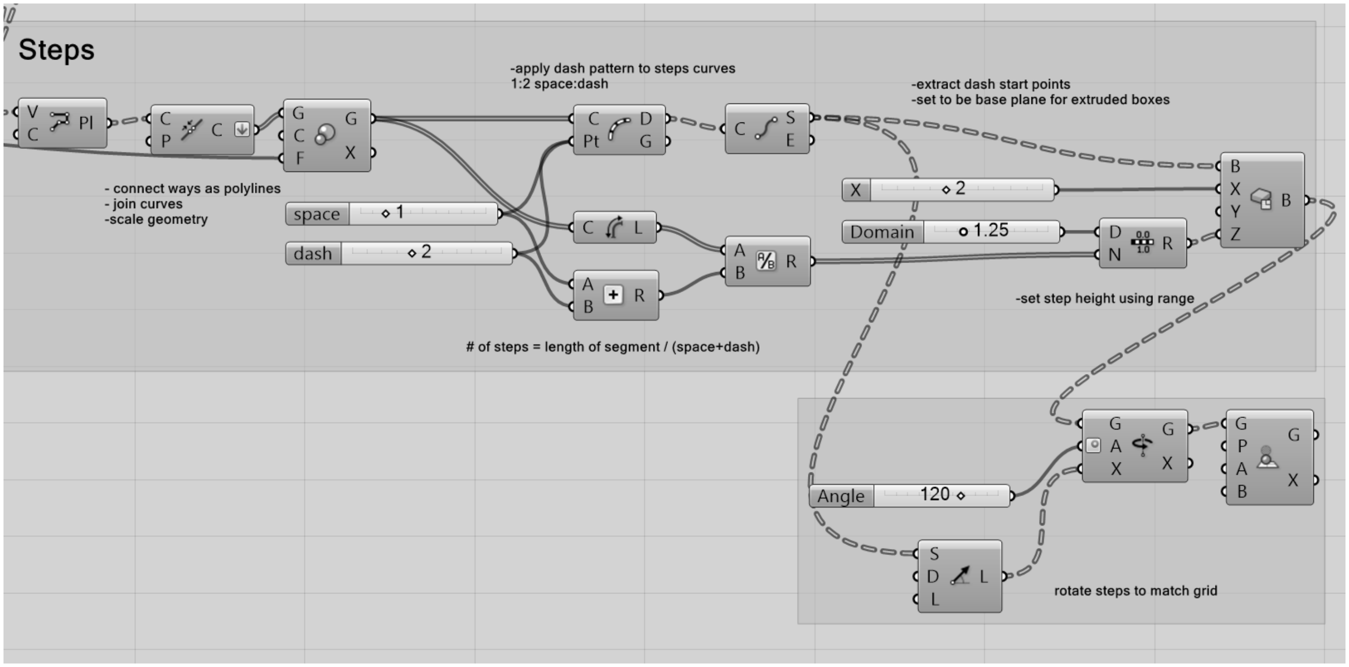
Base Rectangle and North Edge



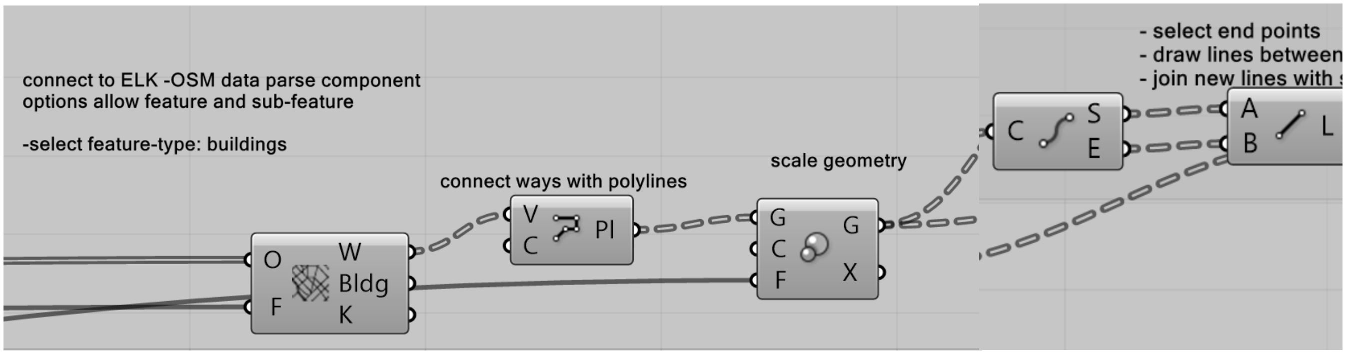
Sidewalks and Pedestrian ways



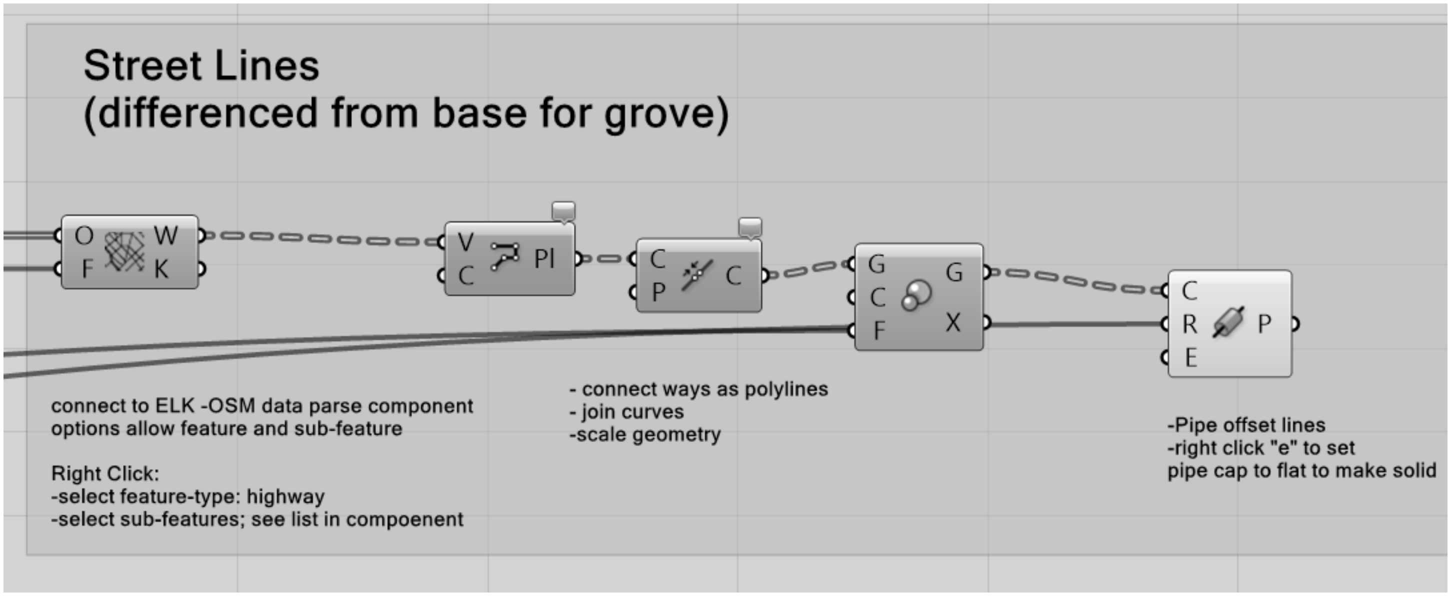
Streets



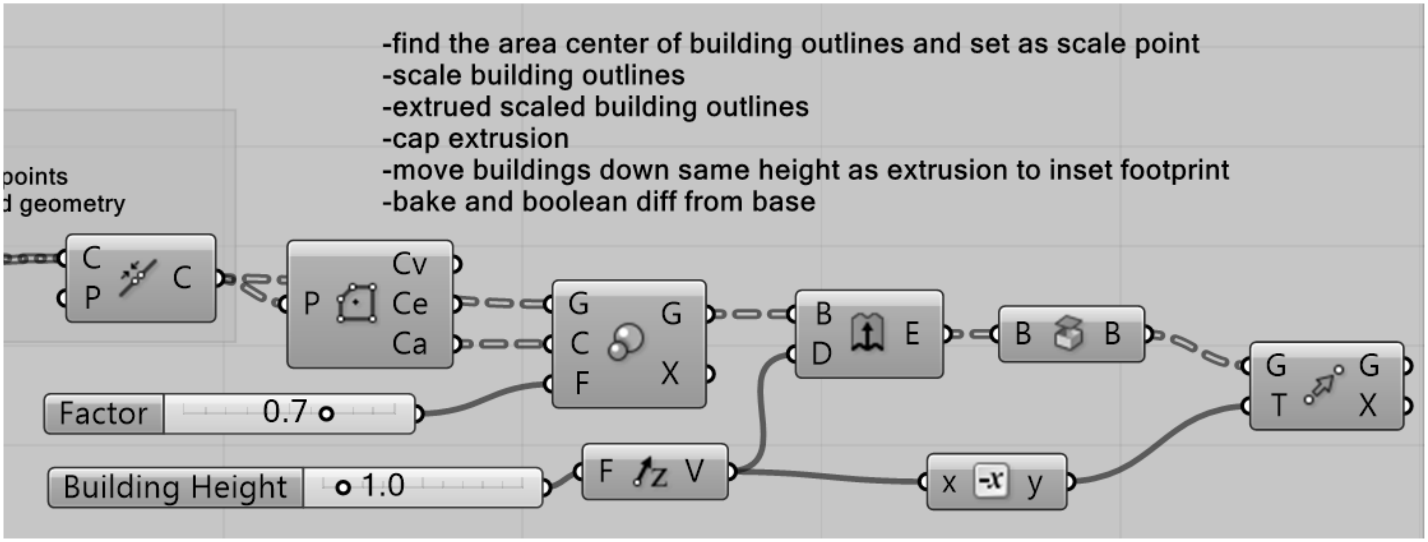
Buildings



Streets

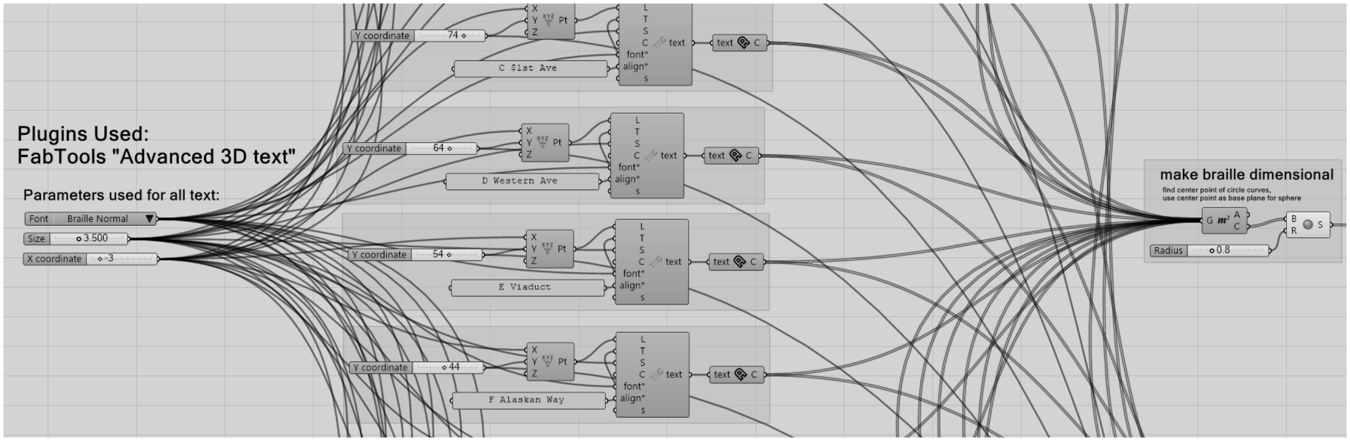


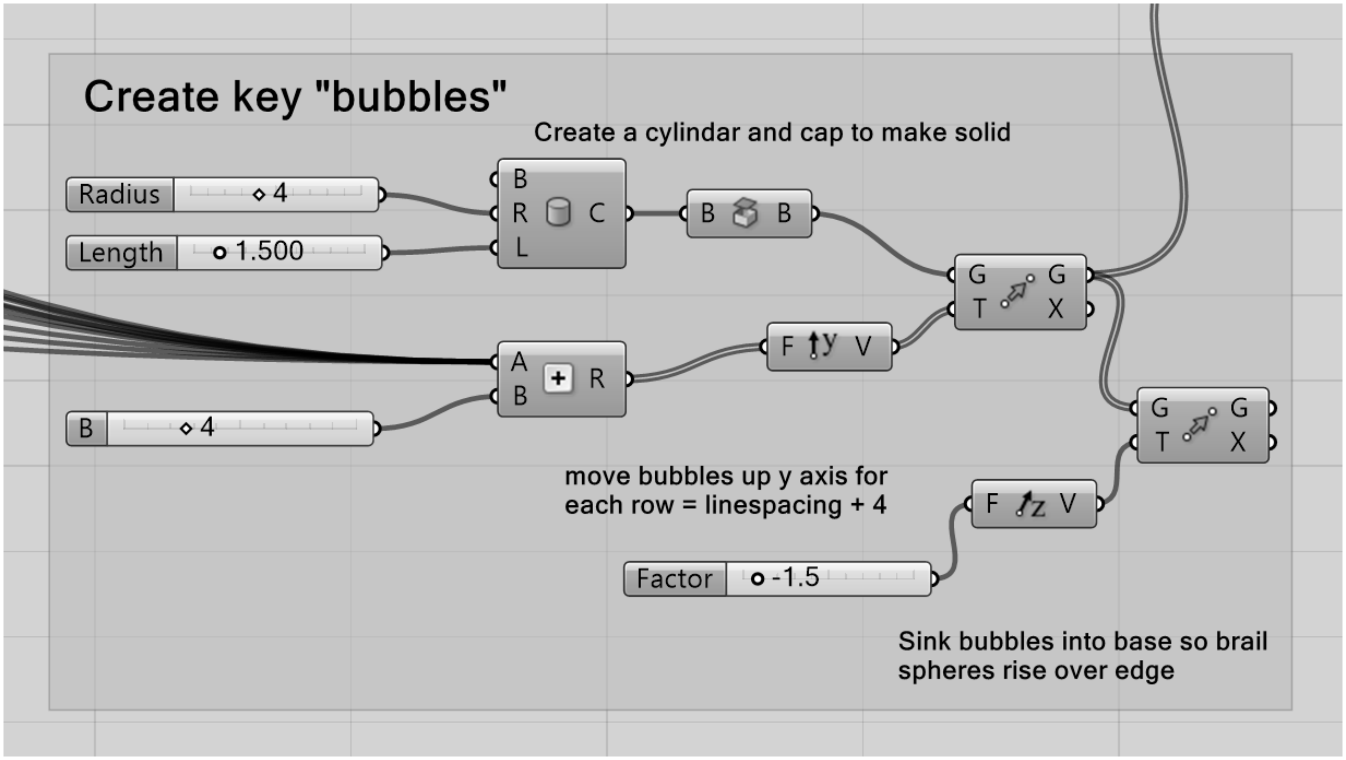
(buildings continued)



Braille Key

Plugins Used: FabTools “Advanced 3D Text





MODELING RESOURCES

Tactile MapTile Scripts
Map; http://bit.ly/2sm0AhZ

Braille Key: http://bit.ly/2sbgtb6

Other Symbols: http://bit.ly/2rdxZGF

Grasshopper / Rhino
http://www.food4rhino.com/app/elk

http://www.grasshopper3d.com/group/elk

http://www.grasshopper3d.com/group/fabtools

https://rhino.github.io/components/fabtools/text3DAdvanced.html

OpenStreetMap
http://www.openstreetmap.org/

https://www.opensidewalks.com/

https://overpass-turbo.eu/

Tactile MapTile
Repo: https://github.com/uwcse481h-2017/touch-mapper

Forked from: https://github.com/skarkkai/touch-mapper

Touch Mapper https://touch-mapper.org/en/

OSM2World: http://osm2world.org/

Blender: https://www.blender.org/

Appendix D: CASE STUDY MAP PARAMETERS

All values in mm
Hills - based on AccessMap (https://www.accessmap.io/), #'s reflect max heights

Map Scale
1/2400

North West
Primary St: unioned, r .9, dash 3
Secondary St: unioned, r .5
Sidewalks w/h: 1.6 / 1
Mixed path h/y/z: 3/.8/1
Crossings: Vibrating
Label height / width: 3 / 4.5r
Hills yellow / orange / red: 1.7 / 2 / 3

South West
Primary St: unioned, r 1.1, dash 3.5
Secondary St: unioned, r 1.1
Sidewalks w/h: 2 / 1.5
Crossings max h : 2
St label h/w: 3 / 4.5r
Transit labels: 2h
Hills yellow / orange / red: 1.7 / 2 / 3

South East
Material: Wood PLA
Streets: none
Crossings shape / max h: slanted / 3
Sidewalks w/h: 1.5 / 1.7
Label h/r: 3 / 4.5
Lighthouse: star

Braille
Radius: .75
Spacing: 3.5

Appendix E: PRINT FILES AND SETTINGS

Print Log: http://bit.ly/2rJd026

Wood PLA Print Settings Wood Settings,fff: http://bit.ly/2sbEw9N

PLA Print Settings: http://bit.ly/2sbJJyJ

File	Resolution	Shells	Infill	Time	Map Base	Raft	Support	Platform	Extrude	Notes
0104-tactilemap-v1.stl	0.2	2	10%	6h 34m	7mm	n	y	40	230	Too thick, more model like than map, buildings too tall, need skinny fingers
0107-swatches.stl	0.2	2	10%	4h 22m	6mm	n	n	40	230	Too thick, one texture failed
0115-elevationtest.stl	0.2	3	10%	5h 4m	3mm	n	n	40	230	Failed - loaded filament backwards
0119-braille-crossing-key.stl	0.2	3	10%	4h 25m	2.5mm	n	n	40	230	Printed well, though braille a little rough
0115-elevationtest.stl	0.2	2	10%	5h 21m	2.5mm	n	n	40	230	Printed well, good map thickness, edges warped
0123-swatchesthin	0.2	2	10%	2h 38m	1.5mm	n	n	40	230	Printed well, flexible base
0123-thin-map-failed.stl	0.2	2	10%	4h 53m	1.5mm	n	n	40	230	Failed - didn't finish printing..I think it warped
0125-pike-map-labels.stl	0.2	3	10%	4h 56m	1mm	n	y	40	230	printed, seems bumpier than white fill, and slit in north edge failed a little
0125-pike-street-key	0.2	3	10%	2h 10m	1mm	n	y	40	230	printed, seems bumpier than white fill, and slit in north edge failed a little
0128-pike-stairs-key.stl	0.2	2	10%	5h 5m	3mm	n	n	40	230	Failed - filament tangled
0128-pike-stairs-key.stl	0.2	2	10%	5h 5m	3mm	n	n	110	230	Failed - double check platform heat!

File	Resolution	Shells	Infill	Time	Map Base	Raft	Support	Platform	Extrude	Notes
0128-pike-stairs-key.stl	0.2	2	10%	5h 5m	3mm	n	n	40	230	Success! - long edges a little curled and melted
0128-pike-stairs-key.stl	0.2	2	10%		3mm	n	n	40	230	Success! - long edges a little curled and melted
0208-pike-inline-white + 0208-pike-inline-black	0.2	2	10%	4h20m	2mm	n	n	40	230	2 color - failed, map warped and knocked extruder out of registration
0208-pike-inline-white + 0208-pike-inline-black	0.2	2	10%	4h20m	2mm	n	n	70	230	
0218-pike-transit-unioned	0.15	2	10%	5h10m	1.75mm	n	n	70	230	
0218-pike-transit-unioned	0.1	2	0	7h10m	1.75mm	n	n	40	220	
0331-joint-samples	0.2	2	10%	3h 29m	1.8mm	n	y	40	230	Support stuck to base, likely because of curing
0331-joint-samples	0.2	2	10%	3h 42m	1.8mm	n	y	70	230	leveled bed for no tape, better print, supports still too hard to remove
0406-lfb-key	0.2	2	10%	3h 41m	1.8mm		y	70	230	leveled bed
0406-lfb-test-corners	0.2	2	10%		1.8mm	n	y	70	230	leveled bed
0412-key-lhfb	0.2	2	10%		1.8mm	n	n	70	230	
0218-pike-transit-unioned	0.2	2	10%		1.8mm					leveled bed, failed
0412-nw-lhfb	0.2	2	10%		1.8mm	n	n	70	230	good, some warping

File	Resolution	Shells	Infill	Time	Map Base	Raft	Support	Platform	Extrude	Notes
0218-pike-transit-unioned	used woodsettings.fff preset file with simplify3D slicer									good, some slag. bed and nozzels should be pre-heated and file ready to go. Wood filament can clog nozzel easily, must be removed as soon as print is over.
041617-key	used woodsettings.fff preset file with simplify3D slicer									
0422-sw	0.2	2	10%	4h 25m	1.8mm	n	n	70	230	
0422-ne	0.2	2	10%	3h 49m	1.8mm	n	n	70	230	FAILED,simplify 3d slicer, makerbot desk froze
0422-nw	0.2	2	10%	3h 33m	1.8mm	n	n	70	230	failed. simplify 3d slicer, makerbot desk froze, slowed first layer to 30% for better adhesion - bed wasnt raised for tapeless print
0424-se-ext				3h 52m						used woodsettings.fff preset file with simplify3D slicer
0424-sw-key-wood				3h 22m						
0424-stkey-wood				3h 24m						
0424-se-star				3h 50m						