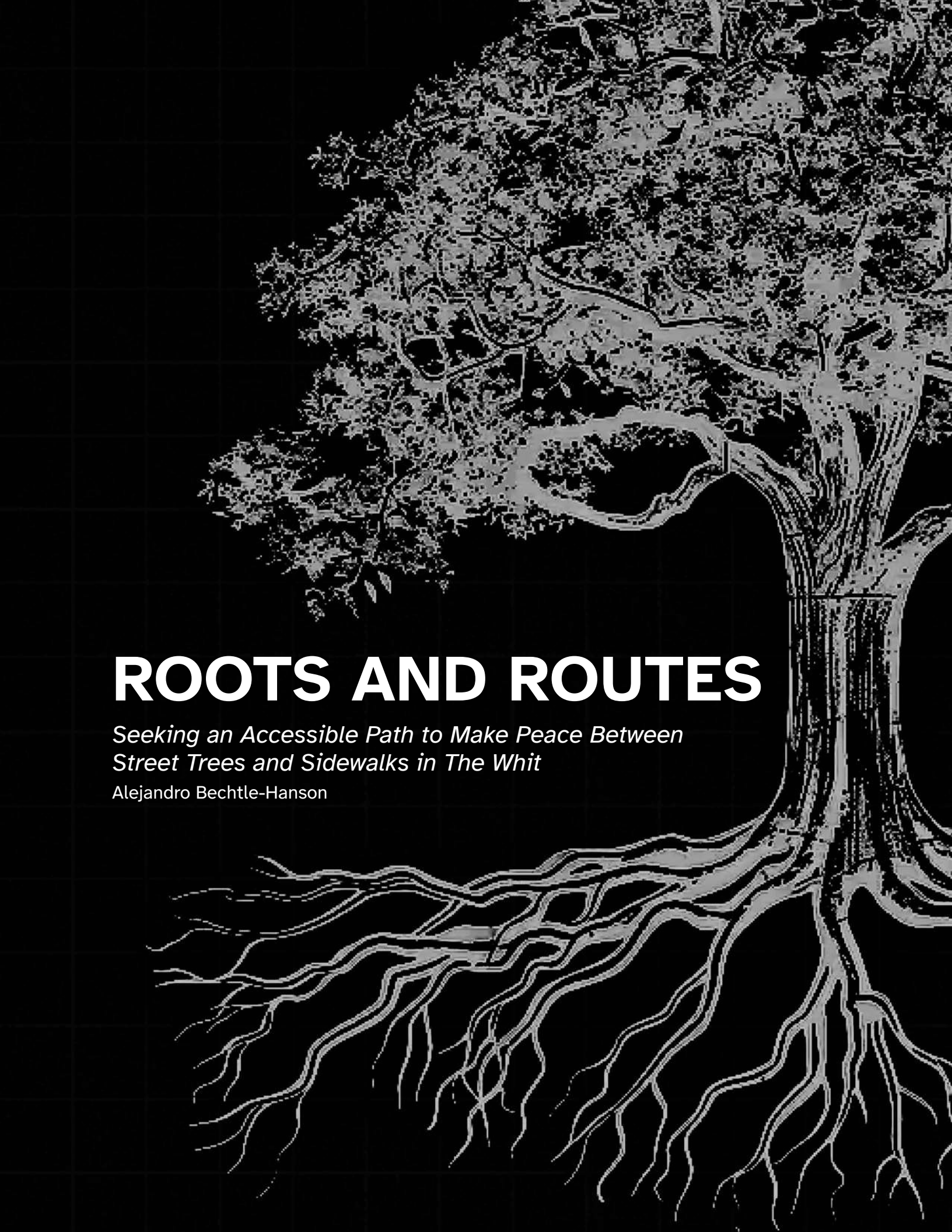


ROOTS AND ROUTES

Seeking an Accessible Path to Make Peace Between Street Trees and Sidewalks in The Whit

Alejandro Bechtle-Hanson

Roots and Routes: Seeking an Accessible Path to Make Peace Between Street Trees and Sidewalks in the Whit

by Alejandro Bechtle-Hanson

An applied research project accepted and approved in partial fulfillment of the requirements for the degree of
Master of Landscape Architecture

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Consulted Groups and Organizations
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City of Eugene Urban Forestry
City of Eugene Public Works Engineering
CURBS (Community United to Repair our Broken Sidewalks)
Friends of Trees
Oregon Department of Forestry
Wednesday Wheelers

University of Oregon
Department of Landscape Architecture
Spring 2026



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ABSTRACT

Using **Whiteaker**, Eugene's oldest neighborhood, as a local example of the global conflict between street trees and sidewalks, this work ties multi-disciplinary research to design through an intensive street tree study that presents several new findings about the **relationship between tree morphology and sidewalk accessibility**. The standard poured-on-grade concrete sidewalk system puts root growth in direct conflict with accessibility and repairs typically require root pruning or removal, which threatens the mature street trees that uphold our cities' livability in the face of climate change. Of the 146 street trees over 25" in diameter in Whiteaker evaluated in this study, nearly 90% appear to be breaking sidewalks, but removing these trees would likely damage the neighborhood's historic character, **the local microclimate**, and the community's sense of place. The most dominant species, **Bigleaf Maples**, are especially at risk. We also urgently need to repair our broken sidewalks because they are a **civil rights issue that endangers pedestrians with disabilities**. In search of a tree-preserving solution to root heave, this project proposes a **system of design experimentation** using arborist-informed precedents and original scientific evidence.

DEDICATION

For the Paddle Tree.





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PREFACE

The work reflected in this document is just one part of a broader story that redefined my career trajectory. The animus that drove this project and continues to push me forward is a **deep need to find an answer** to a real, palpable problem that has plagued me my entire life: sidewalk root heave, or roots lifting sidewalks. This design problem may seem pedestrian to some, but it's an important issue that's close to my heart. I am an architect with dual passions for ecological and accessible design that are rooted in my personal lived experience. I braided these parts of myself together to approach root heave in a unique way.

My interest in this issue is rooted in my upbringing by a single mother with disabilities in the Ojibwe community in Minnesota. I spent much of my childhood walking alongside my mother in her wheelchair or walker, navigating over broken sidewalks, or keeping an eye out as she wheeled through the street. The **pattern of raised sidewalks beneath large trees** is ingrained deep in my memory and I know it seriously harms people with disabilities, including me at times, but I have never resented or blamed trees. Instead, I have wondered about **their perspective** because of what I learned from my elders.

During important times of year, like the annual Sundance in Pipestone, MN, sweat lodges, and community gatherings, I had the honor of listening to my Ojibwe and Lakota elders, who passed on their knowledge and view of the world. They gifted me with an understanding that we, as people, have a responsibility for how we impact the world and other beings around us, including plant communities. They told me of generation after generation failing to listen to other species and suffering for it. Thanks to them, I believe everything has a way of speaking and that other beings' way of existence is something to work with, not against. If we can't hear it, then we need to **find the right way to listen**. I reconnected with this part of my personal paradigm through this work,

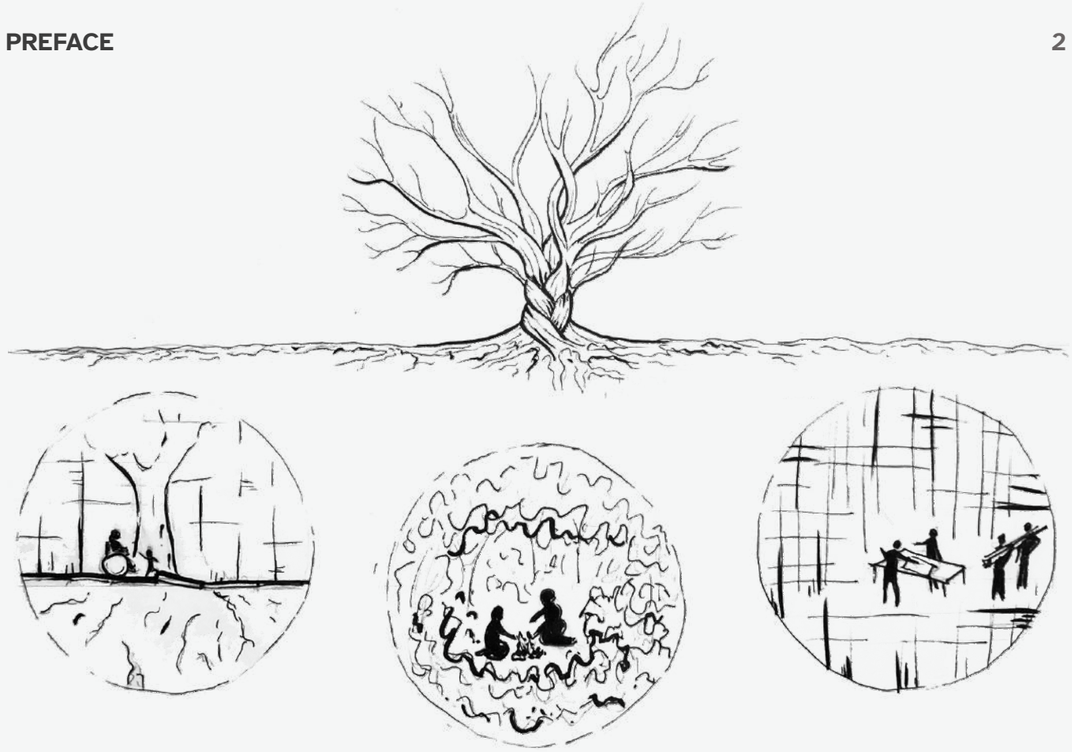


Figure P.1
My Background
Illustrative portrayal of the lived experiences that informed my personal approach to this work.

alongside an important part of **my personal story**.

My first introduction to Whiteaker was during the winter of 2015, when I was a homeless teenager new to Oregon with nowhere to go, who passed the time wandering. I walked for hours, sometimes entire days around the streets of Eugene and found particular comfort in the incredible urban canopy Whiteaker is known for. Although that was a difficult time in my life, that is when I became attached to this place.

These trees are a part of my story; they have watched over me through the years and I will always remember fondly. I've revisited them as a Bachelor of Architecture student, a designer developing a career in disability-inclusive design, a licensed architect, and now as a scholar learning how to design for them.

As an intentional pedestrian, who has been living without a car for as long as possible, sidewalks lifted by tree roots is something I cannot ignore. Stumbling over pavement every day as I walked to and from my old office as an architect is

what led me to go back to school so I could pursue a Master of Landscape Architecture. After being inspired by the landscape architects I worked with in the field, I knew **this is the discipline I had to join in order to better understand trees** and have a chance at finding a solution to root heave.

Over the last two years, the MLA curriculum has enriched my world perspective and deepened my understanding of root heave. I am still enchanted by the incredible beauty of the canopy in Whiteaker, which I now know is characterized by Bigleaf Maples draped in licorice ferns, lichens, and moss. I also now understand that the broken sidewalks beneath these beautiful trees may not be fixable without removing many of them. The reality of the circumstances frankly scares me, but **I am committed to finding an answer** for the benefit of the local urban forest I fell in love with ten years ago, every tree at risk of removal for lifting the sidewalk, and the people who are being harmed by broken pavement.

I have walked across the sidewalks I studied for this project hundreds of times, but I saw them in a different light this past year. On many occasions Whiteaker's residents fearfully asked me if I was there to survey trees for removal and plead that they didn't want to fix the sidewalk out of the concern repairs would harm the trees, which helped me recognize that this community sees the same problems I do. Others told me they recently fixed their sidewalks, which are already lifting, and that they're considering removing the long-beloved trees shading their homes, showing me **people are tired of paying for sidewalk repairs that don't last**. The work compiled in this document is a summary of the answers I've found so far, but my search for a solution to root heave is ongoing and may continue for the rest of my career.



Figure P.2
Animus
Illustration of myself admiring a Bigleaf Maple I revisited in January, which faced potential removal due to its conflict with the sidewalk.

ACKNOWLEDGMENTS

Spearheading this work would not have been possible without the incredibly supportive, wide network of people who helped me turn burning questions into real, meaningful research. First, I would like to thank faculty at the University of Oregon, starting with Dr. Gwynne Mhuireach, my research methods instructor, who encouraged me to consider root-sidewalk conflict from all angles while maintaining an approachable research scope. Dr. Robert Ribe, a professor emeritus with decades of experience in public engagement, advised me to spread my connections out and beyond the university to find people with field knowledge about sidewalk root heave who are interested in my work, and my winter Master Clinic instructor, Ignacio Lopez Buson, offered his technology and time to help me digitally model the most circumstantially significant tree identified in this project to realistically apply and visualize my design proposal. I'd also like to thank Mark Eischeid, a professor who teaches studios and the history of Landscape Architecture, who brought me to a very important precedent design, reaffirmed my historic revival design approach, and provided suggestions for locating early photos of Eugene.

And a **special thanks to my advisor, Dr. Elizabeth "Ellee" Stapleton**, who provided ongoing encouragement, advice, support, and proofreading to help me collect my work into a legible deliverable. I would also like to thank my colleagues in the landscape architecture department, especially my MLA cohort, who have continuously uplifted me and shared photos of broken sidewalks across the country.

I am also sincerely grateful to the staff at the City of Eugene, starting with Marina Wrensch, the landscape architect who supervised me through my summer 2025 internship, helped me gather much needed insight, and connected me with colleagues interested in my work. This includes Jody Trendler, the COE Senior Transportation Planner, who invited me to a meeting of city staff invested in improving sidewalk conditions and connected me with Community United to Repair our Broken Sidewalks (CURBS). They showed me the incredibly detrimental impact broken sidewalk networks have on urban communities, especially people with disabilities. And I am especially grateful to Heidi Lakics, who opened my eyes to an entirely different side of sidewalk root heave, showed me how to "read" a tree, allowed me to participate in root pruning to support a new curb ramp installation, and shared an incredible amount of advice that was integral to my work. I would also like to thank Scott Altenhoff, a master arborist at the Oregon Department of Forestry, for the time, resources, precedents, and connections he offered me, along with his decades of wisdom.

My work led me to connections I never anticipated, ranging from Erik Burke, a master arborist at Friends of Trees who helped me consider sidewalk designs that prioritize trees' needs, to Tim Lewis and Lee Feldman-Redick, members of the Whiteaker community who truly understand the value of trees, and Kari Johnson, who shared her personal history of



Figure A.1
Planting a Sapling
Illustration of people helping a Bigleaf Maple sapling establish while preparing to plant new trees. This is a metaphor for the wide network of people who supported this project, which spread far and wide like the roots of a Bigleaf Maple.

leadership in Whiteaker's tree activism that goes back years before I was born. Thanks to Tim, I was able to connect with the Whiteaker community, including Lester, a local artist who painted the tree central to this project whose work now occupies the center stage in my living room.

I am grateful to the people who inspired my work, starting with my mother, who showed me the impact of broken sidewalks at a young age as I walked alongside her wheelchair. And my neighbor, Steve VanDevender, who I've seen rolling through the streets for the last decade. I would also like to thank my Ojibwe elders for their years of wisdom teaching me to listen to plants to recognize the relationship we have with them and the stewardship responsibility we have for the ecosystems we affect.

I also greatly appreciate the local chapter of the American Council of the Blind and the Wednesday Wheelers, who offered me significant amounts of time in their meeting agendas and allowed me to present my work, expressed an incredible amount of support, and offered to test my sidewalk prototypes for accessible functionality.

I also need to thank my research subjects, design clients, and longterm friends: the old trees of Whiteaker. After learning more about their history, the services they are providing, and the suffering they have endured, I feel indebted to their sacrifice. They have watched over me for ten years, providing protection in their canopy and beauty in their presence; **this project was my way of giving back to them**.

Most of all, I would like to thank my wife, Lilika Bechtle-Hanson, who has walked beside me for hundreds of hours over the years, talking with me about sidewalk root heave, and ultimately encouraging me to go back to school to research this problem. Without her support I would have never had the opportunity to do this work, and she has been there for me every step of the way.

There are too many other people who I would like to thank. So, to everyone who I ever spoke with about my research, the people who taught me every piece of relevant information that supported this work, and everyone who helped me get through it, **thank you**.



INTRODUCTION

This project centers around root heave, an issue that pervades any city with concrete sidewalks and street trees, using the Whiteaker neighborhood in **Eugene, Oregon** as a pertinent example. This introduction provides an overview of what root heave is, why **Whiteaker** is the area of study, and why the **Bigleaf Maple, The Paddle Tree**, is this work's target species.



Figure I.1
The Problem with Root Heave
Photos of sidewalk root heave taken around Eugene with annotations describing the ways root heave makes sidewalks inaccessible.

THE CORE ISSUE - ROOT HEAVE

Sidewalk root heave, which is when **tree roots lift sidewalks**, creates public hazards and obstructs pedestrians with disabilities. This is because the pavement's surface is often lifted by the roots in excess of code-required slopes, cross slopes, and level changes (see figure I.1). The stable, level surface required for people to safely navigate over sidewalks has strict tolerances that do not leave room for much root growth (see figure I.2). In other words, **roots lift sidewalks because sidewalks were constructed in a way that only remains accessible if roots do not grow beneath them**.

Root heave is a civil rights concern because it seems to dramatically worsen the rate and severity of sidewalk failure, which is a public safety hazard. This is particularly a problem for people who cannot see buckled sidewalks and thus risk personal injury walking over broken sidewalk networks alone.

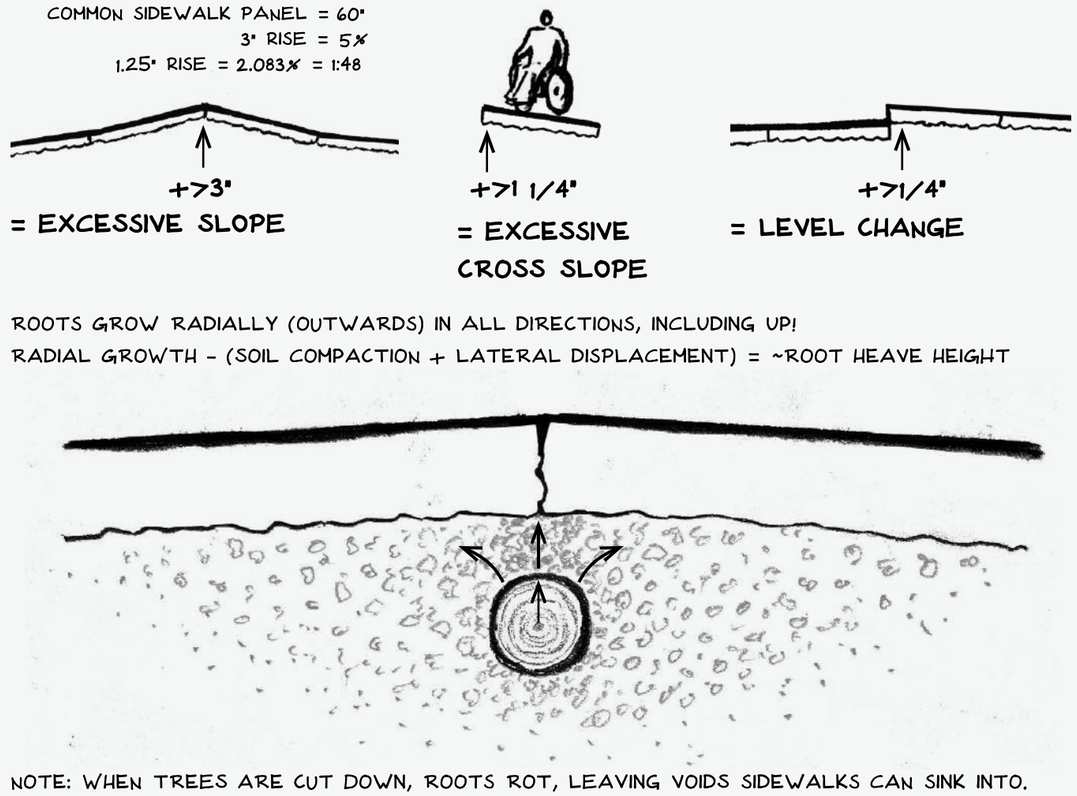


Figure I.2
The Root Cause
Diagram illustrating the underlying physics of root heave and the actual margin of error for sidewalk accessibility. Numbers shown were calculated with an assumed sidewalk width of 60" and the current accessibility code requirements per the 2017 version of A117.1 (iccsafe.org).

Additionally, root heave is a climate resilience and microclimate stability problem because resolving it often threatens the health and lives of street trees. Urban streets already heavily restrict root space, and sidewalks are constructed where trees would naturally grow roots to support themselves. When their roots grow in an undesirable location, such as beneath the sidewalk, cutting them may be the only available solution. If the roots are too large then cutting them risks the structural stability of the tree, requiring that the entire tree be removed for public safety (eugene-or.gov). And even when root pruning is possible, it may still harm the tree depending on the species, amount of roots cut, and a number of other factors.

Harming and removing individual trees not only reduces the shade, stormwater management, and other ecological benefits on a particular block, it has the potential to

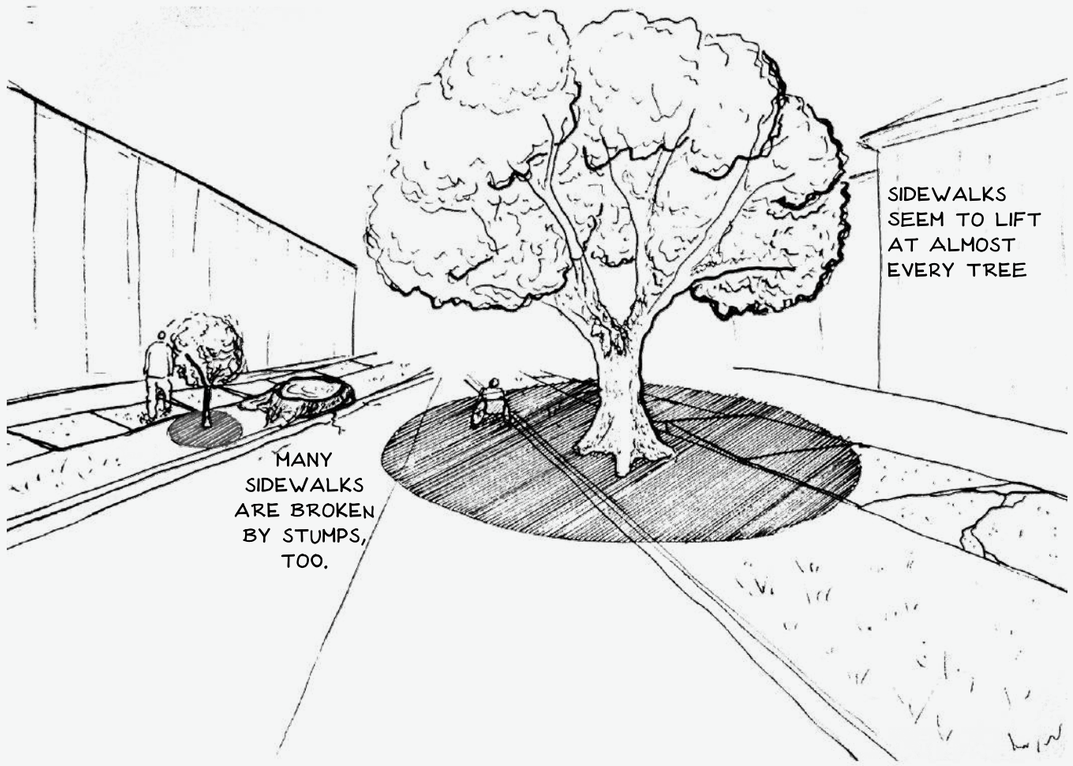


Figure I.3
The Root Heave We See
Illustration of an urban street with a mature tree, a sapling, and a stump alongside broken sidewalks that are nonfunctional for many people with disabilities.

weaken the entire urban forest in aggregate. Widespread tree removal also results in sidewalk networks becoming holistically less habitable.

CITY INTRODUCTION

Eugene is a growing college town in the **Willamette Valley** where root heave is a particularly relevant problem for both people and trees. It's known for its public green space, politically active community, and support of the arts (McQuiddy, 2023). The city is located south of Salem, Oregon's capitol city, and east of Bend (see figure I.4).

There is active ongoing work to repair Eugene's broken sidewalks both within the city and through public advocacy work led by CURBS (**Community United to Repair our**



Figure I.4
Location of Eugene, OR
Map illustrating Eugene's location within Oregon created with ArcGIS.

Broken Sidewalks), a walking working group supported by BEST (Better Eugene-Springfield Transportation) (best-oregon.org). Articles like "Eugene sidewalk neglect poses safety risks, property owners responsible" and "Watch your step: Should Eugene change the way sidewalks are built and repaired?" show that the community notices and plans to change the local broken sidewalk problem (Ryan, 2024; Richards, 2025). A Community Voices entry in LookOut Eugene-Springfield titled "Eugene's sidewalks are finally getting attention. Let's make it last." indicates that the community is making positive progress toward repairing the city's sidewalks, and the author of that article – a central member of CURBS – cites tree roots buckling sidewalks as a visible problem, pointing out a noticeable pattern this project's original research confirms (Craig, 2026). Tree roots

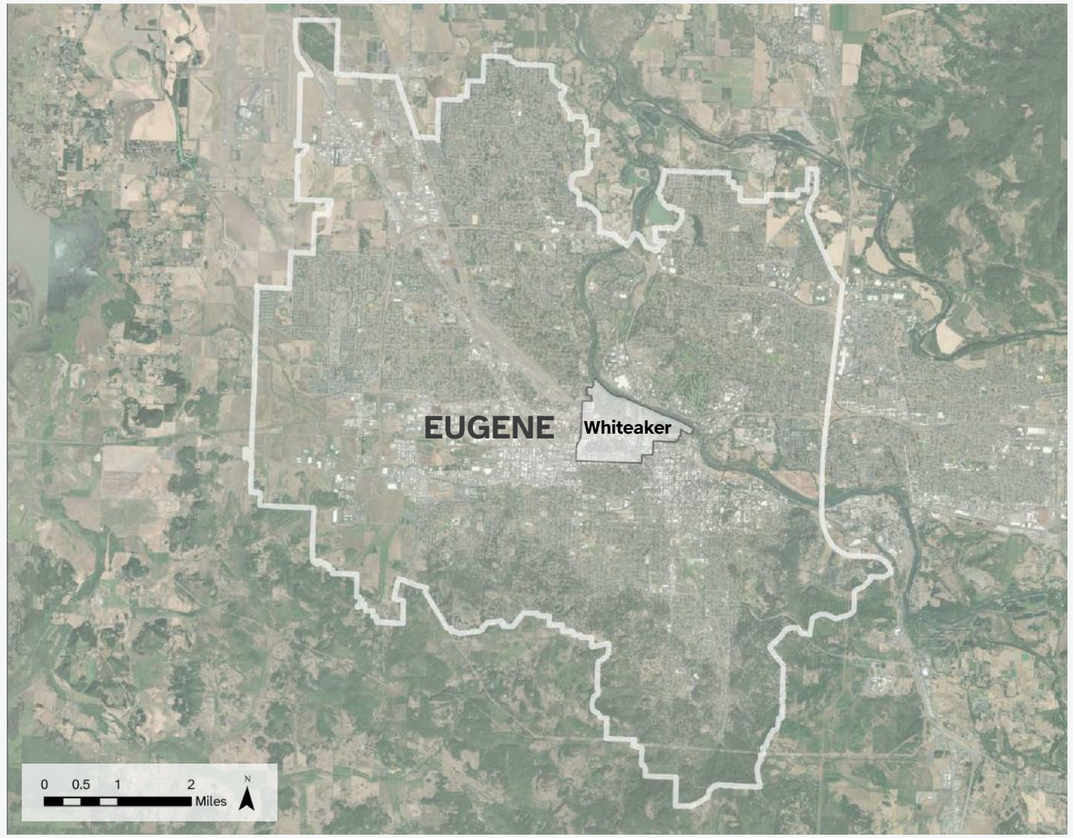


Figure I.5
Location of Eugene's First Neighborhood
Map illustrating Whiteaker's location within Eugene's urban growth boundary created with ArcGIS.

substantially contribute to broken sidewalks, particularly where roots have grown to large diameters beneath the pavement.

Locations where root heave has been ongoing for a long period of time, where roots have expanded without pruning, are likely to warrant priority for repairs, but they may also be the **riskiest tree-sidewalk conflicts** where roots may be too large to cut. Communities with large trees and a significant attachment to those trees may be concerned about widespread sidewalk repairs if they are aware of the risk that can pose to trees.

NEIGHBORHOOD INTRODUCTION

Whiteaker is Eugene's first neighborhood, situated at the heart of the city (see figure I.5), and is a place where tree removal is a serious concern. Originally named after John Whiteaker, Oregon's first governor, and first known as the place Eugene Skinner settled, "The Whit" is now known for its eco-anarchical tree-sitting activists (City of Eugene, 1994, p. 11; Finnell, 2012). Tree-sitting protests for the trees that were removed to construct a parking garage in 1997 (see figure I.6) are representative of a long local **history of the**



Figure I.6
Bigleaf Maple Removed in Whiteaker in 1997
Photo of one of the Bigleaf Maples cut down in the Whiteaker neighborhood in Eugene in 1997. The photo, which was taken by Kurt Jensen, shows a tree sitter with a protest banner attempting to defend the tree with their life. The banner hung by the protester reads "Parking Garage My ASS!" in reference to 40 trees being removed for the construction of a parking garage. (Abraham, 2006)

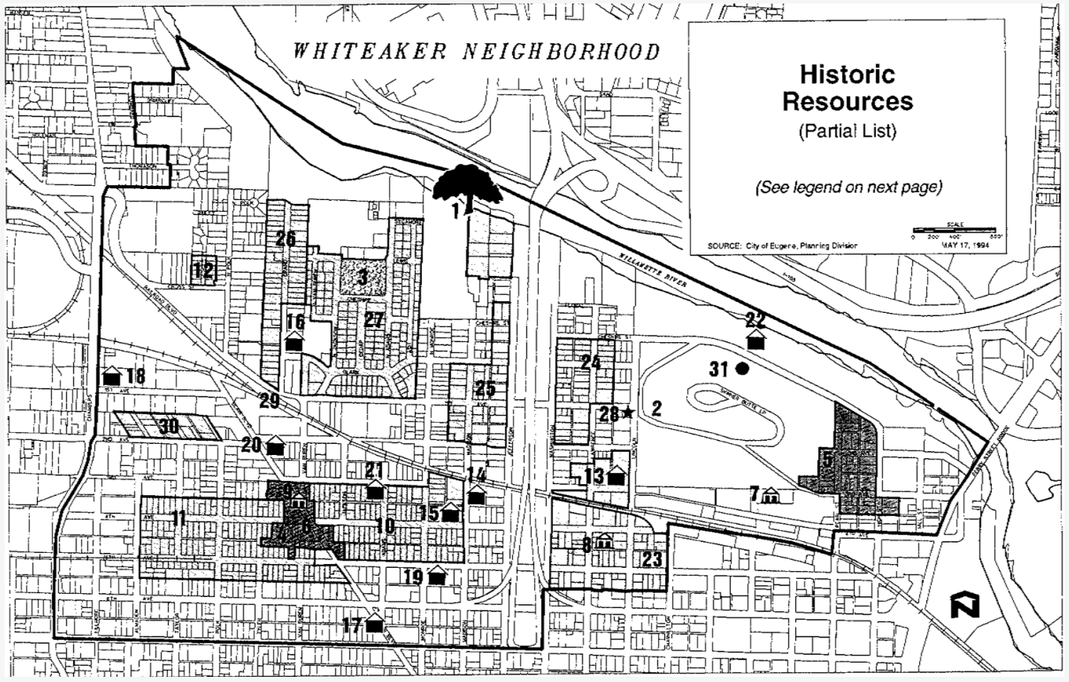
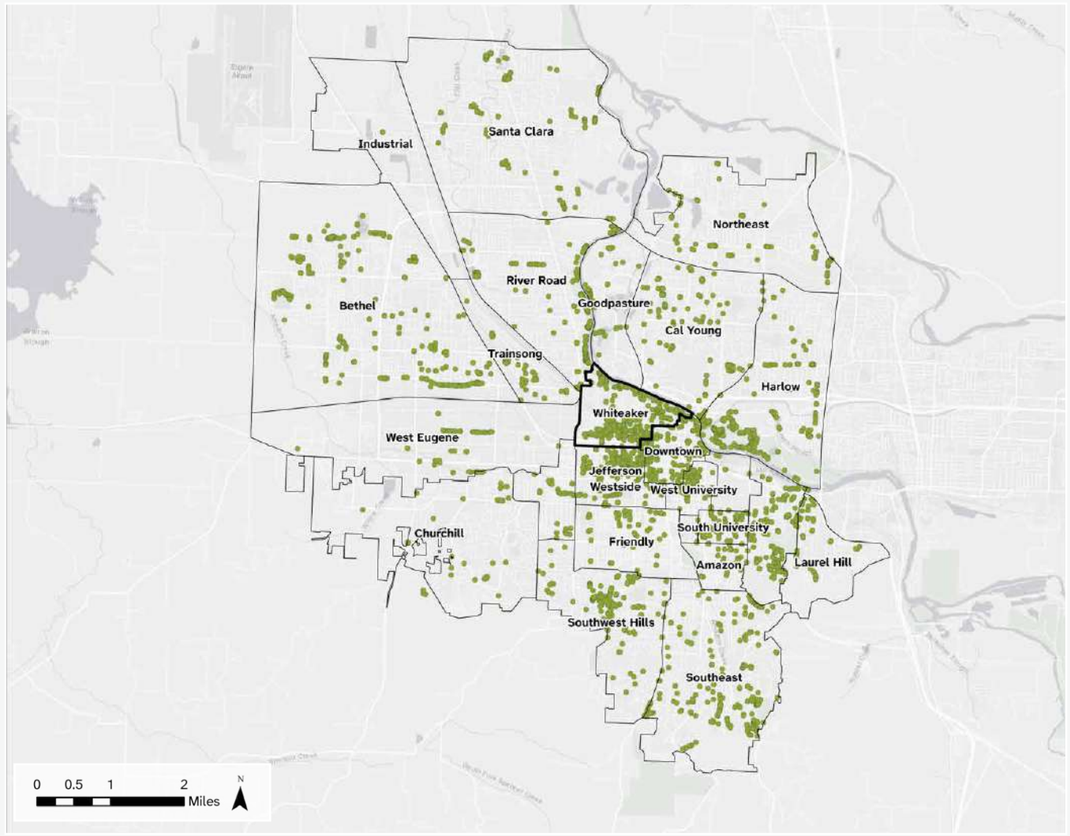


Figure I.7
Whiteaker's Historic Resources
Image of Whiteaker's historic resources taken from the plan for the neighborhood's future published in 1994.
(City of Eugene, 1994, p. 18)

community fighting against tree removal (Abraham, 2006). This has also been documented through videos, including films like *If a Tree Falls: A Story of the Earth Liberation Front*, an Academy-award nominated documentary published in 2011 by Tim Lewis, a longtime Whiteaker resident (library.uoregon.edu).

Preserving the local mature trees, particularly those of **historic species**, is also a formally noted community goal for preserving the neighborhood's historic character (City of Eugene, 1994, pp. 20-21). This is especially important in the neighborhood's two historic districts, East Skinner Butte Historic District and Blair Boulevard Commercial Area. These areas, shaded in deep gray in figure I.7, are two of many historic resources in the Whit and preserving the trees around these features is an ongoing part of historic preservation in this area.



BIGLEAF MAPLE - THE PADDLE TREE

Perhaps the most historic street tree species in Eugene is *Acer macrophyllum*, the Bigleaf Maple. From current city staff statements about the history of the local urban forest, "legend has it" that Bigleaf Maples were brought from the Willamette River as saplings and **transplanted into the public right of way** in the early 1900's (Parks & Open Space, City of Eugene Government, 2023), which is why historic areas of Eugene, like Whiteaker and Jefferson-Westside, have a heavy concentration of these trees (see figure I.8). More research is warranted to understand the history of these specific trees, including testing to confirm if they are direct relatives of the elder Bigleaf Maples growing along the Willamette River today. These trees' stories are an important

Figure I.8
Bigleaf Maple - Historic and Ecologically Significant Trees in Eugene's Urban Forest
Map made with ArcGIS reflecting the distribution of Bigleaf Maples in Eugene, showing elevated density in the Whiteaker and Jefferson Westside neighborhoods, which are historic areas of the city.

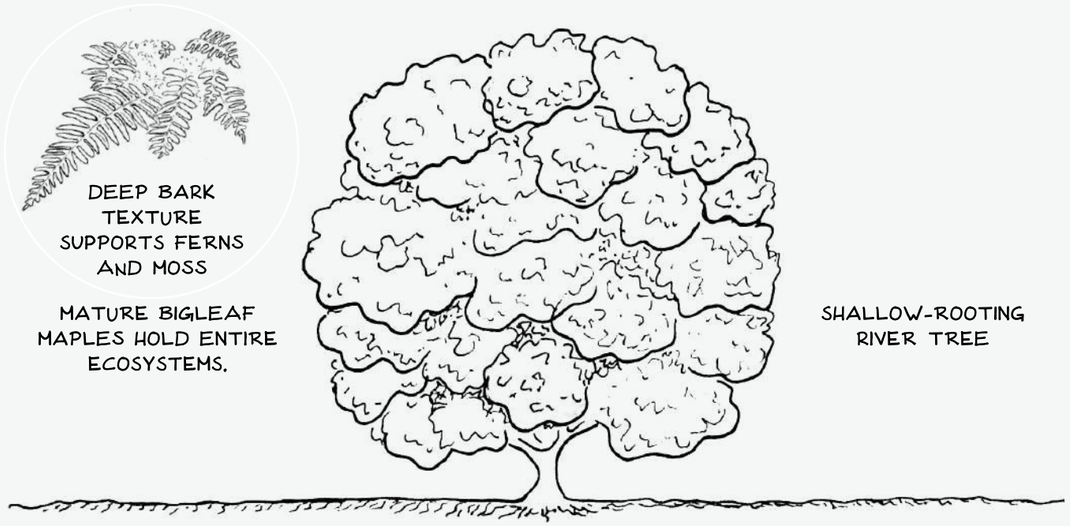


Figure I.9
Bigleaf Maple
Illustration of a Bigleaf Maple tree in profile view, showing the proportional relationship between the crown and root span.

Shallow root systems occupy the top 18” of soil and have an estimated spread that is up to three times with diameter of the tree’s canopy (Pankau, 2024).

part of Eugene’s local history, but their specific, individual origins also seem significant from an indigenous cultural stewardship perspective.

Eugene was constructed on the ancestral homelands of the Kalapuya peoples, who stewarded this land for millennia prior to American colonialism and are gaining increasing recognition and acknowledgment from those trying to improve the city and offer reparations (McQuiddy, 2023).

The Bigleaf Maple, also known as the **Paddle Tree**, is a sacred tree that’s called “Uskan-stik” in Chinuk Wawa, “huulik’” in hanis and miluk (Coos languages) and “sna” in wa’as (a language spoken by the Siuslaw and Lower Umpqua peoples) (oregonstate.edu; P. Phillips, personal communication, March 23 2026). These trees produce many useful materials that are an important part of indigenous cultural traditions that supported local first peoples’ precolonial way of life, ranging from tools and woven goods to medicine and seasonal food. Their most notable use was paddles, because their wood is particularly well-suited for pushing water (oregonstate.edu).

Additionally, according to The Bigleaf Maple Project run by Oregon State University, Bigleaf Maples hold a “greater load

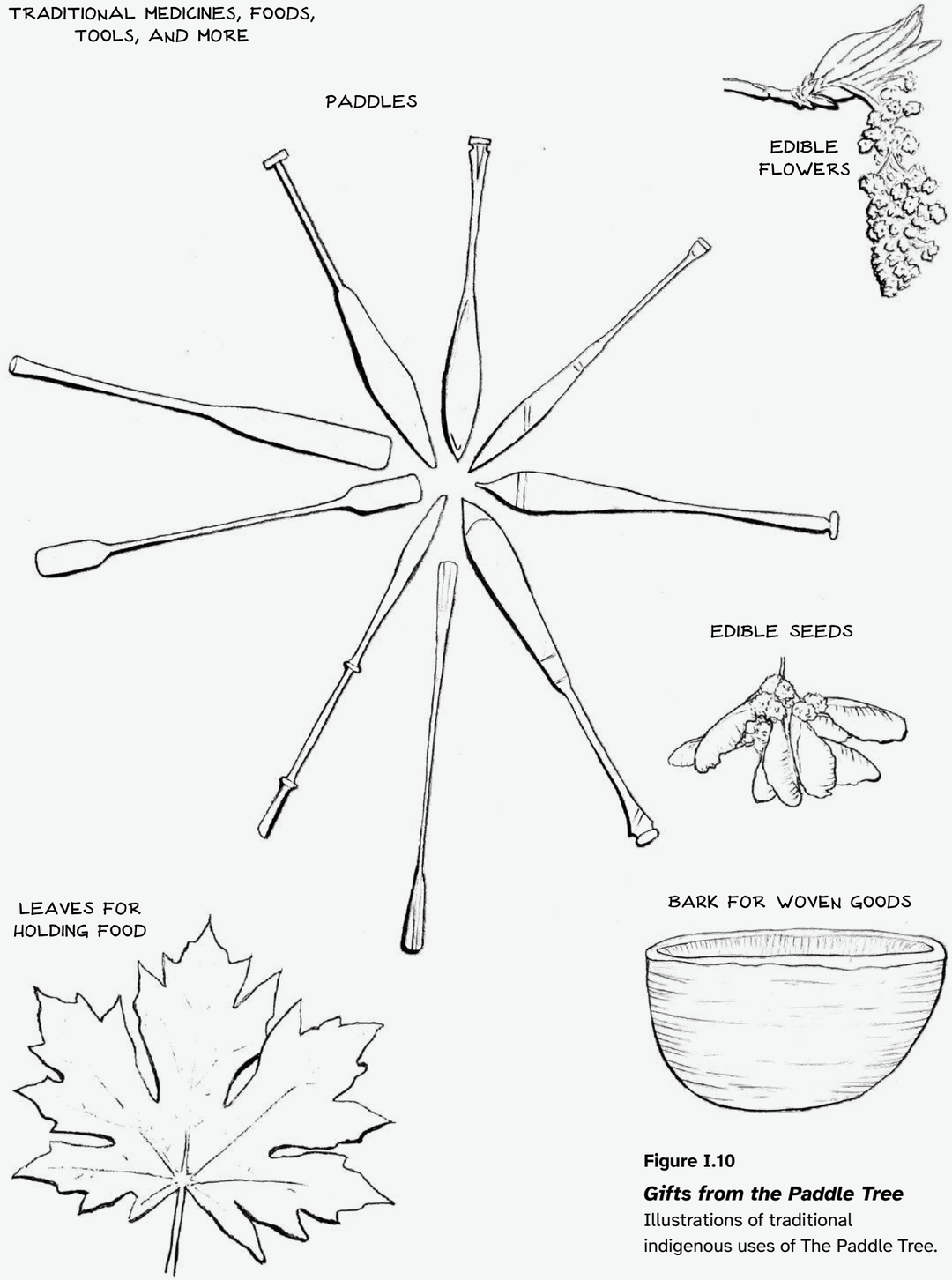


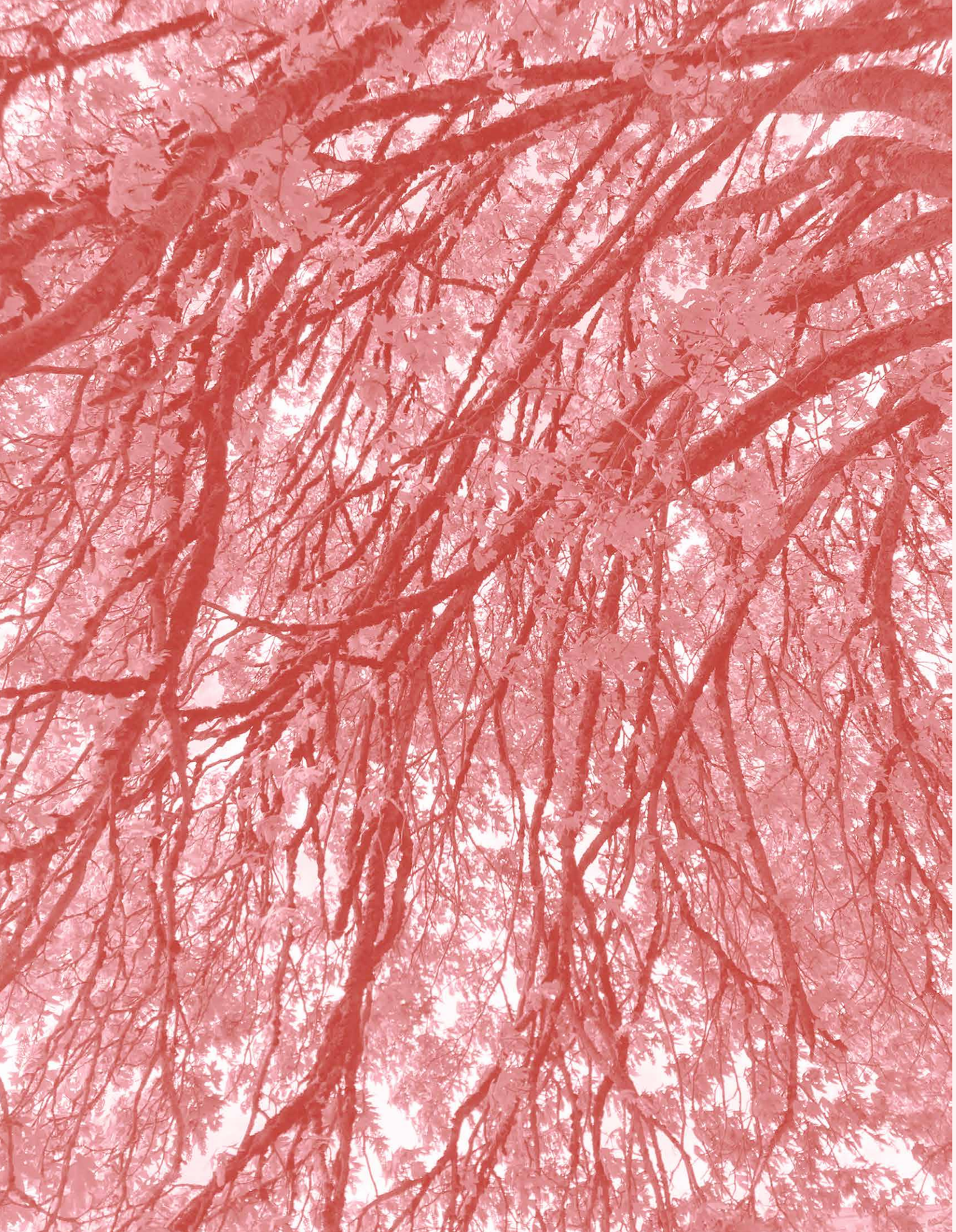
Figure I.10
Gifts from the Paddle Tree
Illustrations of traditional indigenous uses of The Paddle Tree.

of mosses and other plants than any other tree in the PNW region" (oregonstate.edu). Their particular bark texture is prime habitat for many epiphytic[1] species, like the licorice ferns illustrated in figure I.9, another native species with traditional medicinal uses.

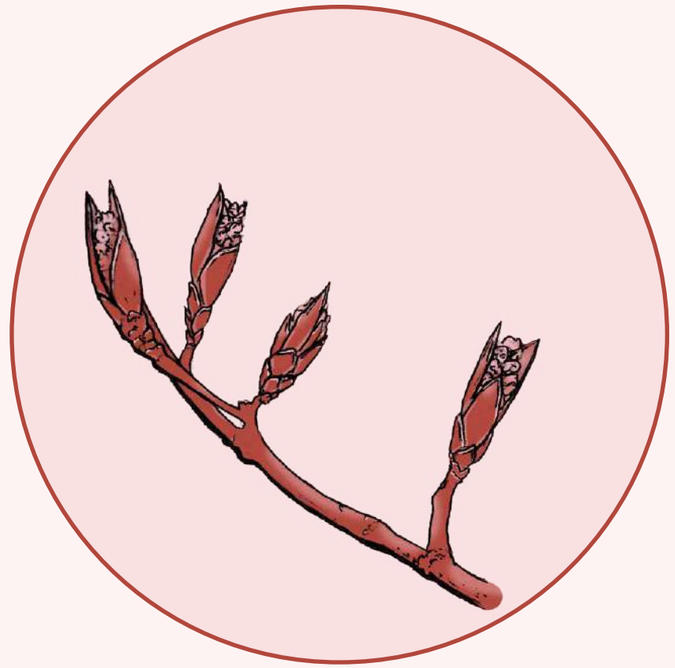
Honoring Bigleaf Maples, particularly those taken from their natural habitats and brought into the streets to benefit city residents, seems like a significant way local urban forestry management could acknowledge the first peoples of this land, which is part of why this project selected them as a target species and **sidewalk design client**.

The ultimate goal of this work is to **help the people of Eugene avoid removing Bigleaf Maples, especially historic ones in Whiteaker**, without compromising or neglecting necessary sidewalk repairs or the needs of the trees themselves.

[1] "Epiphytic" refers to plants and plant-like organisms that grow on the surface of other plants or plant-like organisms.



1.0



CONTEXT

It is critical to recognize and understand what's at stake at every site where **trees and sidewalks are in conflict**, why these conflicts occur, and how challenging it is for communities to fully resolve this issue. The contextual information presented in this section incorporates a review of existing literature to **explain why root-heave issues persist**, what approaches are currently taken to address them, and what costs they impose.

1.1 *Why Tree Roots Lift Sidewalks*

1.2 *How Broken Sidewalks Impact People*

1.3 *Challenges with Resolving Root Heave*

1.4 *Why We Need to Protect Mature Street Trees*

1.5 *The Interdisciplinary Complexity of Root Heave*

1.1 WHY TREE ROOTS LIFT SIDEWALKS

Sidewalk root heave is the direct result of a conflict between the physiological processes of tree root growth combined with the physics of concrete.

HOW TREES RESPOND TO RESOURCES

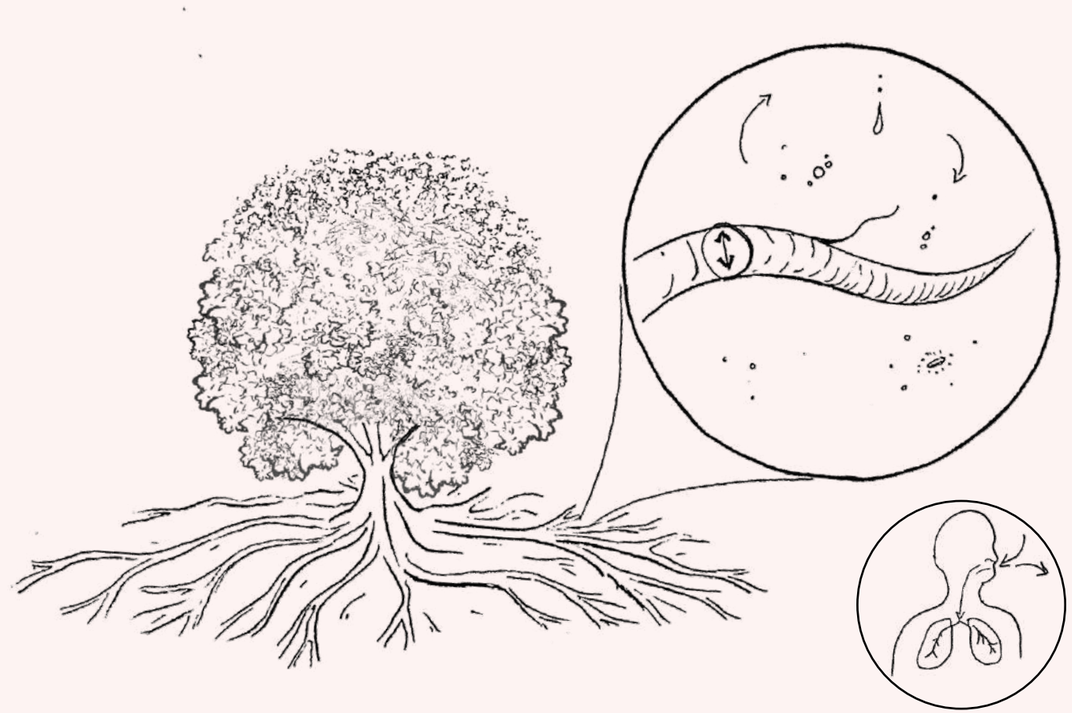
Trees grow in direct response to their growing conditions and available resources. They spread threadlike roots which grow radially, meaning they get thicker over time and naturally lift the soil above them. They grow opportunistically wherever they find resources, meaning water, oxygen, and space to grow (Perry, 1982).

Roots require oxygen because trees need to “breathe” but have no centralized lungs or gills, so their respiration is distributed across their biomass (see figure 1.1.1). Roots’ access to gas exchange is necessary for their survival and also allows them to deposit CO2 into the soil, which is part of how they sequester carbon (Trimble, 2021).

To have greater access to oxygen, all trees have some roots near the surface, which spread laterally out from their trunks. These roots spread dozens of feet (see figure 1.1.2). The rooting patterns of different species vary, but most deciduous species, especially surface rooting species like Bigleaf Maples, grow their roots in a large, shallow mat that is often twice as wide as their canopy or more (oregon.edu; Perry, 1982). However, the majority of their roots are concentrated within their canopy dripline, and their most critical roots grow within a calculable radius around their trunks, which is known as the critical root zone or CRZ. Protecting this area is essential for the health and longevity of trees (virginiatreecare.com).

RESOURCE ACCESS IN URBAN FORESTS

Streets provide limited root space but an abundance of above-ground resources, especially access to sunlight. Trees



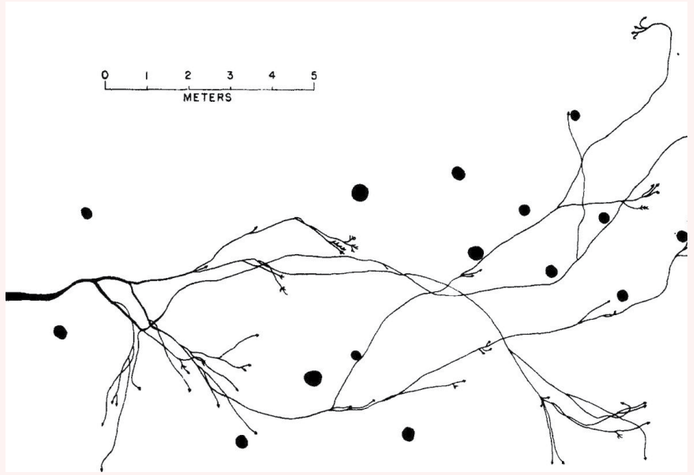


Figure 1.1.1
Tree Root Biology
Illustration of basic tree root growth patterns and needs.

Figure 1.1.2
Tree Root Diagram
Plan view diagram of a single lateral Red Maple root in a stand of other trees, which are shown as black dots, representing other trunks (Perry, 1982).

grow in direct response to these resources, meaning that trees of the same age and species will be different sizes depending on the resources specifically available to them. This was visually illustrated by an experimental forestry project conducted in 1973 in the Miyazaki Prefecture in

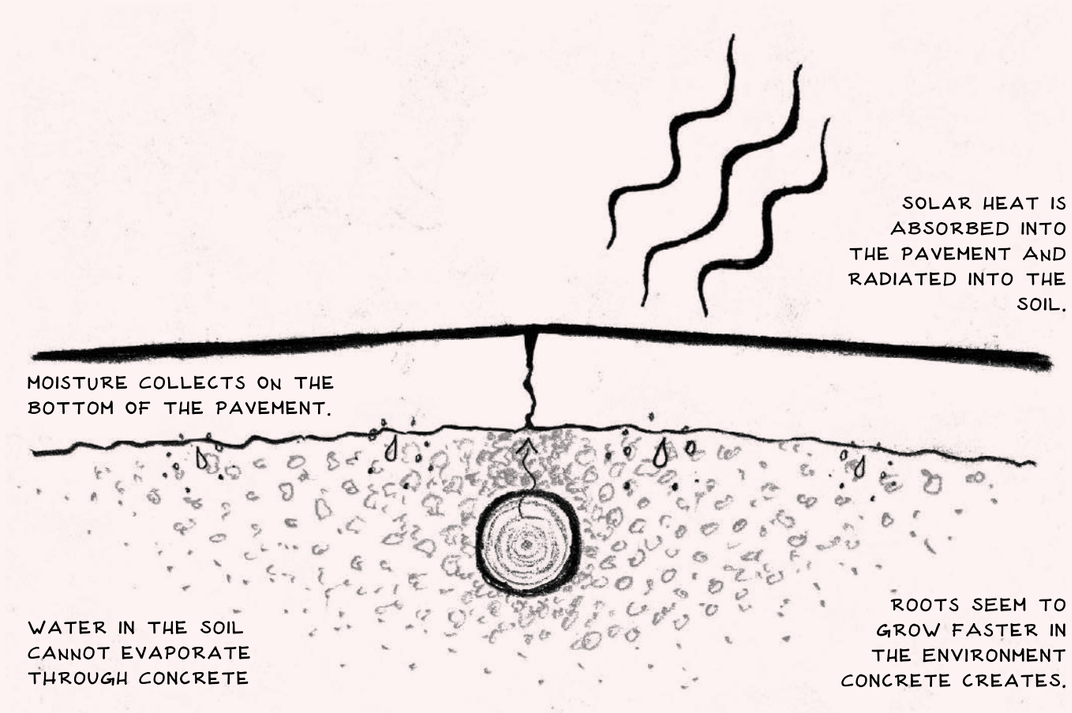


Figure 1.1.3
Experimental Forestry Showing Trees of the Same Species and Age
Drone photo of the results from a post-clear-cutting experiment in 1973. This patch of forest in the Miyaziaki Prefecture in Japan was planted uniformly with Japanese Cedar trees in concentric circles, increasing spacing between saplings in outer rings. This demonstrates how much larger trees of the same species and age grow when they have more room, thus access to resources (Varga, n.d.).

Japan. After forest clear-cutting, Japanese Cedar saplings of the same age were planted at the same time in concentric rings radiating out from a central clearing, which naturally resulted in wider spacing in the outer rings (Marchese, 2019). After about fifty years, the growth advantage of wider spacing is clearly evident (see figure 1.1.3). Because urban streets require significant spacing between trees, due to limited planting areas and visibility requirements, it is logical for trees to grow faster in urban environments, which has been demonstrated in existing literature (Thurston & Scott, 2025).

SPECIFIC RESOURCES BENEATH CONCRETE SIDEWALKS

The specific micro-climatic growing environment beneath sidewalks may encourage and expedite root growth because of the physiology of concrete (see figure 1.1.4). Concrete, as an impermeable surface, prevents water from evaporating in



soil, trapping moisture and collecting condensation along the bottom of the pavement. Sidewalks then create an abnormal humidity gradient, which seems to stimulate **rapid tree root growth specifically beneath the sidewalk** (Randrup et al., 2003, p. 215). The concentration of water beneath and around sidewalks is further elevated in areas with adjacent irrigation, such as well-watered lawns, which may further encourage surface rooting (Randrup et al., 2003, p. 215). The solar energy absorbed into the pavement also elevates the soil temperature, which may correlate with rapid surface root growth.

Through a simulated urban tree pit experiment in Virginia, one team found that newly planted trees with porous-permeable pavement over their roots grew larger than similar trees with unpaved soil. Roots under pavement grew faster and shallower, potentially because pavement increases the soil temperature, thus extending the growing season (de la Mota Daniel et al., 2018).

Figure 1.1.4
Concrete Physiology
Illustration of how on-grade concrete creates growing conditions that encourage tree root growth.

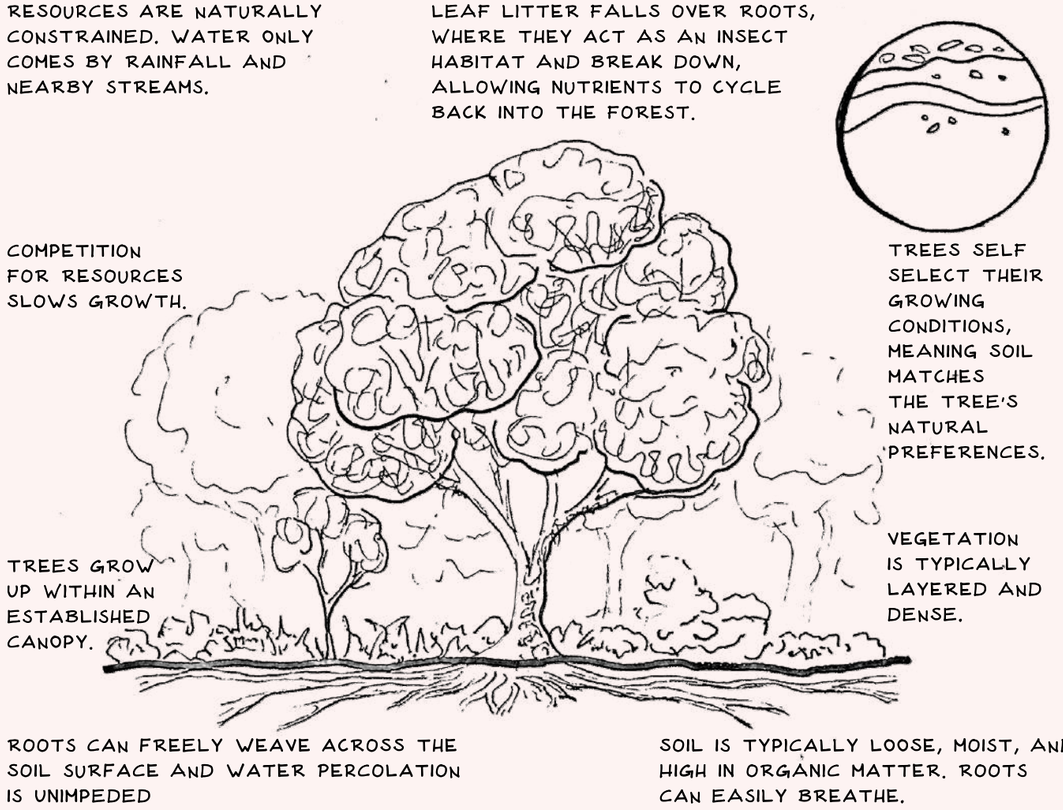


Figure 1.1.5
Conditions of a Traditional Forest
Illustration of the growing conditions provided by a traditional forest, the native habitat of most street trees.

THE GROWING CONDITIONS STREETS PROVIDE

The conditions trees evolved with, especially shallow-rooting river trees like Bigleaf Maples, are dramatically different from urban streetscapes (see figure 1.1.5 compared to figure 1.1.6). Plant medians and other paved surfaces restrict their growing environments and access to oxygen. On one side of the plant median is a curb and driving lane, which is a thick impervious paved surface that is substantially heavier than the concrete sidewalk on the other side. These growing conditions appear to predispose trees to grow their roots beneath the sidewalk, which leads to root heave, particularly in areas where there is surface-level irrigation within the plant median or on the opposite side of the sidewalk.

These surfaces are also constructed in the same space

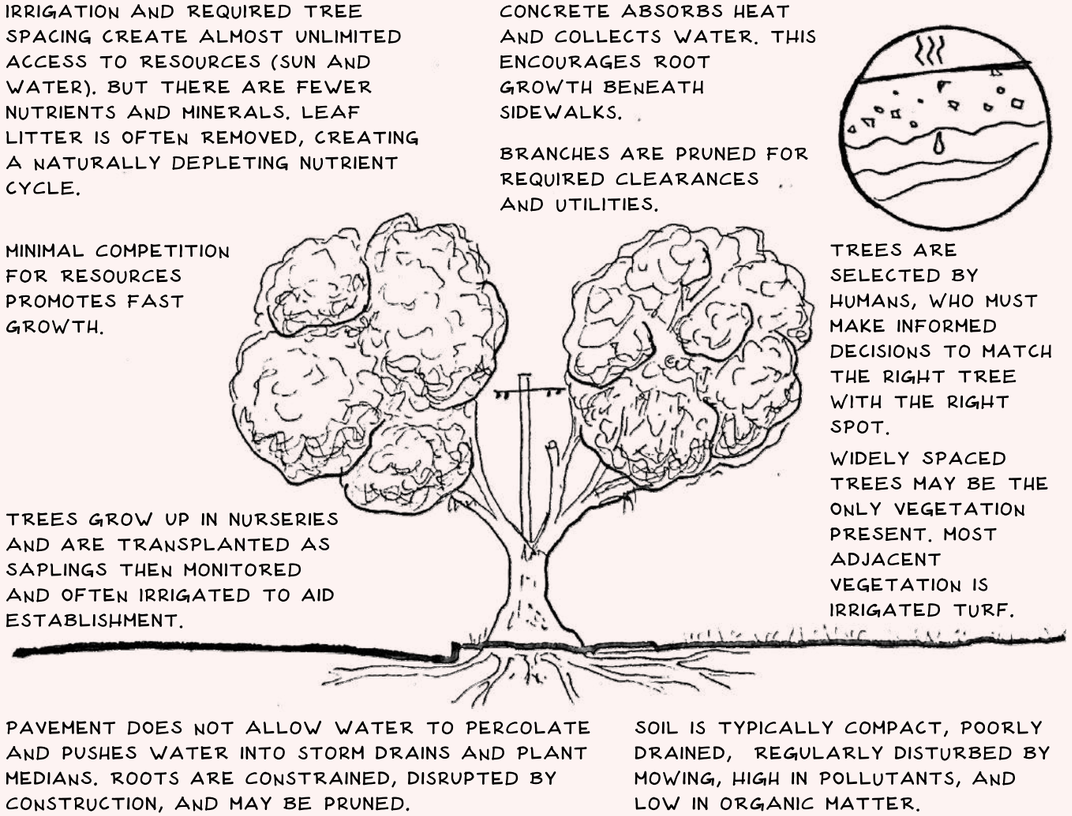


Figure 1.1.6
Conditions of an Urban Forest
Illustration of the growing conditions provided by an urban forest, which many species struggle to thrive in.

where the tree's roots would naturally grow, which tends to be in the top 20cm (about 8") of soil (Czaja et al. 2020, p. 4). Because street trees have limited space to grow their roots and they are planted in close proximity to pavement, there are frequent and mutually detrimental conflicts between street trees and sidewalks. An existing literature review compiled by a team of academics in Australia describes 30 years of research on urban forests and concludes that urban conditions often lead to tree roots "surviving and growing in sites where they are likely to cause damage to pavements and other infrastructure" (Mullaney et al., 2014, p. 164). In other words, street trees may struggle to find places they can grow their roots and the **most optimal place for them to grow is frequently beneath the sidewalk**.

1.2 HOW BROKEN SIDEWALKS IMPACT PEOPLE

Sidewalks can break with or without trees, but root heave is a common and highly visible problem that appears to routinely break sidewalks. The result is a serious safety concern that disproportionately impacts pedestrians with disabilities.

SAFETY ISSUE

Broken sidewalks are notably unsafe, particularly where there are level changes, which create **tripping hazards**. People walking over buckles in the pavement may trip and fall, sustaining serious injuries as they make contact with the concrete. The **risk of falling is elevated for people with low or no vision**, because they cannot see and thus cannot easily avoid tripping hazards. And those using mobility devices, such as wheelchairs and walkers, may be obstructed or fall out of their mobility device. **Level changes are also a nuisance** and potential safety issue for people pushing a stroller, delivery people with carts, and anyone carrying an object that obstructs their view of the ground.

Excessive slope is also a safety concern, particularly for people with mobility devices, because it may be difficult to wheel up a steep slope and even more difficult to wheel down safely at a controlled speed while staying securely seated. Excessive cross slope is also a problem because it requires wheelchair users to twist themselves at an awkward angle to stay upright or risk tipping over (see figure 1.2.1). **Combinations of excessive slope, cross slope, and level change are especially obstructive and dangerous.**

CIVIL RIGHTS ISSUE

Sidewalks that obstruct or endanger people with disabilities exclude them from the public right of way, which they have a legally protected right to use under the Americans with Disabilities Act (ADA). In many ways, inaccessible sidewalks,



Figure 1.2.1
Root Growth vs. Safety and Welfare
Illustration of a tree in cramped growing conditions lifting the sidewalk, creating a hazard for the public, especially people with disabilities.

meaning those that are non-compliant with ADA codes, directly relate to the origins of the law. Sidewalks are the **primary route of travel for pedestrians** to reach any site, including civic buildings.

The ADA was signed into law in 1990 following widespread protests, namely the Capitol Crawl. That protest, where people threw down their wheelchairs and crawled up the stairs leading to the front entrance of the U.S. Capitol building, was a demand for **the right to be included as part of the public**. The protesters pictured in figure 1.2.2 fought for justice in a way that was directly modeled after the 1964 civil rights movement and proclaimed that "**access is a civil right**" (Sanders, 2022). Without accessible sidewalks, entire areas of neighborhoods and cities may become inaccessible, leaving people with disabilities unable to safely reach their destinations.

Under the ADA, sidewalks must be as accessible as



Figure 1.2.2
Capitol Crawl Protest
Photos of the 1990 Capitol Crawl Protest at the stairs of the US Capitol Building.
(sydneyseverance.org)

practicable. That means sidewalks do need to be made into ramps on slopes that naturally exceed 5% but they must comply with other code requirements and wherever the slope does not naturally exceed 5% the sidewalk must also be below 5%, except at curb ramps, which have limited length but are allowed to have slopes up to 1:12 (access-board.gov).

As explained in the introduction, Eugene is a city that is working toward sidewalk repair system improvements, and

that is in direct response to community requests. Sidewalk repair is a spatial justice issue that must be addressed.

THE INVISIBLE ADDED WORK REQUIRED FOR PEDESTRIANS WITH DISABILITIES

Without sidewalk repair, pedestrians with disabilities face **added burdens and invisible labor** to navigate their communities. Even where there is a way to get around a broken sidewalk, such as crossing the street and doubling back to access a site, obstructed paths have a measurable effect on relative accessibility, which is a concept that recognizes how technically accessible spaces still specifically hinder people with disabilities, creating spatial inequity (Church & Marston, 2003). This principle has already been applied to sidewalks with a proposed weighted accessibility index specific to sidewalks that considers how important users feel each attribute is and the cumulative impact of localized obstructions on pedestrian routes. Respondents to a survey conducted through interviews using questionnaires rated slope and leveling as the most important factors for sidewalk accessibility, followed by surface condition (Ferreira et al., 2007, pp. 7-8). That means the most important aspects of sidewalk accessibility are impacted by root heave, which increases slope by lifting sidewalk panels and creates level changes by lifting panels differentially.

Broken pedestrian networks also have wide-reaching impacts that ultimately cut people off from their communities, as described in works like *Where the Sidewalk Ends: Disability, Mobility & Environmental Factors,* a thesis written at the University of Illinois by W. Vassilakis. Vassilakis surveyed users across the country and received 270 responses spread across eight U.S. States (Vassilakis, 2009, p. 11). His research notes the differences between respondents' "Perceived Ability," self-identified capacity to travel, and "Functional Ability," their physical environment's capacity to support their travel, and identified key resources people with disabilities need to access. He found that people with



Figure 1.2.3
The Reality of Urban Sidewalks
Photo of a non-compliant sidewalk in Eugene that has been spray-painted, which alerts pedestrians of the problem but does not remove the safety hazard or obstruction.

disabilities often rely on public transit for daily commutes to work and school, especially those living on public assistance (Vassilakis, 2009, p. 24). This indicates that physical access to transit is necessary for upward socioeconomic mobility, implying that urban path accessibility is a significant spatial justice concern. Buckled paths, like the example pictured in figure 1.2.3, have the potential to block residents from public transit, workplaces, schools, neighbors, grocery stores, and any other destination people with disabilities still need to access, even if that means walking or wheeling through the street. Broken sidewalks, and root heave by extension, is a recognized, **serious problem that requires a solution for the public's safety, health, welfare, and justice**.

Unfortunately, root heave appears to be a long-term problem that will take a considerable amount of time to solve, so it is necessary to consider short-term fixes to improve spatial access while searching for a permanent solution. This may include digital means of augmenting physical urban environments, creating a stopgap solution that may still be useful following path improvement and repair. For example, "Modeling Access with GIS in Urban Systems" or "MAGUS" demonstrates one digital option, which is mapping the circulation experience of wheelchair users and using AI to create accessible routes. The underlying goal of MAGUS is to promote relative urban accessibility. Through their supporting research, the team proposing MAGUS found that the same trip through urban space can take nearly three times as long for a wheelchair user as an ambulatory pedestrian due to obstructive conditions and reduced travel speed (Matthews et al., 2003, p. 37). They suggest remediating this type of disparity through a digital platform that can help users find more suitable routes through AI assistance, reducing trial and error. However, the functionality of this kind of tool relies on the presence of accessible routes, which appear to be severely lacking in many cities like Eugene. This means that **primary pedestrian routes urgently require sidewalk repair**.

1.3 CHALLENGES WITH RESOLVING ROOT HEAVE

There are a variety of reasons broken sidewalks, particularly root-heaved sidewalks, are such a pervasive problem despite public awareness. Root heave can occur surprisingly quickly; decades-old literature shows that root heave often begins when trees are only 11-20cm (4” to 8”) in diameter (Randrup et al., 2003, p. 213). Sidewalks may break frequently, and there are broad, systemic issues that slow the rate of sidewalk repair, compounding with local obstructions and leading to holistically broken sidewalk networks.

STREET TREE AND SIDEWALK POLICY

In many cities, including Eugene, residents are legally and financially responsible for installing and maintaining sidewalks (eugene-or.gov). Evidence suggests this kind of sidewalk repair system leads to inaccessible sidewalk networks (Corning-Padilla & Rowangould, 2020). The primary problem with this structure is that it **relies on individual property owners for maintaining public infrastructure** and requires pedestrians to make individual reports about specific broken sidewalks (see figure 1.3.1). If a pedestrian with disabilities is required to report each individual obstruction, they are required to effectively report their neighbors – likely many of them – and rely on the city to ensure repairs are made. It seems infeasible to establish even one accessible path through this process, at least within a reasonable timeframe, especially if one obstruction prevents someone from reaching the next one. Residents may also be unaware that sidewalk repair is their responsibility, reducing the likelihood they would proactively fix their broken sidewalk before it is reported.

The problems with a privately funded sidewalk repair system have a visible impact on the City of Eugene that the community is working with the city to improve (best-oregon.org). The community’s goal is to move toward a model resembling Corvallis, Oregon, which **publicly funds sidewalk**

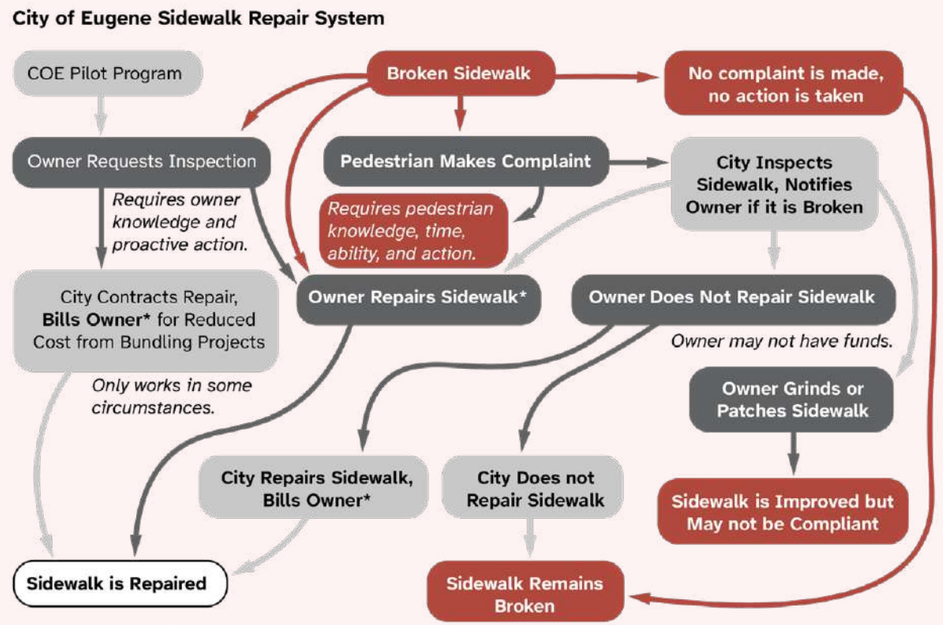


Figure 1.3.1
Systems of Repair
Flowcharts describing how sidewalks are typically repaired in Eugene and Corvallis. (eugene-or.gov; corvallisoregon.gov)

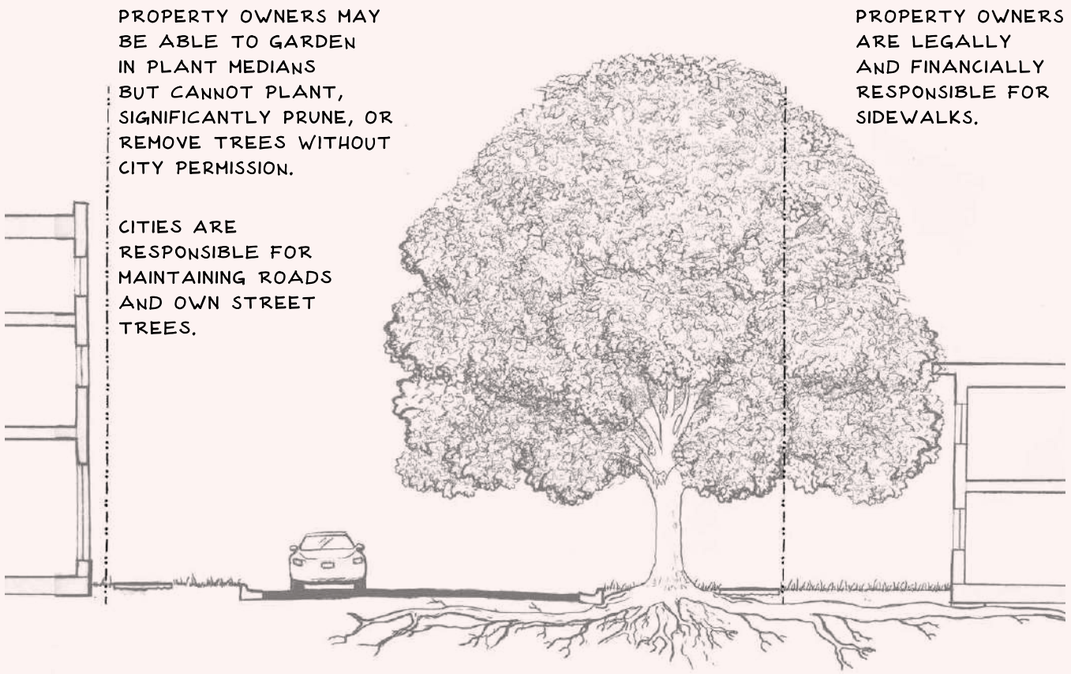


Figure 1.3.2
Ownership and Responsibility in an Urban Streetscape
Cross section of an urban street spanning from the driving lane to private property, showing that the city is typically responsible for the street and tree but the property owner is responsible for sidewalk repair and maintenance. Illustration reflects the current policy in Eugene, Oregon, which is representative of the majority of U.S. cities.

repairs. This seems likely to increase the rate of sidewalk repair, which is critical and any improvement would benefit disability-inclusion and public safety. However, there are hurdles to implementing this system, so it may take time to establish. While this does not necessarily move legal responsibility onto the city, depending on how the local ordinance is written, it requires public buy-in and may end up lacking the funds to keep up with the rate of sidewalk failure.

The problem with all sidewalk repair systems, whether they are private or publicly funded, is the scale of damage compared to repairs made. Part of the problem is urban sprawl, leading to large sidewalk networks that are difficult to manage. However, the real problem appears to be an unknown rate of failure. More extensive, clear research is needed to understand how long sidewalks can remain ADA compliant after they're constructed in a tree's critical root zone, **how frequently tree roots lift sidewalks**, and the actual success rate of interventions meant to prevent the need for recurring repairs.



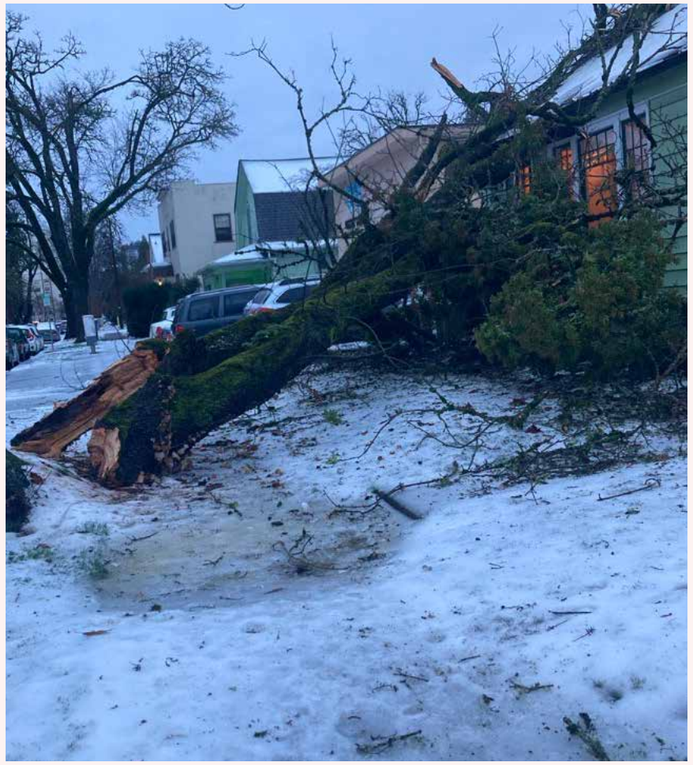
THE COST OF SIDEWALK REPAIR FOR TREES

Even if sidewalk repair systems were fully resolved, there would still be serious barriers and hurdles with resolving root heave. The standard means of **sidewalk repair presents concerns for street trees**, especially surface rooting trees. If large surface roots are lifting the sidewalk, they are likely growing in the same space the sidewalk will need to be repoured. To make it physically possible to repour the sidewalk and to limit recurring root heave, it is necessary to prune, meaning cut, the roots (see figure 1.3.3).

Root pruning is often the only and best way to preserve a tree while repairing the sidewalk, but it is done with great care. It requires a holistic consideration of the tree's structure, proper climatic timing, and whether available conditions will help the tree recover (Hamilton, 1988, p.

Figure 1.3.3
Root Pruning
Photos from the City of Eugene Urban Forestry department of Bigleaf Maple roots before and after root pruning. Root pruning is a common urban forestry practice that addresses conflict between tree roots and adjacent infrastructure, especially sidewalks. Not all species or specimens tolerate this intervention and it typically causes die-back in the tree's crown. (Lakics, personal communication, January 21 2026)

Figure 1.3.4
Risk of Urban Street Trees
Photo of an especially large tree branch that fell through the roof of a house taken in Eugene on January 17, 2024 during a major ice storm.



288). Root pruning is generally tolerated and negative aesthetic impacts typically reverse if the tree has sufficient vigor, but stability must be a top priority when cutting large roots (Hamilton, 1988, p. 292). Roots are effectively a tree's foundation, and if too many are cut too close to the tree the entire structure may fall over. That said, trees can be surprisingly resilient after root pruning. One study conducted in six parks in Quebec City, Canada found that even root trenching within the recommended protection zones did not impact stability of Acer platanoides or Tilia cordata (Pallafray et al., 2024).

Unfortunately, **root pruning is not always an option**. Root heave caused by large structural roots typically requires tree removal to fix because the city must avoid public hazards from falling trees (eugene-or.gov). Even a large branch can cause serious damage (see figure 1.3.4)

so risking an entire tree falling is not an option. Root pruning can also be a problem for specific species, even where there is no structural concern. **Bigleaf Maples are specifically at risk** because they often struggle to tolerate root pruning according to an experienced urban forester and certified arborist at the City of Eugene (Lakics, personal communication, January 16 2026).

Because of the risk of removal and potential health impacts of root pruning, repairing root heave has a real cost for street trees, particularly mature trees. This is due to technical problems with the relationship between sidewalks and tree roots, not a lack of care for the trees. The City of Eugene, like many municipalities, has a team dedicated to managing the urban forest, routinely works to plant street trees, and is especially invested in preserving existing mature trees (eugene-or.gov).

THE COST OF SIDEWALK REPAIR FOR PEOPLE AND THE PLANET

After pruning tree roots and removing broken sidewalk panels, root heave repair has a real cost to the people paying for the sidewalk, the planet, and the locations where limestone, the primary ingredient in concrete, is sourced.

Concrete is required for sidewalk repair, unless the lifted panels are salvageable, because it is the code-required material for sidewalks in the public right of way. City of Eugene Sidewalk Code Requirements, which seem standard for most urban areas in the U.S., have tight restrictions and requirements around sidewalk construction. These rules are necessary to protect the health, safety, and welfare of the public. According to Eugene City Code 7.375 and associated specifications, new **sidewalks must be constructed with concrete** that is at least 4" deep in general and 5" deep at driveways (eugene-or.gov). Using any alternative materials or methods for a sidewalk in the public right of way would require an additional approval process, a building permit

accepting the code variance, and likely a specialized team of contractors separate from those who pour concrete.

Concrete is the most common sidewalk material because it is **considered the most durable, accessible path material**. Actual lifespan estimates are inconsistent, but it seems like a common assumption that sidewalks last about 80 years in ideal conditions and 25 years in high-use areas (reliablecontracting.com). However, root heave seems likely to significantly shorten this lifespan, based on how quickly trees can lift the sidewalk and concrete's apparent proclivity for encouraging rapid surface root growth.

Frequent sidewalk repair is a concern for city residents because of its **financial cost**. According to recent cost estimates provided by the City of Eugene, the base fee for ≤ 25 sf of sidewalk, or a standard 5 foot square (see figure 1.3.5), is $1,700 which means the **mobilization cost** is essentially **$1,170**. The additional cost for sidewalk segments is $21.22 per square foot for a 4" deep sidewalk, which equals **$530.50 per 5 foot square** of minimal depth sidewalk (Trendler, personal communication, April 10 2026). Using these estimates, replacing the sidewalk on just one side of a single 240 foot residential block would cost $26,634. If an entire sidewalk network including hundreds of blocks is broken, it makes sense that public funds are often not able to accommodate the cost of repairs at the necessary scale. And making changes to the sidewalk construction that reduce the risk of root heave recurrence, like increasing sidewalk depth, adding more sub base material, and incorporating rebar, would add costs.

Concrete also has a substantial **environmental cost** that increases a city's carbon footprint. As reflected by embodied carbon estimates (figure 1.3.6), concrete is so carbon intensive that a single 5 foot square embodies 124 to 250 lbs of carbon, which equates to about 3-6 trees' annual carbon sequestration capacity with generous estimates. More conservative estimates suggest trees may only sequester 22

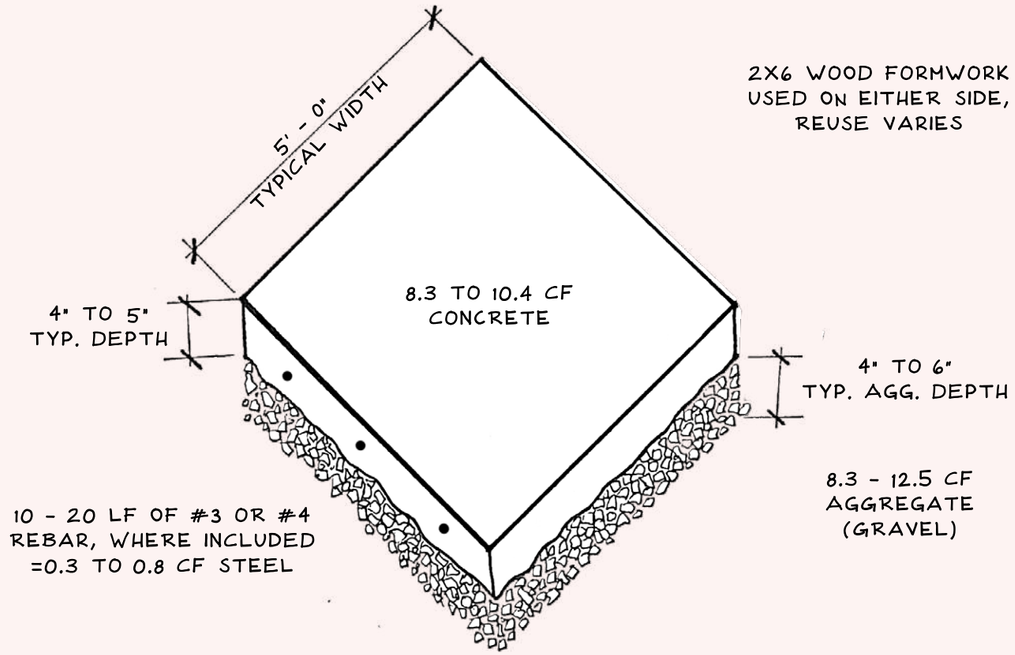


Figure 1.3.5
One Sidewalk Block
Simplified illustration of the material required for a typical 5 foot square block of sidewalk.

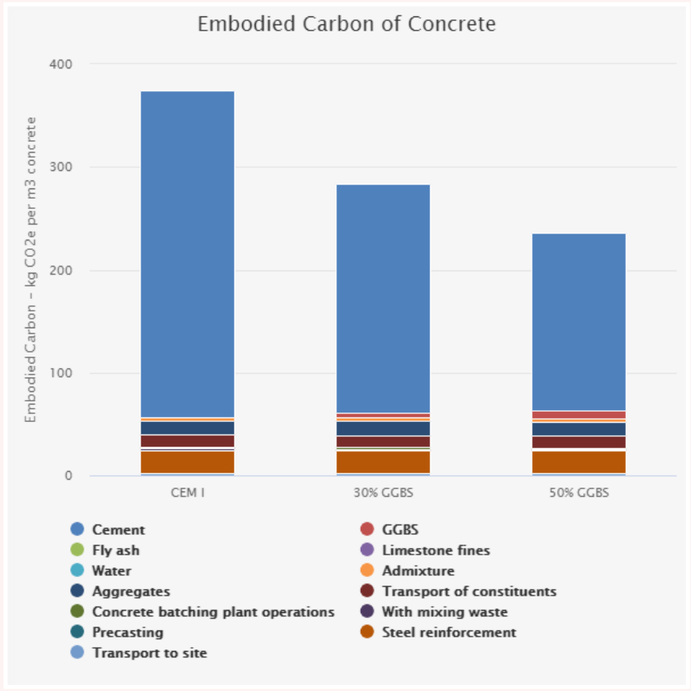


Figure 1.3.6
Embodied Carbon of Concrete
Example of common embodied carbon calculations for different mixes of concrete. Represents a range equivalent to 15lbs/cf to 24lbs/cf. This means a single block of sidewalk has 124 to 250 pounds of embodied carbon just from the concrete (circularecology.com). This represents at least 3-6, possibly 6-12 trees' annual carbon sequestration capacity (Ross, 2023).



Figure 1.3.7
The True Cost of Cement
Image of limestone mine. Cement extraction destroys the local ecosystem and leaves behind a hazardous landscape. The primary ingredient, limestone, forms underneath habitats that must be removed to extract it before the stone itself is drilled or blasted out with explosives.
(Lyngseth & Krok, 2023)

pounds of carbon per year for their first 20 years, meaning one 5 foot square of concrete could take 6-12 trees one year to offset (Ross, 2023).

Concrete's environmental cost goes beyond its embodied carbon. Concrete is a mixture of cement (which is made from limestone), aggregate (gravel), water, and admixtures. The processes required to obtain and manufacture these materials **devastate ecosystems**, contribute to fossil fuel use, and permanently alter landscapes (see figures 1.3.7 and 1.3.8). Quarries are extractive industries that strip the top soil (destroying ecosystems on the surface) then drill and blast the supporting stone (destroying ecosystems beneath the surface). Because the resource being mined (i.e. limestone) is finite, quarries are eventually abandoned and tend to fill with rainwater or become landfills meaning that "**quarries are temporary, but their environmental impacts are forever**" (Lyngseth & Krock, 2023). Although pedestrians using sidewalks in the U.S. are removed from these consequences of resource extraction, it is a serious environmental cost that must be considered when we choose to use concrete.

Concrete repair also has a **temporal cost** due to required



sidewalk closure. In Eugene, sidewalks are closed for 3-5 days after sidewalks are poured, which can only occur after trees have been inspected and pruned after sidewalk removal at sites with substantial root heave (eugene-or.gov). Even after this period, sidewalks may be vulnerable and unusable for some. Concrete takes 28 days to fully cure and it is typically recommended to wait at least **7 days** before driving light vehicles over concrete, which likely includes electric wheelchairs. Concrete also requires the correct temperature to cure and poorly timed rain can damage its structural integrity, which is why the City of Eugene standard building specifications requires concrete to be poured between 50°F and 90°F (City of Eugene, 2021, p. 1027). The result is that concrete repairs could take longer to fix as teams **wait for the right time and weather**, and when the sidewalk is fixed the path will need to be **closed for several days to a week or more** depending on the circumstances. This especially impacts visually impaired pedestrians, who rely on familiar routes for spatial navigation.

The true cost of concrete adds gravity to each sidewalk repair, emphasizing the importance of finding lasting solutions to limit sidewalk replacement.

Figure 1.3.8
Ecological Devastation of Mining Bedrock
View of a limestone mine with remnants of the pre-extraction ecosystem visible in patches and around the perimeter.
(Barber, 2022)

Figure 1.3.9
Sidewalk Joint Adjustments
Cross section detail of TripStop, a product that keys into sidewalk joints and reduces the risk of tripping hazards as pavement is lifted.
(kinesik.ca)

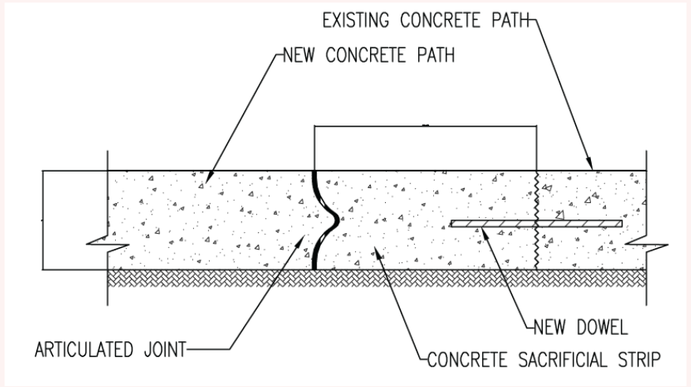
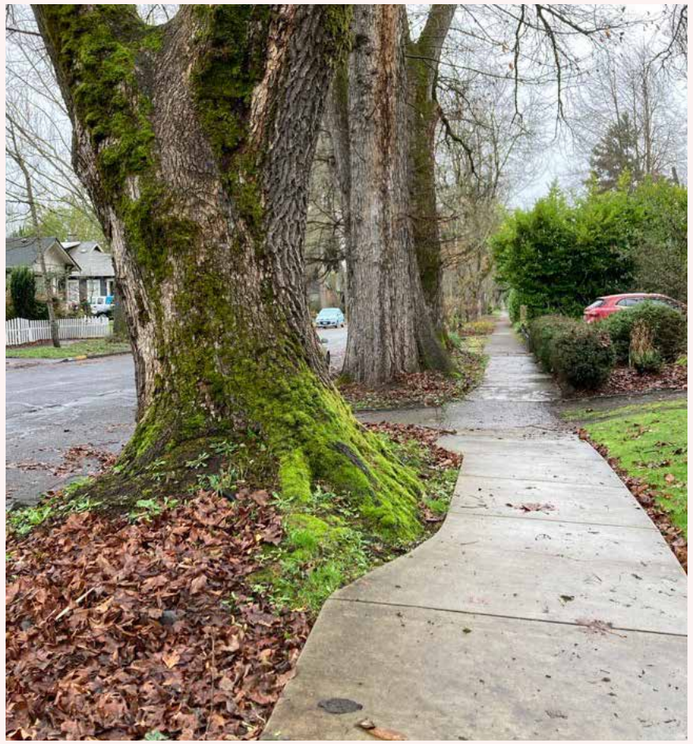


Figure 1.3.10
Sidewalk Width Adjustments
Photo of new sidewalk that is narrowed next to a mature Bigleaf Maple street tree in Eugene.



OPTIONS FOR REDUCING ROOT HEAVE RECURRENCE

The fastest short-term solution to root heave is concrete grinding, which manually reduces the height of level changes, but directly addressing root heave and preventing recurrence is necessary for lasting improvement. There are



Figure 1.3.11
Root Protection
Illustration of vertical root protection, which at least one longterm study found to be the most effective root protection intervention compared to other options, such as horizontal layers of foam and increased aggregate depth (Smiley, 2008; greenindustrytrees.com)

a few ways to **prevent root heave** at a repair site, meaning a place where an existing tree has broken the adjacent sidewalk, root pruning is possible, and there's the budget for preventative measures. For example, Tripstop, a product that connects concrete blocks to one another, is meant to reduce sidewalk hazards (see figure 1.3.9). By keying joints together the risk of level changes is significantly reduced. However, based on field observations during data collection for this project, root heave can lift sidewalk panels to the point Tripstop is broken loose within the joint, eventually leading to level changes. The sidewalk can also be narrowed next to the tree, allowing for more space at its base (see figure 1.3.10). The concern with this approach is that narrowing the path width reduces accessibility by constraining clear width, and narrowing the path does not necessarily reduce the risk of root heave recurrence.

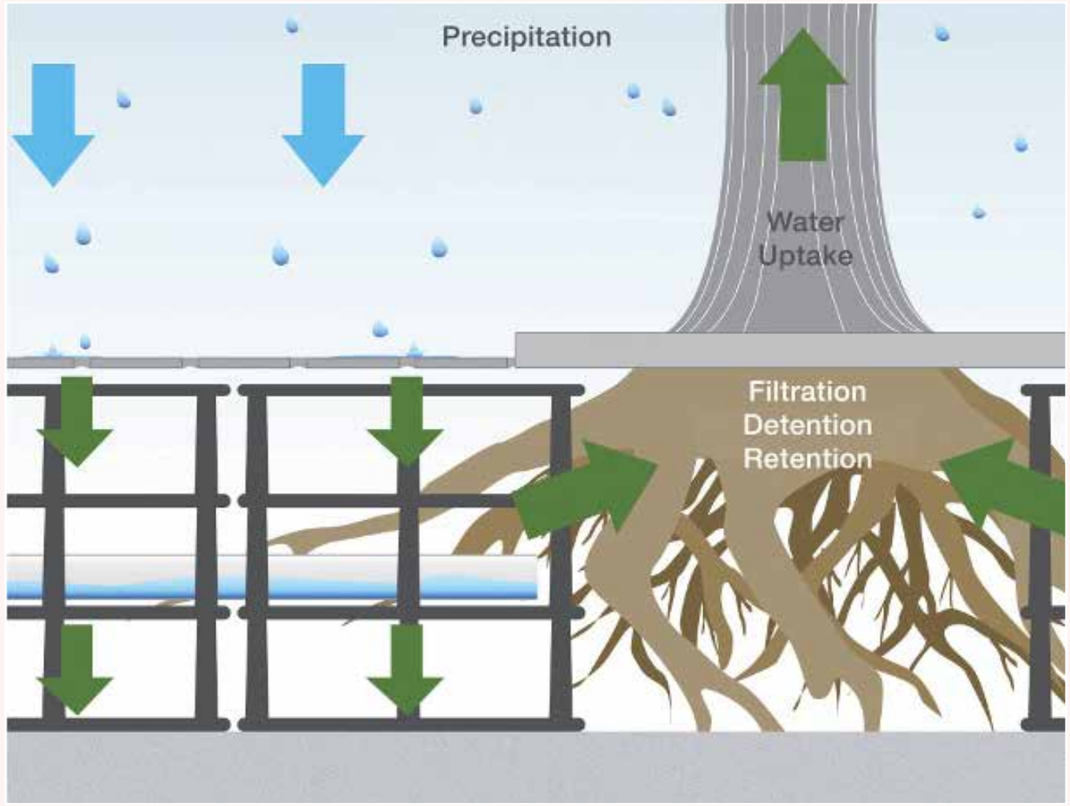
OPTIONS FOR PREVENTING ROOT HEAVE

There are far **more options for preventing root heave at new construction sites** when planting a sapling near a sidewalk than repairing root heave from a mature tree. The efficacy of most approaches seems to be **untested on mature trees** considering the timescale of tree lifespans, which span several entire careers and most mature trees pre-date modern root heave prevention measures. Existing research **focuses on young trees out of necessity** but it

seems no research has monitored trees from establishment to maturity. For example, E. Thomas Smiley conducted a ten year study comparing methods of preventing tree root damage to sidewalks, finding that root contact with the underside of pavement measurably damages and lifts sidewalk blocks (Smiley, 2008, p. 180). Smiley's research confirms that it's necessary to protect concrete paths from trees to reduce sidewalk damage, thus extending the accessible path's lifespan. Some methods of sidewalk protection are more effective than others; vertical root protection (figure 1.3.11) appears to be most effective (Smiley, 2008). The challenge with implementing this knowledge is that root protection is not a stand-alone solution. And while these findings are valuable, **ten years is virtually no time for a tree to grow**, so it is unclear if any root protection, including a combination of multiple methods, could ever fully sidestep root-sidewalk conflict until a tree is at least mature enough to provide the benefits it was planted for. In theory, these concerns could be absolved with more expensive, intensive proactive solutions, like Silva Cells (figure 1.3.12), but they are infeasible interventions for most if not all existing mature trees. There are also less structured alternative subsurface materials, like structural soil, which appears to be a good tool for supporting pavement alongside tree roots (Bartens et al., 2009, p. 646). However, some experts are skeptical about the efficacy of these solutions because even deep roots can lift the sidewalk (Randrup et al., 2003, p. 221). Other potential options include pervious paving, suspended pavement, and root paths; results are mixed but these methods at least appear to benefit growing conditions for trees (Watson et al., 2014).

NEW CONSTRUCTION VS. REPAIRS

Many of the solutions for new construction can also be adapted for existing trees, but different options are better suited for different use cases. Suspended grating systems seem to be most suitable for existing trees, while structural



soils or modular box systems are more effective for new plantings (Wojnowska-Heciak et al., 2025). Most options can be used at existing trees with the help of an air blade to remove compacted soil. The research comparing these solutions is limited because it focuses on synthesizing existing information to describe and compare methods of supporting tree roots alongside pedestrian paths, which does not include **original field research of actual installations**. Further research is needed to verify efficacy for preventing root heave.

Figure 1.3.12
Root Accommodating Subgrade Construction
Illustration of Silva Cells, which provide space for roots to grow beneath pavement. These cells can be prohibitively expensive, difficult to install at existing trees, and may not prevent roots from growing along the interface between concrete and the subgrade. An alternative to these cells is structural soil, a more economic alternative that provides less root space and does not necessarily prevent sidewalk root heave. (deeproot.com)

CONCERNS WITH THE EFFICACY OF CURRENT ROOT HEAVE SOLUTIONS

Alternative sidewalk construction methods can be significantly expensive, and it is discouraging for cities to

try solutions that are backed by academic research only to see them **fail in the field**. Unfortunately, trial and error may be the only option for cities to **make progress toward resolving root heave**. The aforementioned solutions to root heave will need to be in place for several decades before their ability to prevent root heave has been adequately tested. In that sense, all solutions to root heave are ongoing field experiments, and Eugene has already tried experimenting with alternative construction (meaning non-concrete) methods.

The most radical local sidewalk experiment was the Terrewalk System installed around the multi-block apartment complex downtown that is now called The Hayward. This product was backed by academic articles and theoretically makes it easier to maintain street trees alongside accessible routes. This product had been installed at other locations to preserve trees and appears like a great option on paper (figure 1.3.13). These flexible, recycled plastic tiles are considered a tree-preserving alternative to standard sidewalks that reduce long-term costs, because individual tiles can be removed for root pruning then reinstalled with minimal disruption (Dettenmaier & Kuhns, 2016). The tiles are designed to flex over roots and have a thinner profile than concrete, but that flexibility and reduced structural stability seems like significant accessibility concerns, especially for mobility devices. They also have higher up-front costs than concrete (Dettenmaier & Kuhns, 2016).

The Terrewalk System was installed in large stretches around the downtown apartment blocks in Eugene to test the possibility of implementing it elsewhere, with the hope of extending the lifespan of downtown trees. But the product reportedly failed almost immediately, creating accessibility concerns before tree roots ever interfered, leading to widespread public complaints that began shortly after initial installation and have continued for about a decade (City of Eugene Public Works Staff, personal communication, Summer 2025).



Figure 1.3.13
Terrewalk System
Photos of a proposed tree-preserving sidewalk system that is meant to be flexible around tree roots without creating level changes. (Dettenmaier & Kuhns, 2016)

The Terrewalk System experiment represents **positive, tree-preserving intentions** and a strong attempt to resolve root heave in Eugene. However, this precedent provides a clear warning about the risks of experimentation in the public right of way and reinforces reliance on concrete as the default sidewalk material. The implementation of Terrewalks was well-informed and academically supported, but ultimately unsuccessful.

It is clear that sidewalk materials must be thoroughly



Figure 1.3.14
Terrewalk System Failure
Photos of a remaining remnant from an unpopular sidewalk experiment surrounding a large apartment development in Downtown Eugene, installed circa 2016, meaning the pictured sidewalk is ten years old. The product theoretically provides more space for tree roots and provides easier access for root pruning. In practice the surface bows and warps in the heat, allows water to pool, does not prevent level changes at material transitions, and does not meet ADA requirements for a stable, resilient surface for a public circulation path.





Figure 1.3.15
Water Pooling on Terrewalk System Panels
Photo of in-tact Terrewalk system panels with bowls holding water from adjacent irrigation.

tested prior to field installation and **accessibility must be a top priority** for tree-preserving systems to be successful. The Terrewalk system material warps, bulging and bowing, possibly from heat exposure. The system also has weak seams that separate and does not adequately support transitions between materials, leading to pervasive level changes. The majority of the Terrewalk panels in Downtown Eugene have been replaced with a standard concrete sidewalk and remaining portions still have the bouncy, uneven, inaccessible surface that continues to prompt public complaints (see figures 1.3.14 and 1.3.15).

1.4 WHY WE NEED TO PROTECT MATURE TREES

Street trees are critically important for making sidewalks, streets, and even urban buildings livable (see figure 1.4.1). Root heave must be resolved without sacrificing our urban forests, particularly mature trees.

PUBLIC HEALTH, SAFETY, AND WELFARE

Trees are necessary for the public's wellbeing, especially from an accessibility perspective. The shade street trees provide **protects pedestrians from excessive heat and light**, which would otherwise make streets uncomfortable for all pedestrians and potentially dangerous for those with disabilities. Temperature regulation is especially important for people with spinal cord injuries, who are at greater risk of thermal strain due to reduced thermoregulation ability (Mneimneh, 2021, p. 2). Ambient air temperature is also higher closer to the surface of urban pavement, meaning that little people, wheelchair users, children, and dogs are all more likely to experience high temperatures on urban streets (Kim et al., 2018, p. 1). The light filtration trees provide is also critical for sidewalk accessibility because photosensitivity severely affects many people with impaired vision and neurological conditions that affect visual processing (Amini et al., 2006). Blind pedestrians cannot drive and rely on sidewalks for autonomous travel, making it particularly important for sidewalks to accommodate them.

Mature trees in specific are important for sidewalk accessibility because they provide many times more shade and heat mitigation than young trees while also keeping their branches above pedestrians' heads. Young trees and shrubs tend to grow branches that hang lower than 80 inches, which is the required head clearance per ADA code for the safety of visually impaired pedestrians (accessboard.gov). These low-hanging branches, which may be primary branches for a growing young tree, need to be pruned to avoid hitting

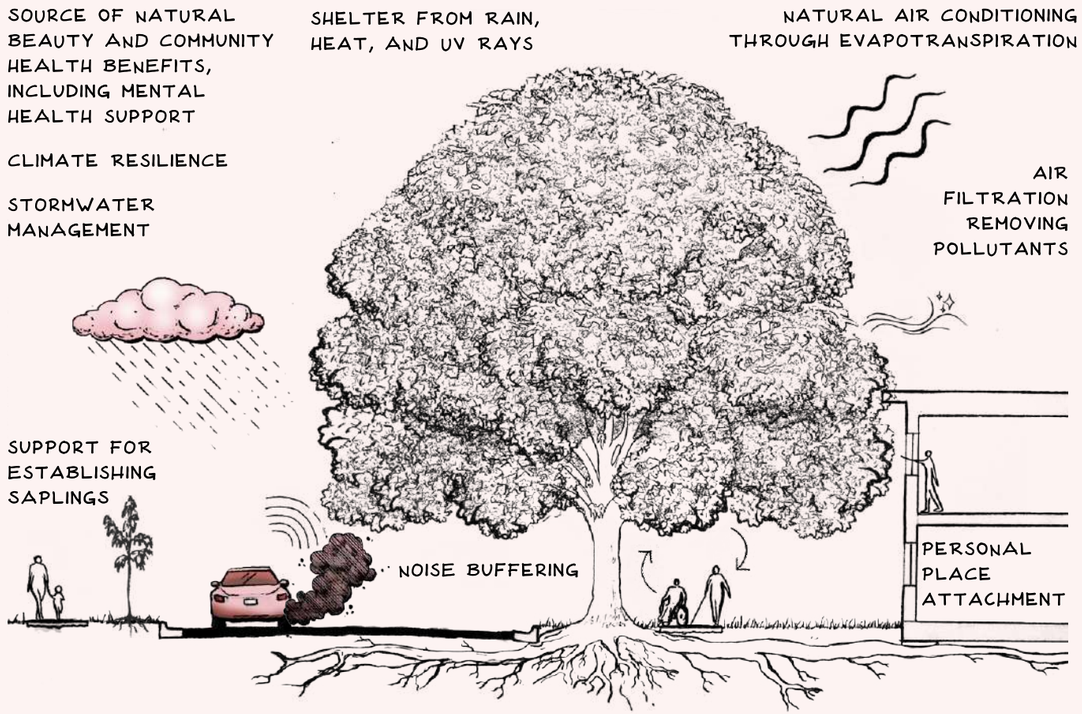


Figure 1.4.1
Benefits of a Street Tree
Illustration of street tree benefits showing a large urban street tree absorbing stormwater, filtering air pollutants, supporting wildlife, reducing the urban heat island effect, sheltering people from the elements, improving neighborhood aesthetics, and benefiting the mental health and comfort of passersby.

pedestrians in the face and possibly injuring them, but removing these critical branches early on may ultimately lead to less canopy cover over the sidewalk when the tree is mature.

Access to the environmental benefits of trees, specifically tree canopy cover, is widely accepted and recognized as a public health and urban livability issue. Streets without trees are substantially less inhabitable (see figure 1.4.2). That is why access to urban trees is an equity concern for communities that lack canopy cover. **Historically disenfranchised communities often have little tree cover**, meaning that low-income households are lacking necessary climate resilience (treequityscore.gov).

Urban forestry is especially important for people who don't have the resources to travel outside the city because trees are "the most prominent elements of urban nature" (Tyrväinen et al., 2005, p. 81). Researchers point out that "many people's experiences with nature are limited to urban

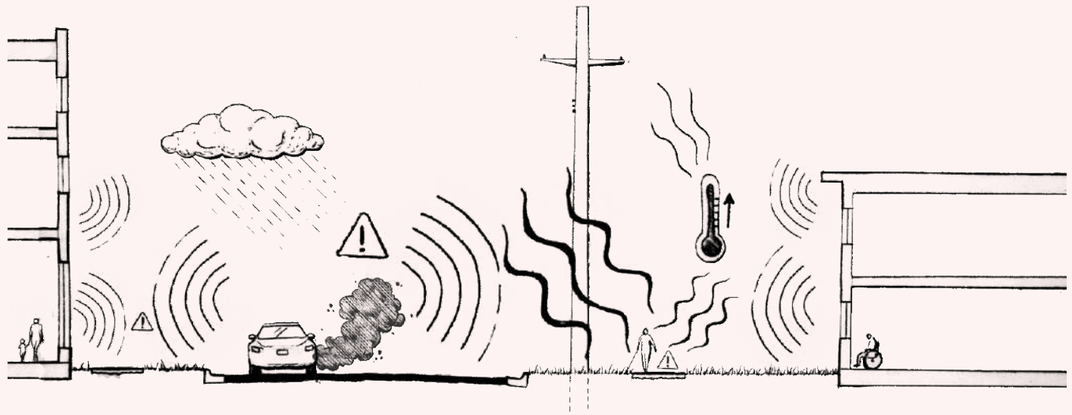


Figure 1.4.2
Our Streets without Trees
Illustrative diagram of the urban heat island effect and other negative aspects of the large amount of pavement in cities that trees offset and filter (Environmental Protection Agency, 2026a).

nature" (Ordóñez & Duinker, 2012, p. 863). The growing recognition of tree equity, meaning equitable access to trees, is driven by important tools like the Tree Equity Score (see figure 1.4.3), a multifactor GIS database that helps people identify priority areas for tree-planting and preservation efforts (treeequityscore.org).

COMMUNITY SOCIAL ECOLOGY

Trees support social ecologies alongside ecosystems by encouraging people to spend more time outside, promoting individual **mental and physical health**, and improving the aesthetic value of urban streets. Wherever they grow, trees are broadly considered **beautiful** and people seem instinctually drawn to them. Their natural beauty is especially appreciated in urban streets, where they represent most if not all of the vegetation in their context, compared to open parks and naturalistic landscapes where they may blend into the background. These improvements encourage more pedestrians to walk instead of drive; tree canopy correlates

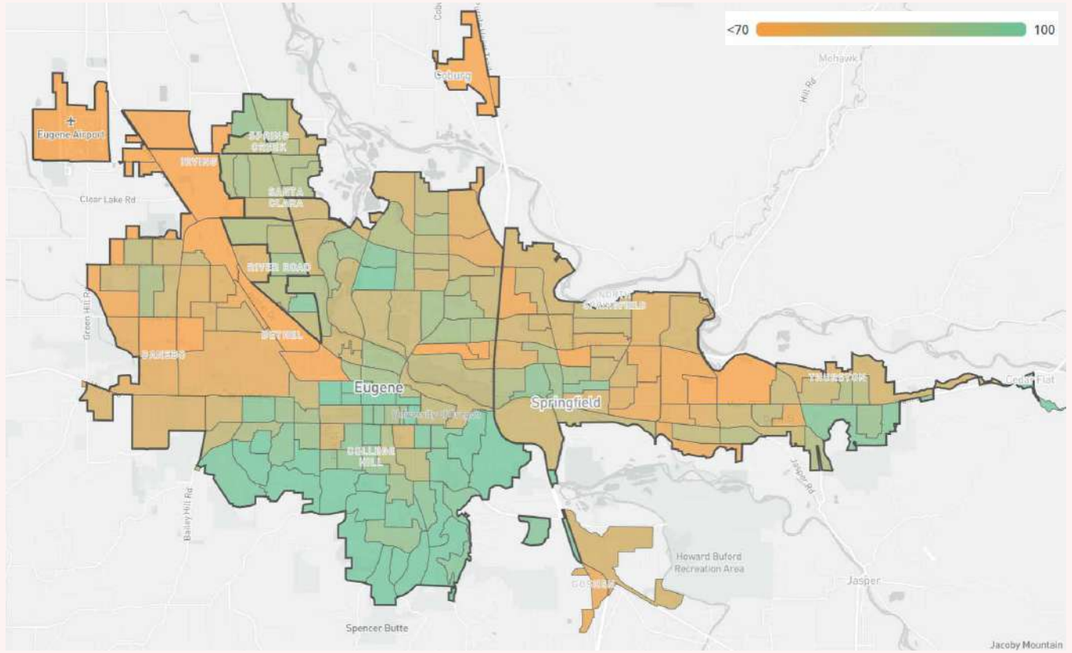


Figure 1.4.3
Eugene-Springfield Tree Equity Score Map
The tree equity score map of the Eugene-Springfield metro area in Oregon.
(treeequityscore.org)

with increased distances people are comfortable walking, which stimulates outdoor exercise, encourages more sustainable lifestyles, and connects communities (Tsai et al., 2019; Tyrväinen et al., 2005). Urban trees also correlate with positive social ecosystems in urban communities, likely because greenery makes urban environments more inviting (Kuo, 2003). Decades of research support the assertion that people prefer outdoor space with trees; see works consulted under References for more information.

More recent research connects social and ecological considerations to acknowledge the complexity of urban ecosystems. Dr. Stapleton's dissertation on place-based urban green stormwater infrastructure acknowledges that "contemporary cities, planners, policymakers, and designers must increasingly consider the ecological and social outcomes of their decisions as a complexly integrated whole" (Stapleton, 2022, p. 4). This is because cities must manage interrelated and potentially competing social vs. environmental issues and the environment has an

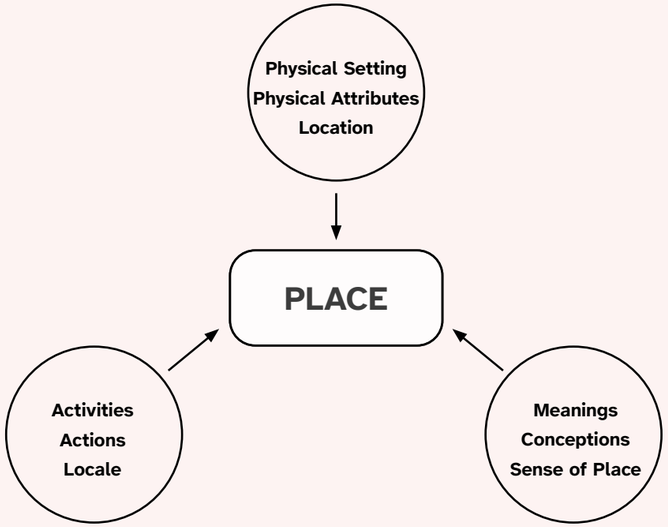


Figure 1.4.4
Trees as Place-makers through the Tripartite Model of Place
Dr. Stapleton's diagram illustrating the tripartite model of place articulated by scholars across disciplines.
(Stapleton, 2022, p. 24)

unavoidable impact on residents' place attachment. As Stapleton explains, the very concept of "place" comes from the connection between humans and their environment; this builds on decades of work interrogating the meaning and creation of "place," including a tripartite cross-disciplinary model that describes "place" as the relationship between location and human experience (see figure 1.4.4). What this means is that a space becomes a "place" when people connect with it by making memories there, associating it with someone they love, or by appreciating its beauty (Stapleton, 2022, p. 25). Using Stapleton's Place-Based Human-Environment framework (figure 1.4.5) which translates a concept of place from across disciplines into landscape architecture, **I argue that urban trees, particularly large mature trees, are an important part of place-making**.

People not only connect with and love individual trees, but need urban forests for their physical and emotional wellbeing. Street trees improve people's individual mental health, allowing them to heal and cope through the modern mental health crisis impacting communities around the world, particularly those in minimally connected urban environments (Nuccitelli, 2023). A wide body of research, including works cited by Yale Climate Connections, have

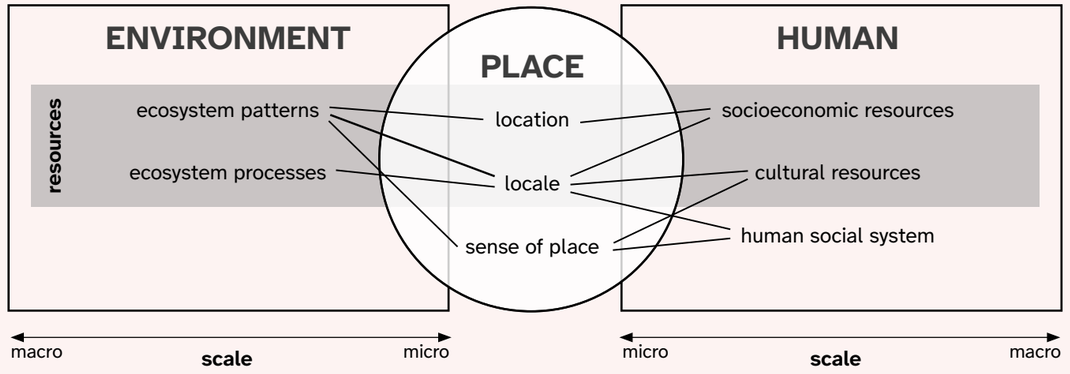


Figure 1.4.5
The Place-Based Human-Environment Relationship Framework
Dr. Stapleton's conceptual model for place-based research on human-environment relationships.
(Stapleton, 2022, p. 18)

"linked exposure to trees to both physical and mental restoration" (Nuccitelli, 2023). This includes a famous Pennsylvania study published in 1984 that connects views of trees to shorter hospital stays (Ulrich, 1984, abstract) and a 2015 study in London which suggests that higher density of street trees may "decrease the risk of negative mental health outcomes" (Taylor et al., 2015, p. 174).

There are many organizations working to spread awareness about the demonstrable mental health benefits of urban forests while promoting their improvement and preservation. For example, Ash & Elm Consulting LLC, a research-based consultancy local to Eugene, asserts that "the most important benefit of nature is its power to promote health and well-being" (Donovan, n.d.). Geof Donovan, the founder and owner of Ash & Elm, has demonstrated that urban trees correlate with improved public health outcomes including lower mortality rates (Donovan, n.d.). These considerations are critical for emphasizing the importance of urban forests, because concern for human health and longevity is effectively universal.

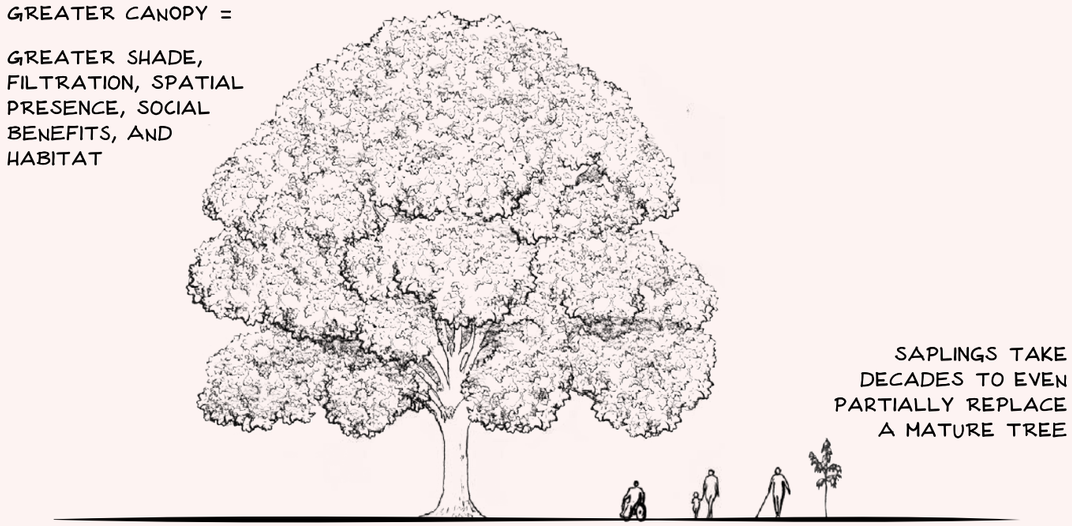


Figure 1.4.6
Benefits of Mature Trees over Saplings
Proportional illustration of a mature tree compared to a newly planted sapling.

HUMAN RESPONSE TO TREE LOSS

People have long recognized the necessity of urban trees and activists have fought against their removal in cities around the world. As Robert Moor explains in “Why We Sit in Trees,” tree activists connect with the evolutionary history of trees protecting humans and reverse those roles by using their own lives to protect trees by camping out in their canopies, which started in 1978 New Zealand (Moor, 2020). As explained in the introduction, this history includes local tree activism, like the eco-anarchy that sparked in Whiteaker in the 1990’s (Abraham, 2006).

Because of the incompatible nature of governmental structures and eco-anarchy, cities may develop a contentious relationship with tree activists, particularly if they use violent means to defend trees. However, cities often agree with the underlying animus that drives tree activists and are putting together plans to preserve and improve their urban forests. For example, the City of Eugene has been publishing Urban Forestry Action Plans since 1992. In their latest 2025 action plan, the City of Eugene reconfirms their interest in planting new trees and preserving mature trees wherever possible in alignment with residents’ values (City of Eugene, 2025a). These efforts are working against all of the forces currently jeopardizing the urban forest, including removal for conflicts with gray infrastructure (i.e. sidewalks). Removal is a significant community concern because mature trees are at elevated risk of removal and they have dramatically greater spatial presence and benefits than a sapling, which will take decades to provide the same benefits if it ever reaches the same size (see figure 1.4.6).

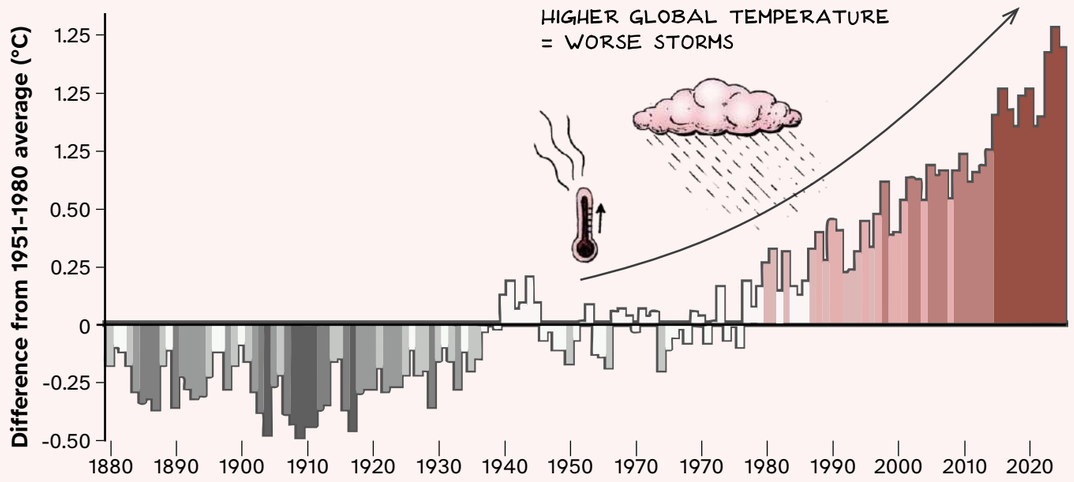


Figure 1.4.7
Climate Change and Projected Hazardous Conditions
Chart reflecting the global increase in average temperatures. Information derived from graphs and associated articles (NASA, 2026).

COMMUNITY CLIMATE RESILIENCE

One of the most pressing reasons we need to preserve mature trees is the climate resilience they provide. “Climate resilience” refers to the ability to adapt to ongoing climate change, which means maintaining tolerable temperatures and manageable stormwater runoff.[1] Temperatures are rising and the climate is destabilizing (see figure 1.4.7). **We need the climate resilience trees provide** by keeping streets cooler, increasing stormwater capacity, filtering pollutants, and improving a community’s impact on the global environment to slow the progression of climate change (Environmental Protection Agency, 2026b). Climate resilience is especially critical in cities because of urban runoff and the

[1] “Runoff” is water, typically storm water, that flows across surfaces instead of absorbing into the ground. Run-off can easily lead to floods as water collects over a large area and flows downhill.

urban heat island effect, which stacks onto the effects of general climate change, meaning that urban communities are especially vulnerable to the adverse effects of globally destabilized weather, which will lead to worsening storms and greater risk of urban flooding alongside heat waves (climate.mit.edu).

Urban forestry is foundational for climate resilience because trees provide an incredible number of ecological services and mitigate negative anthropogenic stressors. They **mitigate noise, filter air, and reduce the temperature on the street** by shading pavement from solar radiation and diffusing water vapor into the air through evapotranspiration (Environmental Protection Agency, 2026a). Mature trees are also the most effective type of vegetation for stormwater management because they capture water on their surface, including leaves, branches, bark, and the ecosystems of moss, ferns, and lichen that grow on them, and absorb it through their roots (Environmental Protection Agency, 2026a).

Trees are especially necessary in streetscapes because of the impervious surfaces (which reflect heat), cars and buildings (which produce heat), and lack of other vegetation (O'Brien et al., 2022). By offsetting these urban microclimate concerns, street trees reduce the risk of high heat exposure, meaning they protect people from heat exhaustion and heat stroke (Ettinger et al., 2024).

Some trees provide even greater benefits. Large trees with closed canopies are especially effective at reducing streetscape temperatures because of their leaf angle, leaf size, canopy architecture, and canopy density (Sanusi et al., 2017, p. 509). These **species-specific benefits** add to the reasons to protect mature trees with large leaves and dense canopies, like Bigleaf Maples.

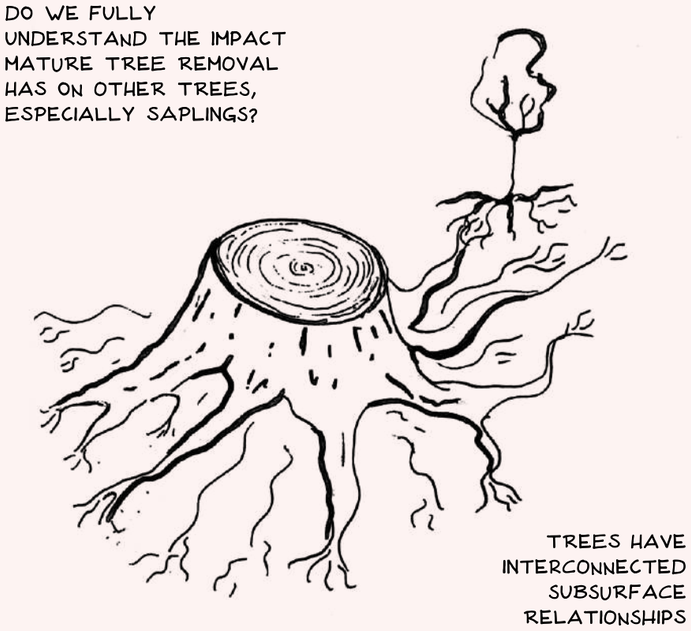
THE ECOLOGY OF URBAN FORESTS

The benefits that trees provide humans also uphold urban ecology by regulating city environments like an ecosystem and supporting urban fauna, including migrating species that pass through urban areas (Wood & Esaian, 2020). Consider birds nesting in trees, squirrels running from branch to branch to cross the street, and pollinators, like bees and butterflies, that feed on tree flower nectar every spring and summer and shelter themselves from the rain in their canopy. Urban trees provide pockets of "nature" in the city, which would otherwise be incredibly sparse ecosystems with more polluted air, excessive heat, and a lack of homes for urban fauna.

Trees also support habitat for one another; mature trees support the ecological integrity of the entire urban forest because trees are vulnerable to the same problems that they mitigate, like the urban heat island effect. Increased surface temperatures appear to be a primary factor for trees' ability to survive and thrive, especially native trees that are adapted to pre-urbanized conditions. For example, a simulated tree well study examining the impact of various pavement types on saplings found that **surface temperature was an even larger factor for tree health than surface permeability**. In fact, permeable pavement can worsen tree health if the material gets hotter than impermeable pavement (Chen et al., 2017). Further research is needed to describe the differential impact heat has on trees of various ages and species, however saplings are likely to be more heavily affected because of their vulnerable natures. The presence of existing established trees improves conditions for new trees, creating a positive feedback loop in urban forestry (Czaja et al., 2020).

Trees are also connected, especially beneath the surface. This has been long recognized by traditional indigenous ecological knowledge and has been demonstrated through empirical western research by *The Mother Tree Project*, which shows that trees not only protect one another but

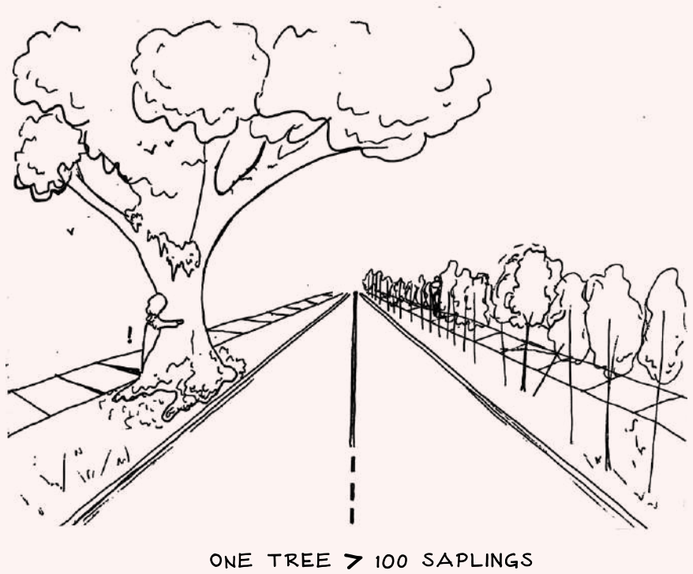
Figure 1.4.8
A Lost Mother
Illustration of a stump with its roots intertwined with a sapling, representing the sentiment of The Mother Tree Project in the context of mature tree removal.



communicate and share resources (mothertreeproject.org). The **relationship between trees in the urban forest** warrants deeper research, especially understanding the impact mature tree removal has on surrounding saplings. It is worth asking how stumps impact surrounding trees, if trees that have been cut down begin receiving instead of providing resources, and if they communicate distress to the trees around them (see figure 1.4.8).

Intergenerational tree support is increasingly critical for modern urban ecosystems because anthropogenic stresses are increasing, making it harder to establish urban forests. Estimates vary, but urban trees' average lifespan appears to barely enter maturity. One of the most frequently cited studies on street tree life expectancy, which shows longer street tree lifespans than common pre-existing estimates, found that street trees' average lifespan was 19 to 28 years and the street tree population half-life was only 13 to 20 years (Roman & Scatena, 2011). These numbers are frightening because trees only have enough biomass to provide their full microclimate regulating benefits when

Figure 1.4.9
Saplings Cannot Replace a Tree until They Grow
Illustration of a mature tree across the street from a line of smaller saplings stretching out into the distance.



they reach maturity after decades of growth – in a way that is when their life really begins (Wagner, 2023). And because we don't know where we will be decades from now, when a mature tree is cut down it may never be truly replaced. Consider just the biomass loss; a tree with a 26" diameter trunk has 169x the cross-sectional area of a 2" caliper sapling, which may take 70 years to reach its predecessor's size, if it ever does. This means cutting down a tree and planting a sapling, or even several saplings, is a net negative for an urban forest (see figure 1.4.9).

SUMMARY

Mature trees are effectively a **nonrenewable resource in modern contexts**. Every tree removed is a real loss that has the potential to permanently damage a community's sense of place, reduce local climate resilience, change the microclimate, harm the urban ecosystem, and even make the adjacent sidewalk less accessible by removing heat and light protection.

1.5 THE INTERDISCIPLINARY COMPLEXITY OF ROOT HEAVE

Sidewalk root heave often feels like an impossible problem with no “right” answer. It seems like an inevitable problem that sits at the **intersection between environmental and civil rights concerns** (see figure 1.5.1). Between unfortunate constraints of existing conditions and competing pressures in favor of leaving all mature trees alone or fixing all sidewalks, cities are left between a rock and a hard place. However, there are several avenues for new research that could reveal a more peaceful path forward.

SUMMARY

- Trees lift sidewalks because of the natural incompatibility between root growth and where and how sidewalks are constructed.
- Surface-rooting species like Bigleaf Maples seem especially likely to lift sidewalks and can not necessarily tolerate root pruning, which is typically required for tree-preserving repairs.
- Concrete seems to encourage rapid surface root growth, likely worsening root heave.
- Sidewalk root heave is a public safety and civil rights issue because lifted sidewalks can easily become tripping hazards for everyone and obstructions for people with disabilities.
- Most solutions to sidewalk root heave rely on root pruning or control.
- Sidewalk repairs have substantial financial and environmental costs while also requiring significant pedestrian path closures.
- Cities rely on street trees for climate resilience, mature trees provide the greatest benefits, and people are often personally attached to mature trees, which anchor their sense of place in their homes.
- Mature trees are an effectively non-renewable resource in modern contexts.
- It is critical to preserve mature trees until they have reached the end of their lifecycle while planting new trees. But for sidewalk maintenance to be sustainable we need to better understand why root heave happens and how to reliably minimize it longterm.

GAP IN KNOWLEDGE

There is insufficient information on the **morphological behavior of mature street trees and their measurable impact on sidewalk accessibility**. This research addresses the gap in knowledge between tree root behavior (which focuses on young trees) and sidewalk inaccessibility (which only partially addresses root heave). The critical part of this knowledge gap is how designers can work to preserve established, mature street trees while raising the bar for sidewalk accessibility.

CONTRIBUTION TO KNOWLEDGE

This research is intended to support ongoing efforts to preserve mature street trees while repairing sidewalk accessibility by considering street trees as a key user group for sidewalk design.

To protect our cities in the present and future, designers need to understand the impact of their decisions, thus the responsibility they hold.

This research includes a glossary of existing resources (see References), an original field study on mature street trees, and a proposed system of design experimentation that acts as a precedent designers can use to inform design decisions on sites that require path repair or construction within a large tree’s critical root zone.

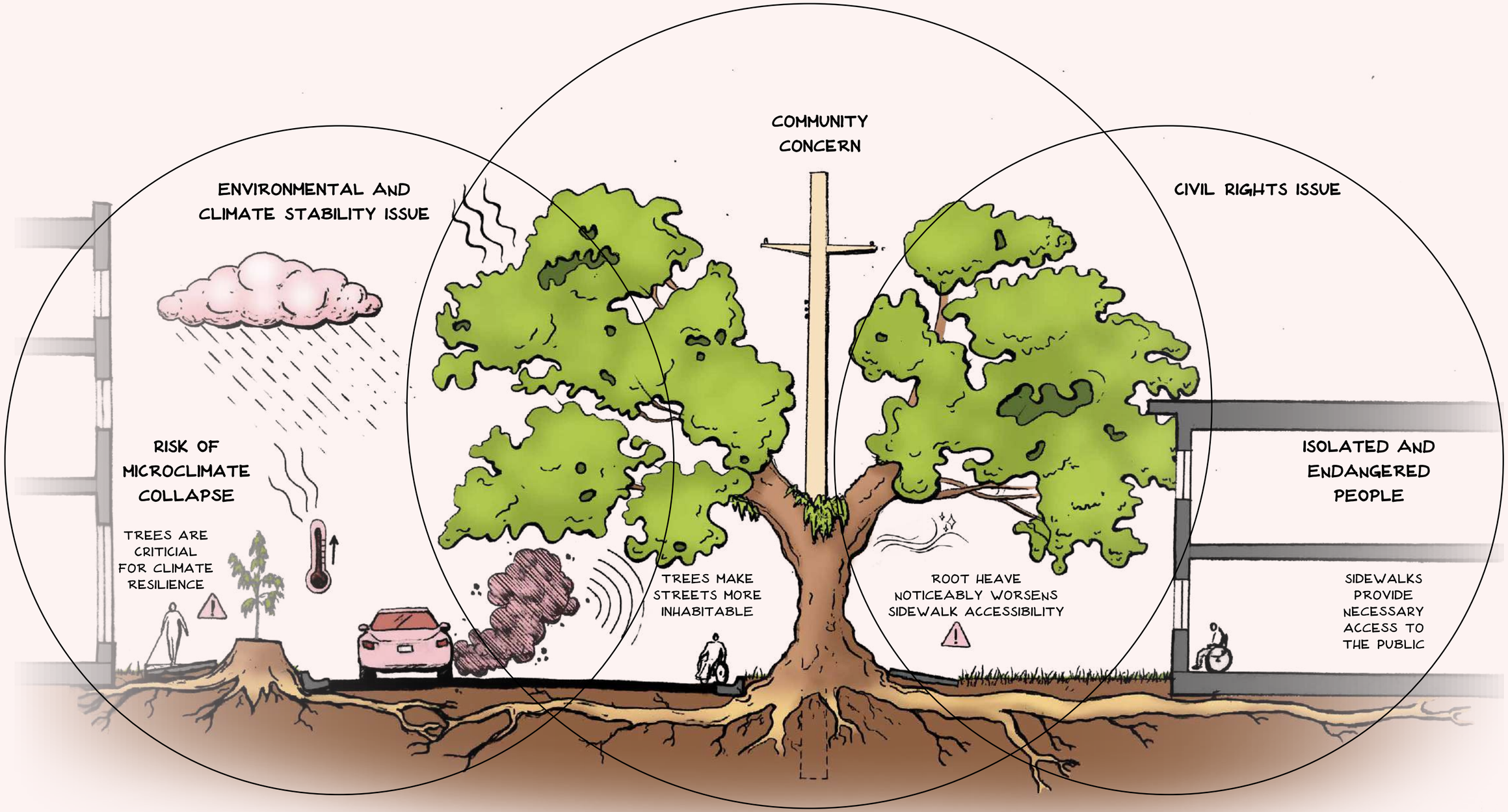
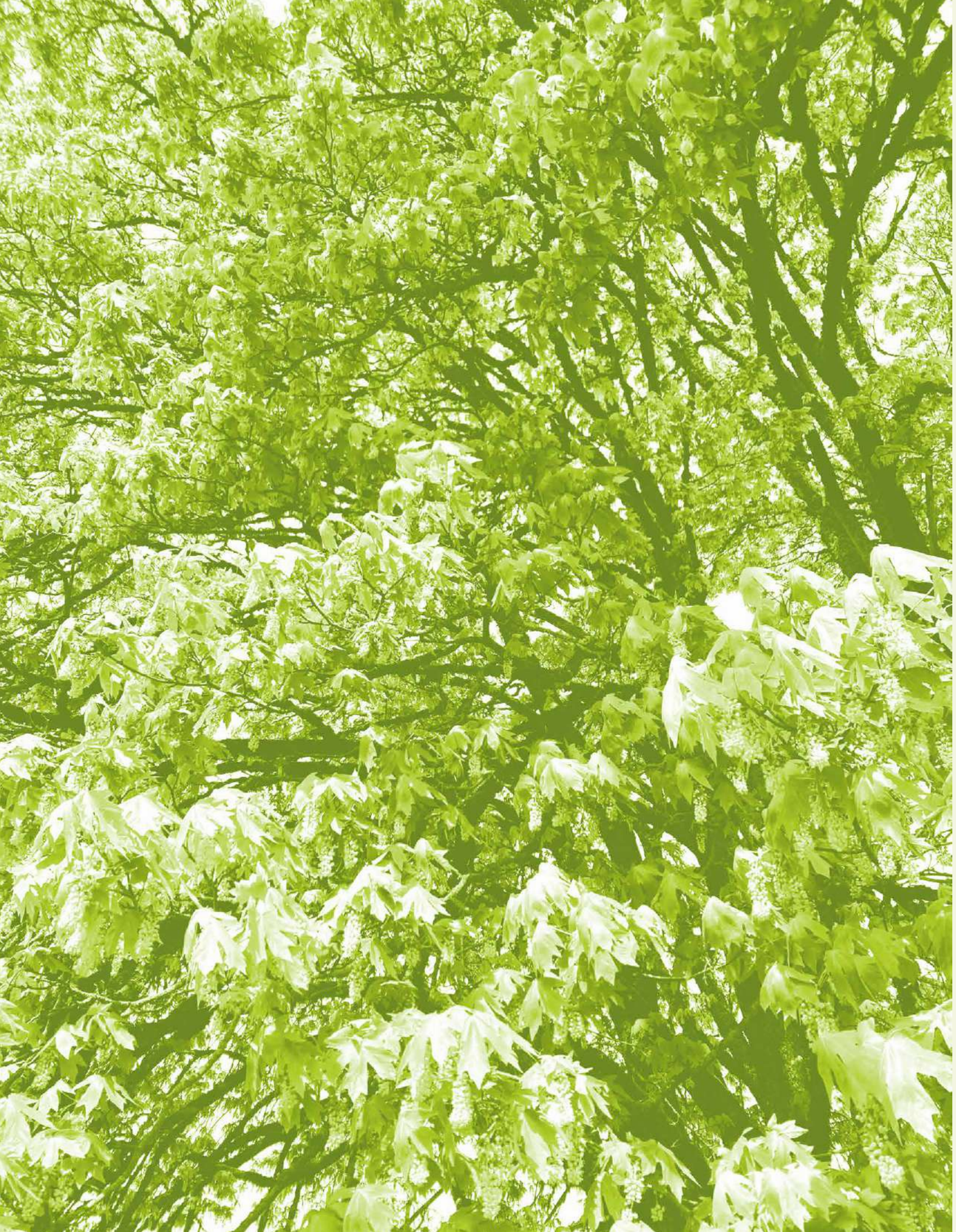
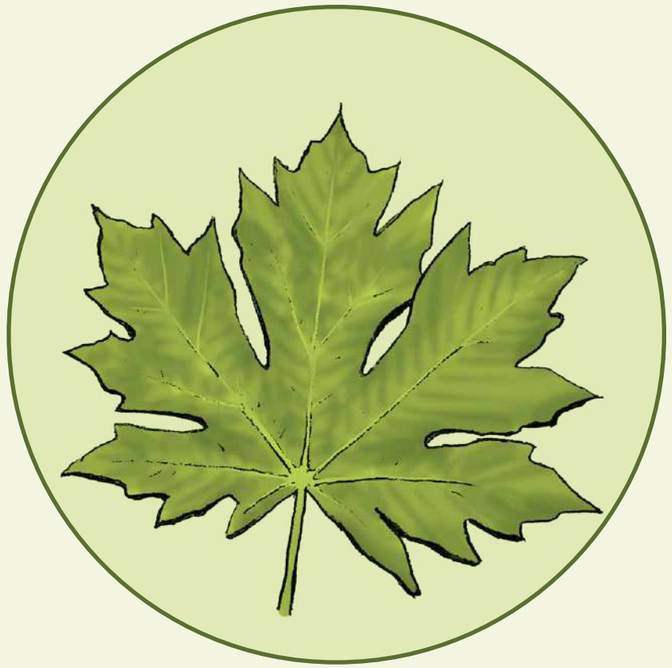


Figure 1.5.1
Background Summary Diagram
Illustration of the complex concerns and constraints surrounding sidewalk root heave caused by mature trees.



2.0



STREET TREE STUDY

2.1 *Hypotheses*

2.2 *Scope & Rationale*

2.3 *Methods*

2.4 *Results*

2.5 *Discussion*

This research investigates root heave around particularly large street trees in Whiteaker to summarize the response the urban forest has had to local growing conditions.

The goal of this study was to **reframe sidewalk root-heave as a design problem where the design clients, mature trees and people, have conflicting needs to be reconciled**. As such, the questions, metrics, and methods outlined in this section were selected with the intent of better **understanding what street trees, specifically Bigleaf Maples, are asking for us to change**.

2.1 HYPOTHESES

RESEARCH GOALS

The primary goal of this research was to provide immediately applicable information for arborists, designers, engineers, municipalities, and residents to use in diagnosing and addressing emerging root heave. **Mature street trees were the subjects of this research** because they are at greater risk of removal and are critical for the future of our communities. Root heave is not an issue of street tree establishment, it is the potentially inevitable outcome of how they grow over time, and the trees that established themselves decades or over a century ago have had the most possible time to respond to their environmental conditions.

A secondary goal of this work was to **directly listen to trees, recognizing them as living beings that react to their surroundings** and permanent inhabitants of the urban streetscape. Trees communicate through their growth patterns, which illustrate their reaction to the surrounding environment and resources.

RESEARCH QUESTIONS

The study centered the following questions:

- How does street tree morphology respond to sidewalks?
- How does sidewalk root heave severity relate to tree growth factors?

By approaching these questions qualitatively and quantitatively, the study aimed to explore how the urban streetscape influences street tree root growth (see figure 2.1.1).

HYPOTHESES

Given the myriad of possible growth indicators, this research covered a long list of possibly correlated factors, aiming to support or challenge other works' evidence-based hypotheses and the tentative hypotheses commonly held

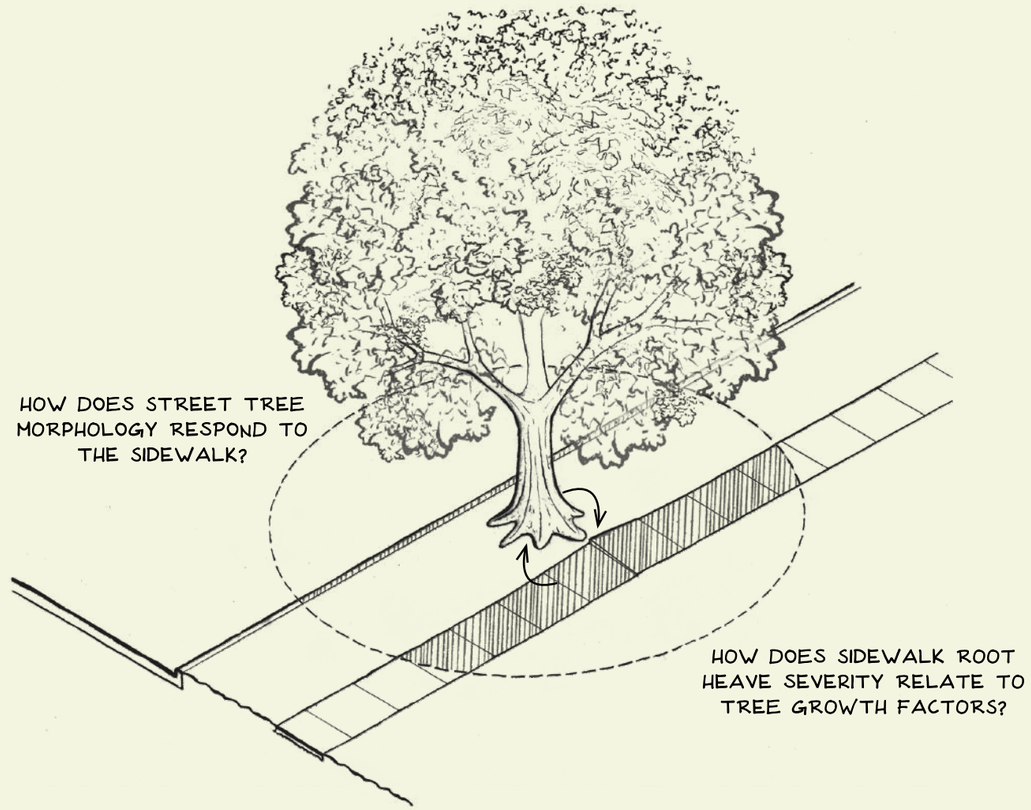


Figure 2.1.1
Research Questions
Isometric drawing of a street tree indicating a focus on the relationship between the base of the tree and the sidewalk.

among people who manage and observe street trees on a regular basis. The scope for this work can be best described by the metrics and possible correlated factors listed below and shown in figure 2.1.2.

Accessibility metrics used to quantify root heave:

1. Maximum **slope** within canopy.
2. Maximum **cross slope** within canopy.
3. Maximum **level change** within canopy.

Reference for the **relative impact of roots within trees' canopy dripline**:

4. Maximum **slope** outside canopy.
5. Maximum **cross slope** outside canopy.

Possible correlated factors:

6. Approximate **sidewalk age**. Older sidewalks were expected to correlate with worse accessibility metrics.

7. Evidence of **concrete grinding**, which indicates a temporary fix for level changes caused by root heave. Expected to correlate with fewer and shorter level changes because the height of the level changes has been manually reduced.

8. **Plant bed and sidewalk widths** (noting where widths were modulated to widen the plant bed at the tree). Less root heave was expected where the sidewalk was modulated, because this shows that it was repaired in response to root heave.

9. Tree **species**. Root heave was expected to vary across species, with surface-rooting species being more likely to correlate with greater root heave.

10. Trunk diameter at breast height (**DBH**). A positive correlation between trunk size and root heave severity.

11. **Root-sidewalk distance** and trunk centerline to sidewalk distance. A negative correlation between root heave and the distance from visible surface roots to the edge of the pavement was expected. This is because, theoretically, the closer the roots are to the sidewalk the more the roots will lift the sidewalk. The trunk centerline to sidewalk distance was also expected to inversely correlate with root heave severity.

12. Tree **morphology**. The way trees grow was expected to respond to the adjacent sidewalk and the four directions because environmental factors influence the resources available to the tree at any given site.

13. **Direction** of the sidewalk relative to the tree. This was expected to primarily influence tree morphology, no direct relationship to root heave was anticipated.

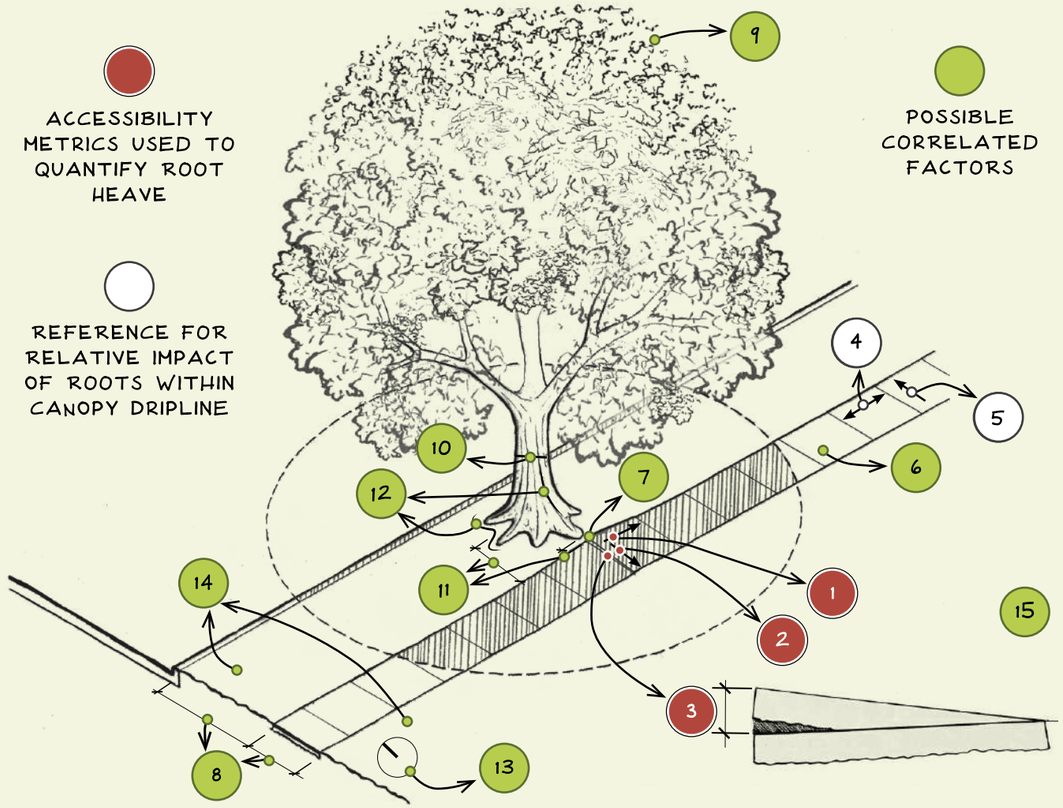


Figure 2.1.2
Hypotheses
Isometric drawing of a street tree noting hypothesized correlations.

14. Signs of surface-level **irrigation**. Because roots seek water, irrigated lawns encourage surface rooting and were thus expected to correlate with greater degrees of root heave. This hypothesis is **untested** because there is no reliable way to determine the presence of irrigation and an overwhelming majority of sites showed some signs of irrigation.

15. **Site context**. This includes adjacent property types, among other information. Residential sites were expected to have greater root heave because property owners may be unaware sidewalk maintenance is their responsibility or lack the funds or interest in maintaining them. The vast majority of sites were residential lots and no other property type had a comparable sample size, so this was also left **untested**.

2.2 SCOPE AND RATIONALE

The scope for this study was limited to **street trees with a DBH over 25” in the Whiteaker neighborhood with sidewalks constructed within their critical root zones**. Trees over 25” in diameter are mature across all species and are often eligible for consideration as heritage trees.

Most significantly, the entire streetscape surrounding these trees is within their critical root zones as defined by the City of Eugene’s tree protection zone calculations. The minimum area to protect around trees in construction sites is a circle around the tree with a radius of 1’ - 6” per 1” of trunk DBH, which equals 39’ - 0” radius for a 26” diameter tree, the smallest size included within the project scope (City of Eugene, 2015). Since a standard residential street with curbside parking in Eugene is 28’ - 0”, plant beds can be as narrow as 6’ - 0” wide, and sidewalks are typically 5’ - 0” wide, the sidewalk on the opposite side of the street is often within these tree’s critical root zones (28 + 6 + 5 = 39) (City of Eugene, 2025b, p. 23). These trees have extensive root networks with large roots near the trunk and beneath the adjacent sidewalks, and are thus likely to lift the pavement.

METHODS OF DEFINING SCOPE

The scope for this research references the City of Eugene’s public GIS tree inventory, which includes data on each tree, such as species, latest measured diameter, and site type. Diameter listed is diameter at breast height in inches, the number of trunks is a significant factor because the diameter of each trunk is added together in this inventory (following standard practices), and the site type is most critical because “T” type sites are trees while “S” sites are stumps and “P” sites are planting sites.

To define the project scope, trees were first filtered by diameter and number of trunks. Whiteaker has a greater number of single-trunk trees over 25” in diameter than other neighborhoods (see figure 2.2.1). They were then filtered



by site type to exclude stumps, and filtered by location to only include trees within the Whiteaker neighborhood. Trees within park footprints and those over 25’ - 0” from a sidewalk were also removed to exclude trees in relatively unrestricted park settings, which are different growing environments than streets, and trees with no adjacent sidewalk to measure. Lastly, trees were field-verified to match the study’s criteria, and those not fitting the scope, such as recently deceased trees, were removed from consideration.

Figure 2.2.1
Scope within Eugene and Selection Process
Map of Eugene’s entire urban forest noting trees with one trunk over 25” in diameter with Whiteaker outlined.

OVERVIEW OF TREES WITHIN SCOPE

The resulting project scope is neatly defined as large street trees shading sidewalks in the Whiteaker neighborhood (see figure 2.2.2).

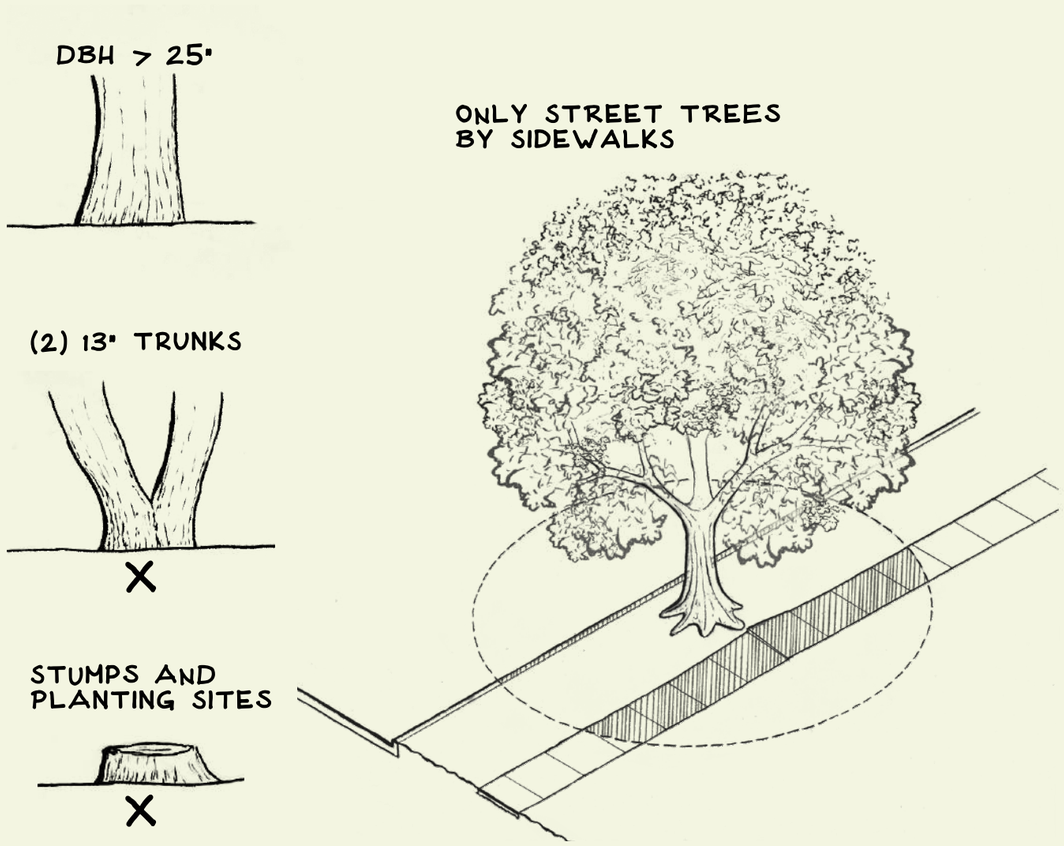


Figure 2.2.2
Scope Selection Process
Illustration of the factors that were filtered in and out of the city's tree database to define the project scope.

Approximately 40% of the trees included in this study are Bigleaf Maples (see figure 2.2.3), including the largest tree within the scope, which measured 61" in diameter.

As described in the project introduction, a likely reason Bigleaf Maple is the dominant species within the project scope is that these trees may have been brought from their natural habitat on the Willamette River into the street early in Eugene's history. Since the Willamette River runs along the north edge of the Whiteaker neighborhood, these trees are growing close to their natural habitat, albeit in dramatically different growing conditions. For context, the primary soil types in Whiteaker are Malabon and Coburg, which are described as **silty clay loam with moderate shrink and swell** in City of Eugene GIS soil data.

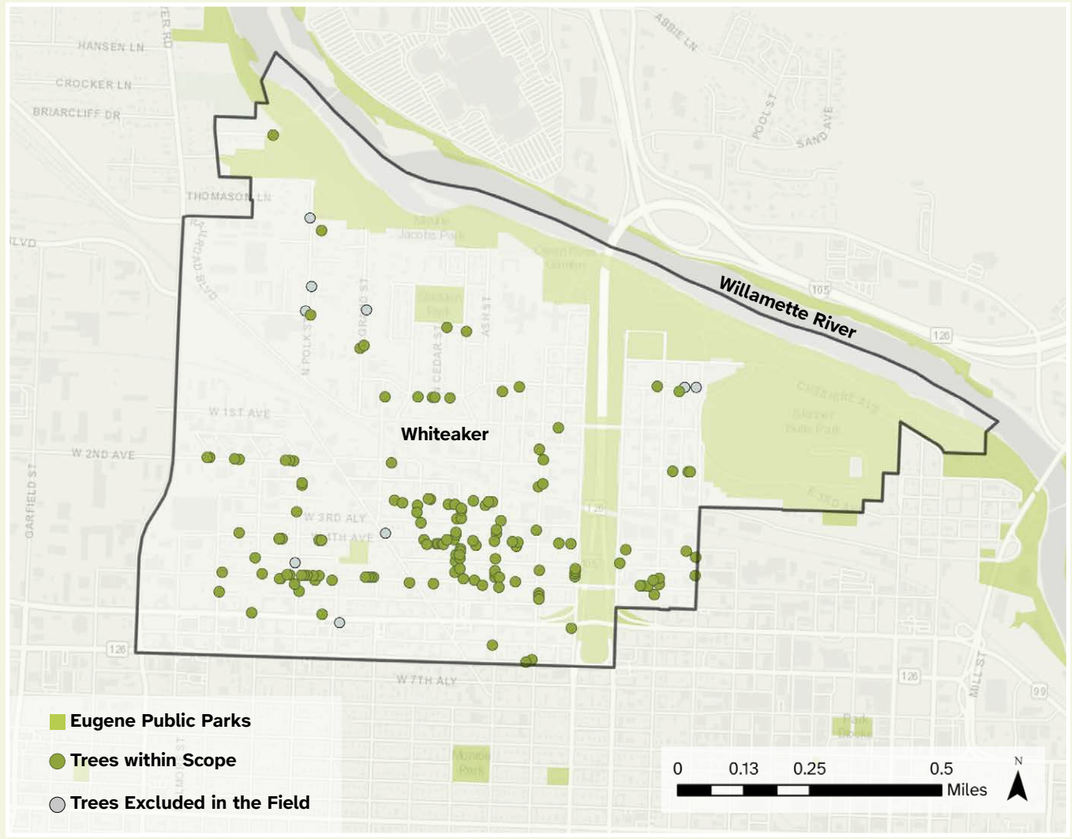
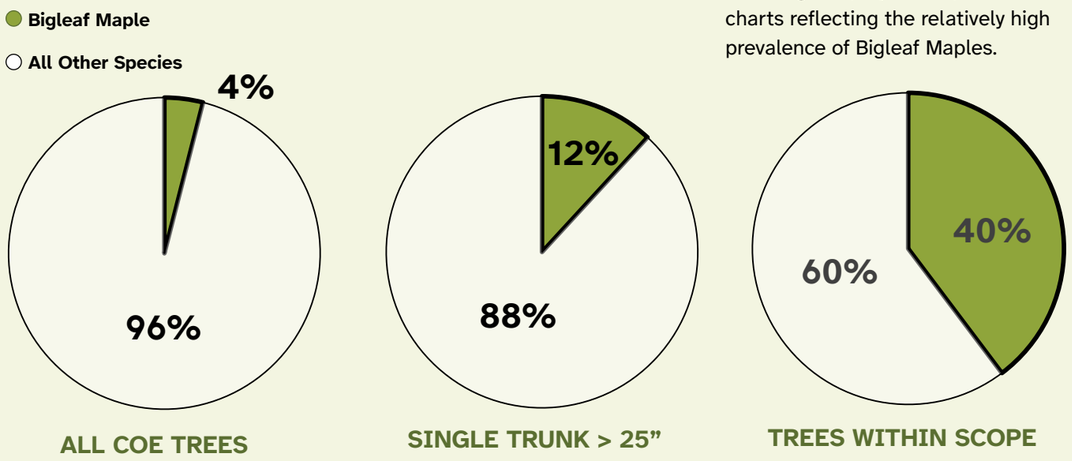


Figure 2.2.3
Selected Scope and Prevalence of Bigleaf Maple
Map of the 146 trees identified as fitting the project scope. Pie charts reflecting the relatively high prevalence of Bigleaf Maples.



2.3 METHODS

The following measurements and evaluations were made at each site between December 2025 and February 2026:

SLOPES INSIDE AND OUTSIDE THE TREE CANOPY DRIPLINE

All slopes were measured using a 24” Stabila smart level following common methods for assessing path accessibility. **(1) Maximum slope** within the canopy was measured parallel to the path of travel, placing the smart level at locations that appeared to have a high slope until the maximum slope that could support the level’s length was identified. Anomalies such as curb ramps were excluded. **(2) Maximum cross slope** was measured in the same manner for slopes perpendicular to the path of travel and assigned a positive value for slopes pointing away from the tree (see figure 2.3.1).

(4) Maximum slope and **(5) maximum cross** slope outside the canopy were measured in the same fashion as those within the canopy, except they were limited to areas outside the tree’s canopy but within the same general area, on a section of the sidewalk that is as similar as possible. Where tree canopy overlapped with adjacent trees, the sidewalk outside the canopy was measured just outside the canopy edge.

MAXIMUM LEVEL CHANGE HEIGHT

(3) Maximum level change height was measured on lines running perpendicular to the path of travel, typically sidewalk joints centered on the tree or between concrete pours of different ages. The height was measured at the peak of the level change from the higher walking surface to the lower walking surface. Level change extent was also noted, but most level changes exceeded 1/4” across the entire width of the sidewalk, so this was not a significant measurement.

APPROXIMATE SIDEWALK AGE

(6) Estimated sidewalk age categories were assessed by

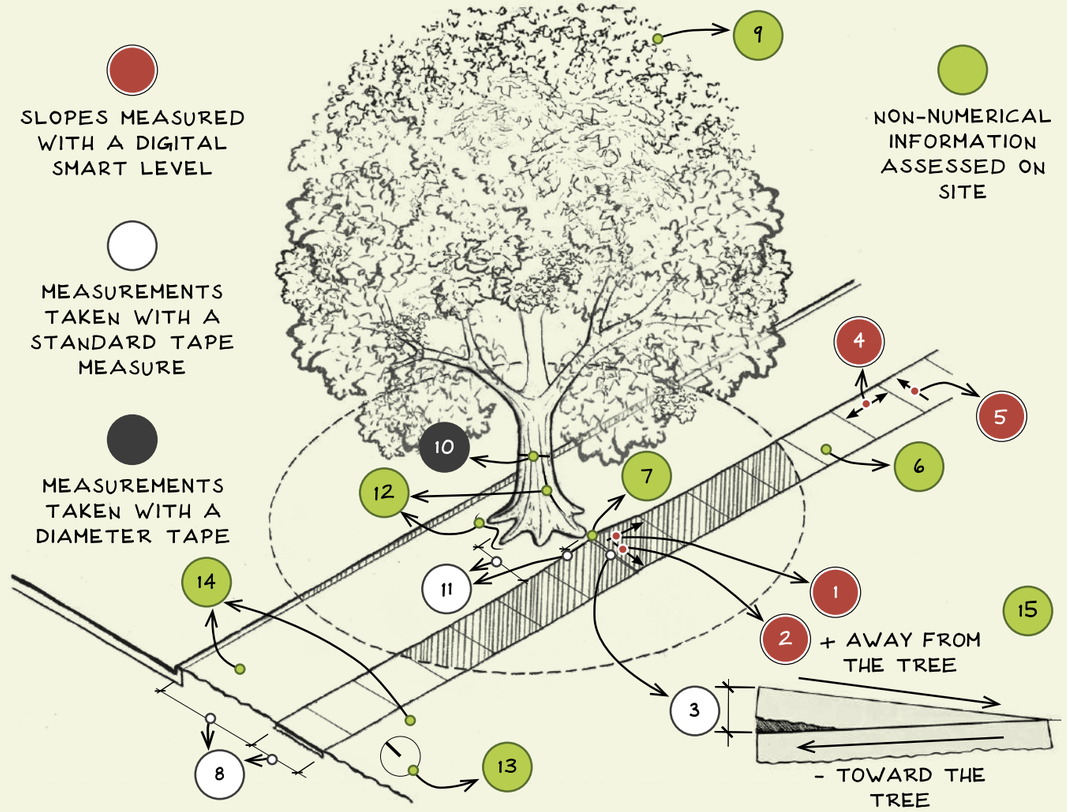


Figure 2.3.1
Methods
Isometric drawing of the measurements taken at each site.

taking simple field notes and photos at each site that were later compared to the references shown in figure 2.3.3. The “new” sidewalks resemble those known to be 5 years old or less, meaning they show no signs of weathering. “Young” sidewalks appear to be older than 5 years but younger than the “weathered” sidewalks, which had pitted or spalled surfaces and often featured a vintage pebble finish. Lastly, “historic” sidewalks match the jointing pattern, tone, and color of sidewalks known to be around one century old, including a local sidewalk stamped with the year 1914. Given that the age of most sidewalks is unknown, this was the best available means of estimating sidewalk age. However, this method was highly qualitative and somewhat subjective. “Young” is also a notably broad category.

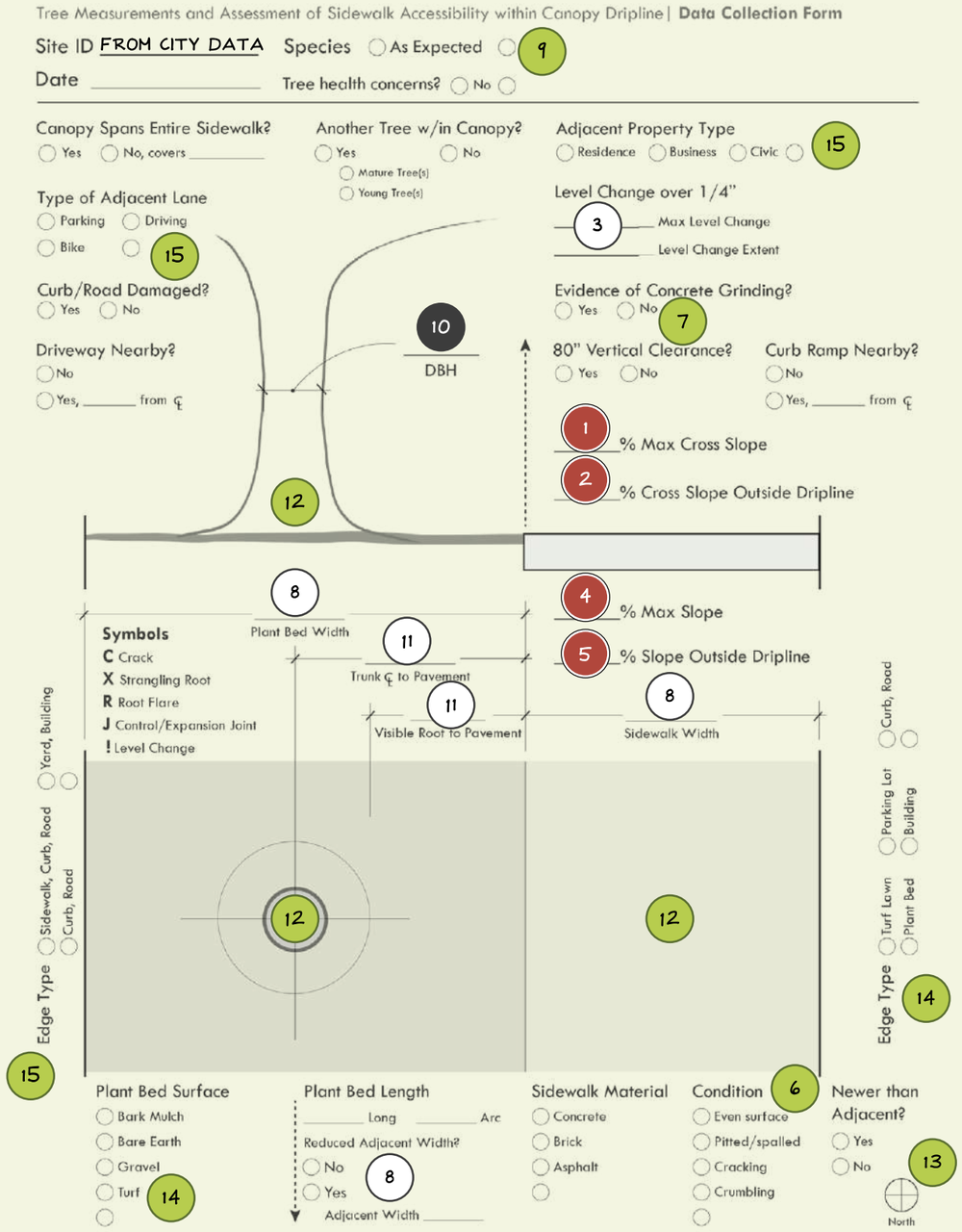


Figure 2.3.2
Data Collection Form
Form created specifically for collecting the data required for this study. See the appendix for a blank version.



EVIDENCE OF CONCRETE GRINDING

(7) Evidence of concrete grinding was assessed by looking for characteristic areas with exposed, flattened aggregate, clearly indicating the concrete had been ground down.

PLANT BED AND SIDEWALK WIDTHS

(8) Site dimensions were measured with a standard tape measure perpendicular to the path of travel, rounded to the nearest 1/2".

TREE SPECIES

(9) Tree species was confirmed on site using the city's tree inventory and physical identification using seeds attached to the tree and winter buds.

TRUNK DIAMETER

(10) Tree **DBH** was measured following best practices, meaning the diameter was measured 4' - 6" from the adjacent grade except to avoid low branches and burls.

TREE DISTANCE TO SIDEWALK

(11) Root-sidewalk distance was measured using a standard tape measure perpendicular to the path of travel and rounded to the nearest 1/2". The trunk centerline to

Figure 2.3.3
References for Sidewalk Age Estimation
Photos of sidewalks with approximately known ages used for reference when estimating the age/assessing the weathering of sidewalks evaluated in Whiteaker.









Figure 2.3.4
Methods in Action
Photos of research methods in the field, taken by Lilika Bechtle-Hanson.

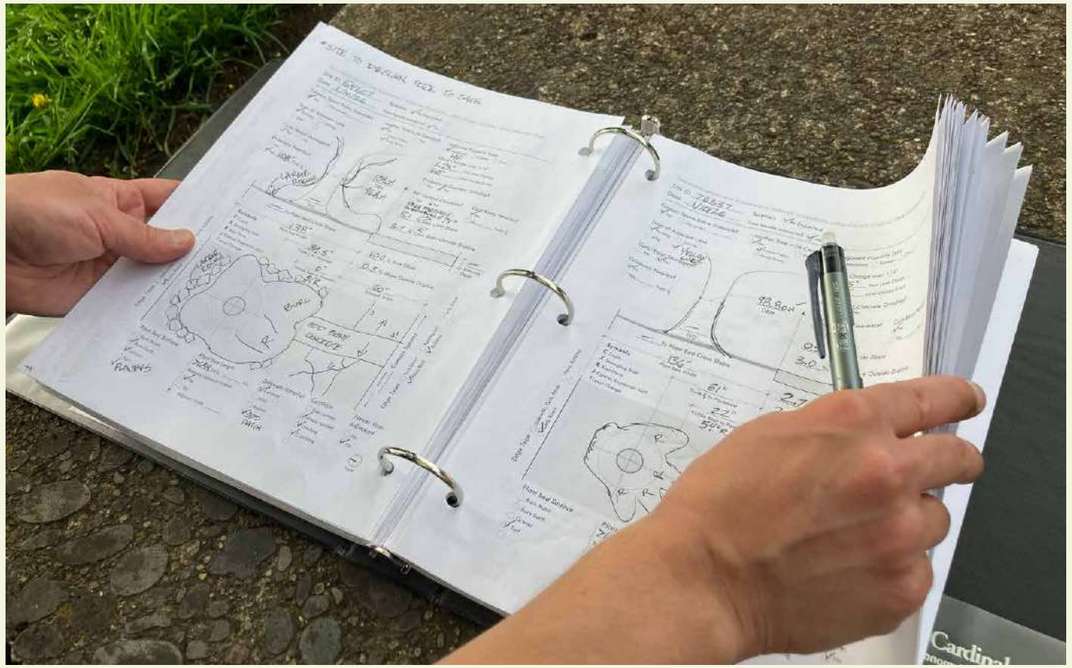


Figure 2.3.5
Collected Data
Photo of the binder used to hold tree data collection forms, taken by Lilika Bechtle-Hanson.

sidewalk distance was measured in the same way after approximating the trunk centerline. The root-sidewalk distance was the more precise, accurate measurement but it is an effect of tree growth, while centerline distance was an initial design decision.

TREE MORPHOLOGY

(12) Tree morphology was evaluated using similar methods to those demonstrated by an Urban Forestry Consulting Arborist at the City of Eugene; this meant “reading” the tree by noting the location, direction, and relative size of root flares where the tree meets the ground, and noting its form in profile. This information was diagrammed in the field alongside sidewalk crack and slope information using the guides on the data collection form (see figures 2.3.2 and 2.3.5). This is the least empirical but most illustrative method used.

DIRECTION

(13) The **direction** of north was noted at each site using the compass in Avenza Maps, the software used to find each tree

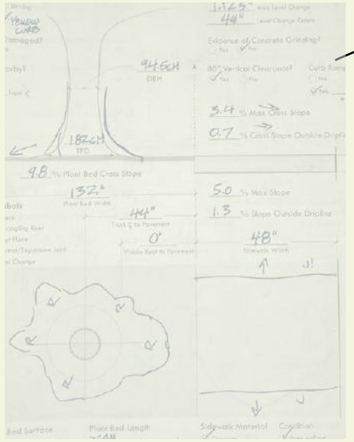




Figure 2.3.6
Overlay Analysis Diagram
Illustration of how diagram sketches made in the field were used to identify patterns of tree growth.

within the project scope and take geolocated photos of each tree and completed data form. This was used to deduce the sidewalk direction relative to the tree.

SIGNS OF SURFACE-LEVEL IRRIGATION

(14) Visible **irrigation** was not typically found, so surface-level irrigation was estimated by documenting the presence or absence of plants requiring irrigation near the tree.

SITE CONTEXT

(15) **Site context** was assessed by observation of site qualities and documented with check boxes in the tree data collection form.

QUANTITATIVE DATA ANALYSIS

Data was tabulated in a spreadsheet to generate charts and graphs to communicate the measured ranges and their factors' correlatory relationships.

QUALITATIVE DATA ANALYSIS

To visualize patterns recognized across the trees, the diagrams made in the field were overlaid in Adobe Photoshop, aligned using the underlying guides, and

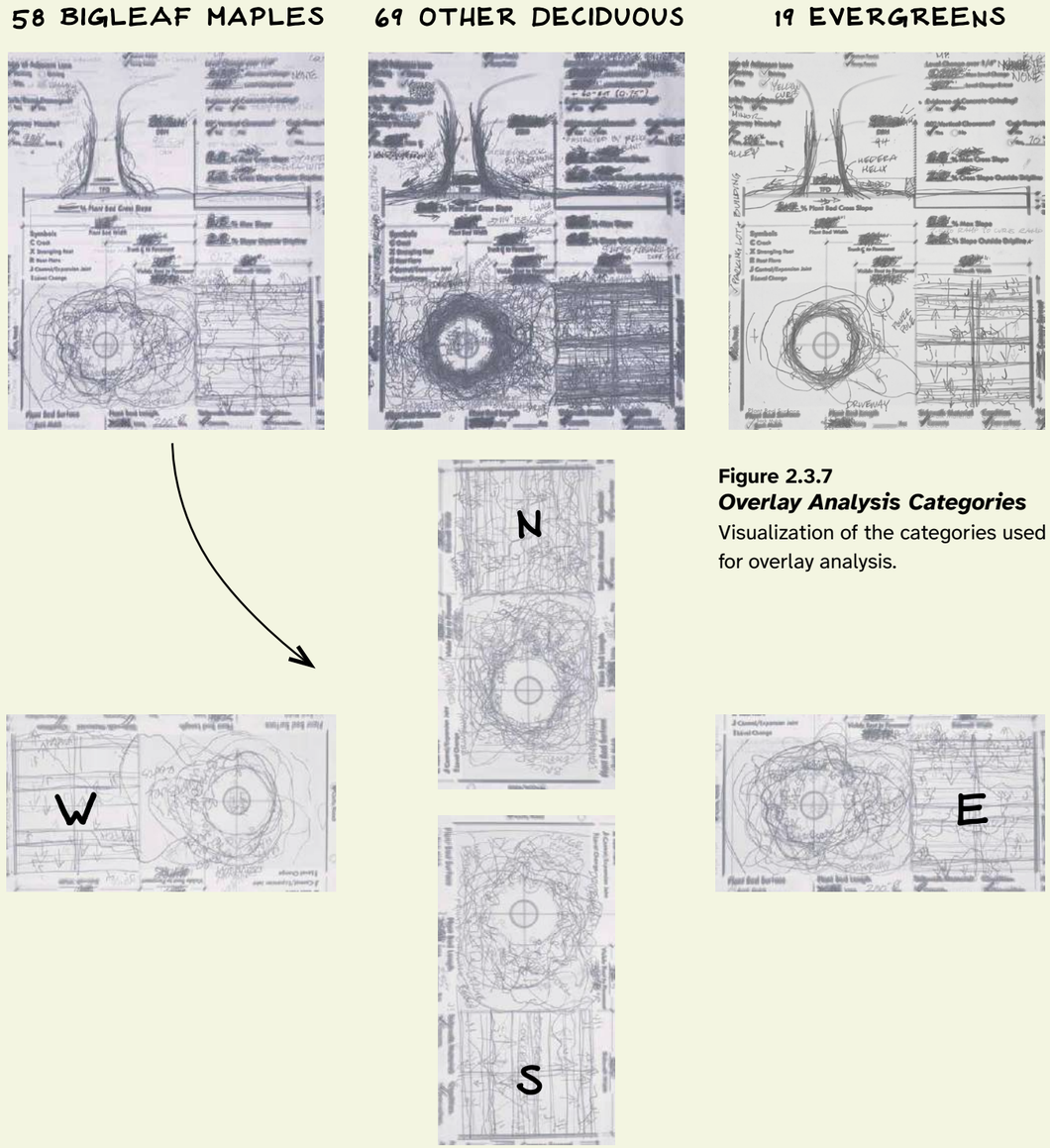


Figure 2.3.7
Overlay Analysis Categories
Visualization of the categories used for overlay analysis.

exported to images that were used as underlays for illustrative vector diagrams in Adobe Illustrator (see figures 2.3.6 and 2.3.7). The intention with this method is to summarize the "reading" of each tree, helping to identify common patterns for arborists, particularly those who manage these trees. For researchers, these diagrams are meant to support hypotheses for future empirical studies using more exact methods like photogrammetry.

2.4 RESULTS

OVERVIEW

The results from this street tree study were surprising, negated many of hypotheses presented in this work, and provided unexpected correlations that warrant further research (see figure 2.4.1).

While **root heave has a clear, measurable impact on sidewalk accessibility** that is notably greater within the tree's canopy, the underlying variables are complex. Most, if not all, documented variables appear to be significant, but root heave seems to be **site-specific and potentially unpreventable with on-grade sidewalks**, at least around existing mature trees.

The lines noting "ADA failure" in the graphs in this section show accessibility code requirements, illustrating the proportion of measured sites that exceed these thresholds.

These figures appear throughout the results section and each metric a site "fails" means it exceeds code allowances for that metric. Graphs noting the number of "**modes of failure**" describe whether the sidewalk near a tree had excessive slope, cross slope, level change, or a combination of all three.

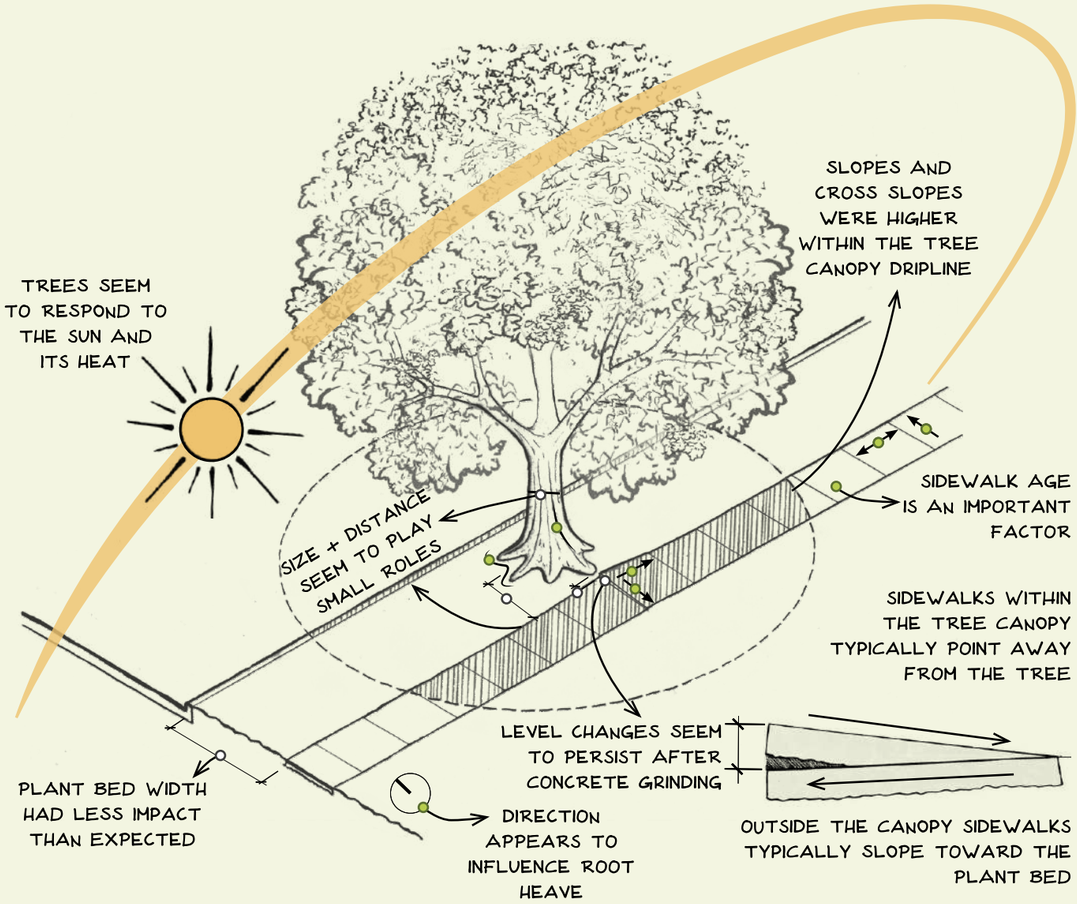
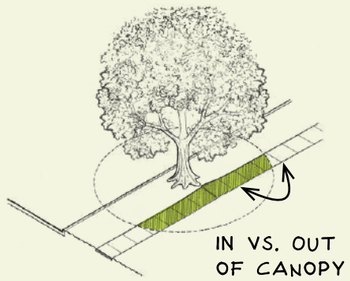


Figure 2.4.1
Overview of Results
Isometric drawing of a street tree noting correlations identified in this study.



INSIDE VS. OUTSIDE CANOPY

The maximum measured slopes and cross slopes were higher within the tree canopy compared to outside the canopy dripline (see figures 2.4.2 and 2.4.3). The cross slope was typically positive, meaning pointing away from the tree, within the canopy and negative, or sloping toward the plant bed outside the canopy, indicating that the sidewalk was typically lifting away from the tree. This is most likely due to tree roots expanding radially, displacing soil upwards, thus lifting the pavement. Even locations where the sidewalk is tilted toward the tree may be influenced by root heave; roots may not always grow straight out and can resurface after diving deep (see figure 2.4.4).

Figure 2.4.2
Slope Inside vs. Outside Canopy
Box and whisker charts reflecting slope inside vs. outside the tree canopy.

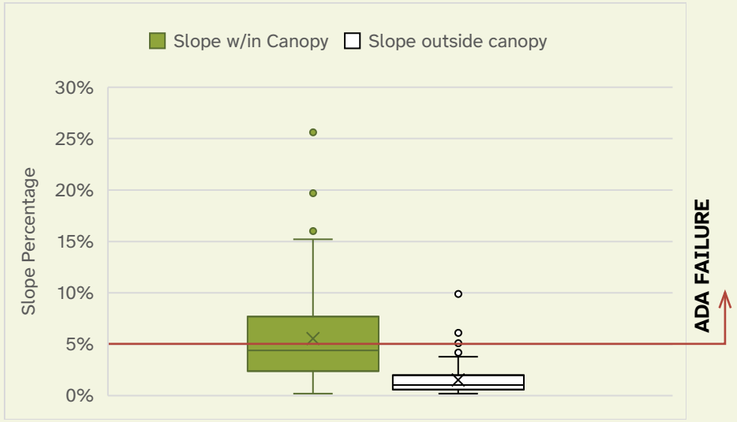
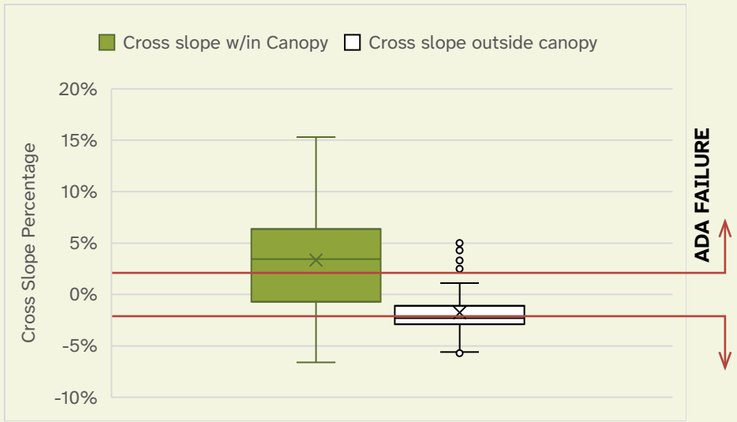


Figure 2.4.3
Cross Slope Inside vs. Outside Canopy
Box and whisker charts reflecting cross slope inside vs. outside the tree canopy.



These results have significant implications for the overall relationship between tree roots and sidewalk accessibility because they show that **large mature trees appear to substantially increase the rate and severity of sidewalk accessibility failure**.

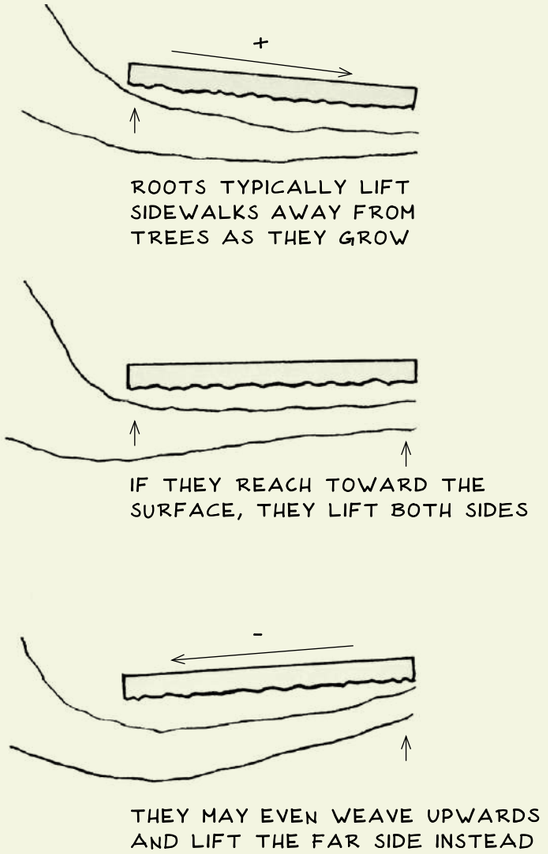
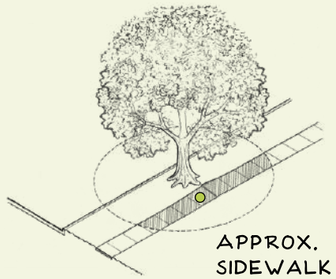


Figure 2.4.4
Overview of Sidewalk Cross Slope
Sketch of sidewalk slope directions and likely causes.



ESTIMATED SIDEWALK AGE CATEGORIES

Sidewalk age appears to play a substantial role in the rate and severity of sidewalk root heave, but sidewalks of any age can be lifted to the point of failure. The most represented approximate sidewalk age category is “young” (see figure 2.4.5), especially near deciduous tree species (see figure 2.4.6). “Young” sidewalks include all sidewalks that did not appear to be “new,” meaning five years old or less, or “weathered” meaning pitted or spalled. The number of modes of failure is significantly related to the sidewalk’s approximate age (see figure 2.4.7.), but further research is required to determine a sidewalk’s actual lifespan and how that may be influenced by tree root growth.

Figure 2.4.5
Representation of Estimated Sidewalk Age Categories
Bar chart reflecting the number of sidewalks estimated to fit each age approximate age category.

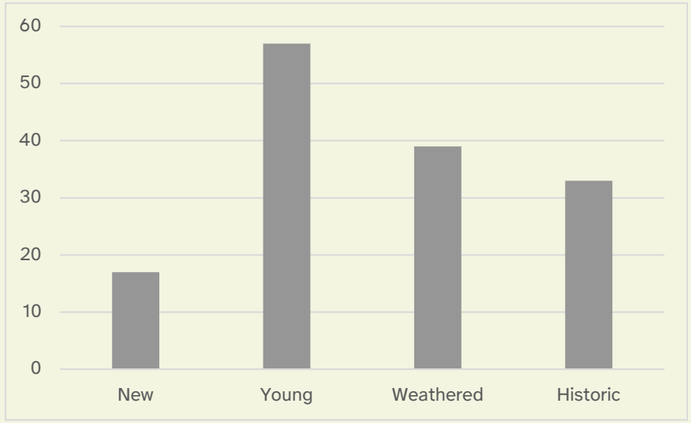
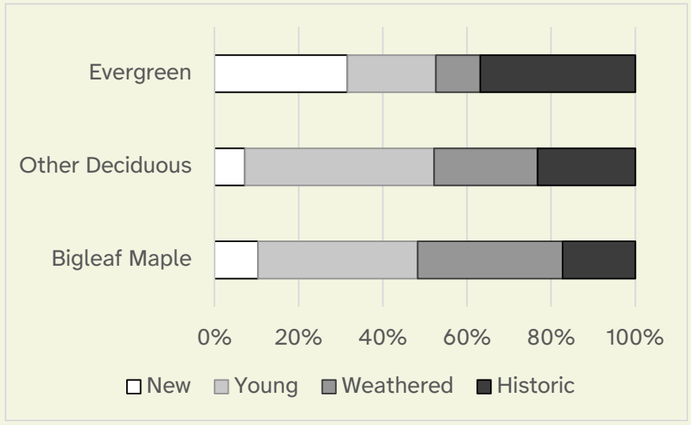


Figure 2.4.6
Estimated Sidewalk Age by Species Category
100% Stacked horizontal bar chart showing the proportion of sidewalks that appear to be new, young, weathered, or historic at trees in different species categories.



These results are important primarily because they show that **sidewalk age is likely a complicating factor that influences the severity of root heave adjacent to a tree**; this must be taken into account when considering all other results. The distribution of sidewalk age groups also provides interesting information, like the apparent increased sidewalk ages to the east of trees (see figure 2.4.8). Note that the direction of the sidewalk relative to the tree also likely changes the concrete’s surface quality due to differences in solar exposure, which may have skewed age estimation.

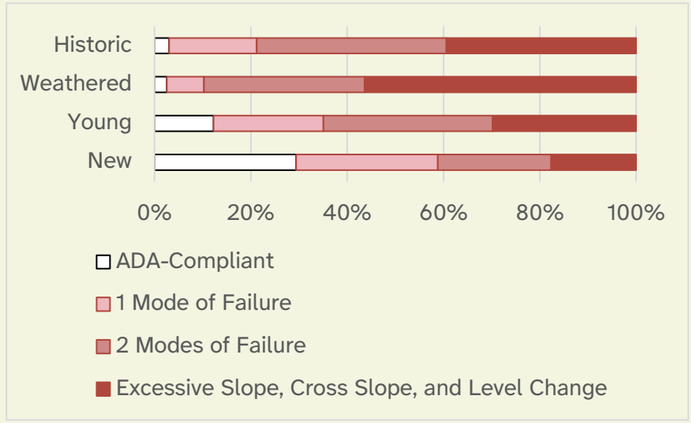


Figure 2.4.7
Number of Modes of Failure by Estimated Sidewalk Age
100% Stacked horizontal bar chart reflecting the number of modes of path failure at sites with sidewalks estimated to be new, young, weathered, or historic.

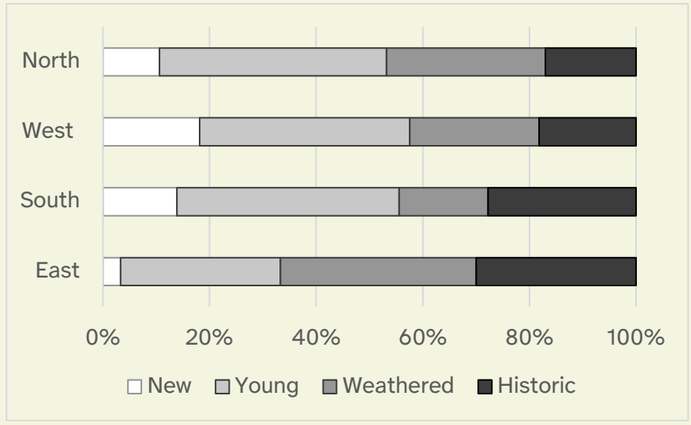


Figure 2.4.8
Estimated Sidewalk Age by Direction
100% Stacked horizontal bar chart showing the proportion of sidewalks that appear to be new, young, weathered, or historic at trees in different directions relative to their adjacent trees.

CONCRETE GRINDING

Evidence of concrete grinding is a more conclusive metric than approximate sidewalk age because, while qualitative, it is still fairly objective and certain. Evidence of concrete grinding (see figure 2.4.9) can be described as **areas with exposed, flattened aggregate and a smoothed concrete surface** that has been clearly ground down. This evidence was noted at 34% of sites (see figure 2.4.10).

Higher level changes were measured at sites with signs of concrete grinding (see figure 2.4.11) and these sites had more modes of failure than sites without signs of concrete grinding (figure 2.4.12). These results do not imply that concrete grinding worsens accessibility in itself; it suggests that sidewalks continue to lift after concrete grinding, implying it is only a short-term solution to root heave. More research is required to confirm how long concrete grinding is effective at eliminating level changes, but few sites with concrete grinding were found without level changes, which often occurred where concrete had already been ground down, implying the sidewalk continued to lift after grinding.

Figure 2.4.9
Visual of Concrete Grinding
Example photo taken in the field showing evidence of concrete grinding.



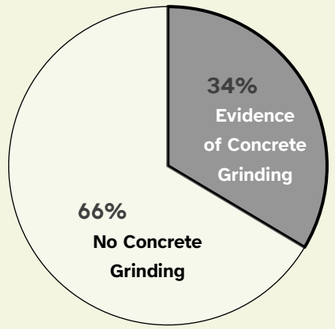


Figure 2.4.10
Prevalence of Concrete Grinding
Pie chart showing the proportion of sites that had some evidence of concrete grinding.

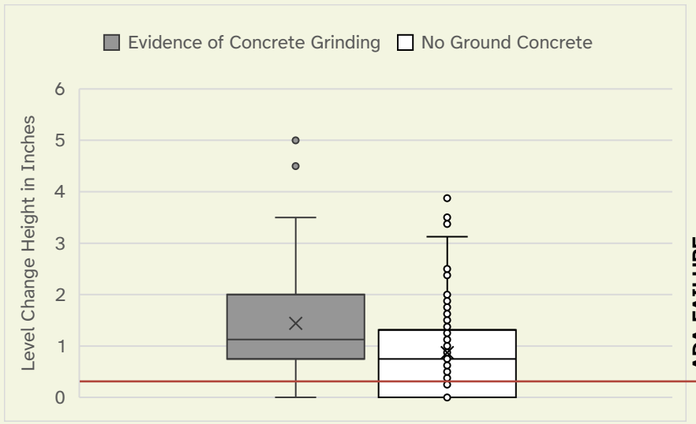


Figure 2.4.11
Accessibility of Sidewalks with and Without Evidence of Concrete Grinding
Box and Whisker Chart showing the height of level changes at sites with vs. without signs of concrete grinding, showing that sites with concrete grinding had notably higher level changes.

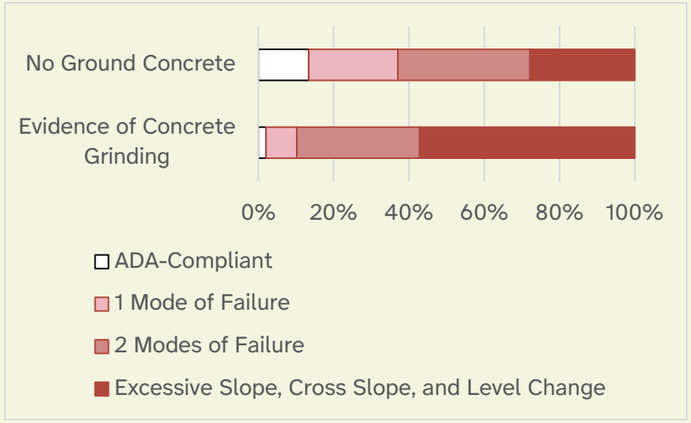


Figure 2.4.12
Accessibility of Sidewalks with and Without Evidence of Concrete Grinding
100% Stacked horizontal bar chart showing the accessibility of sidewalks with vs. out concrete grinding showing that sites with evidence of concrete grinding had substantially more accessibility failures.

MODULATED BED WIDTH

Modulated width implies that the sidewalk was repaired near the tree, likely due to root heave, and the sidewalk's footprint was modified to accommodate the tree (see figure 2.4.15). Modulated width was found at 11% of sites (see figure 2.4.13). Sites with modulated width had more modes of failure on average (see figure 2.4.14). While more research is needed to confirm these results with a wider sample size of modulated sidewalks, this evidence suggests that **root heave is likely to recur after sidewalk repair**.

The sidewalk may fail fairly quickly after these repairs if the sidewalk is ramped upwards or sloped sideways. If a sidewalk is designed to be at a 5% slope or 2% cross slope pointing away from the tree, then the sidewalk will quickly exceed

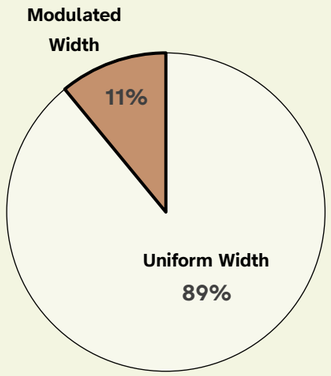


Figure 2.4.13
Prevalence of Modulated Width
Pie chart showing the proportion of sites that had some widening of the plant bed at the tree.

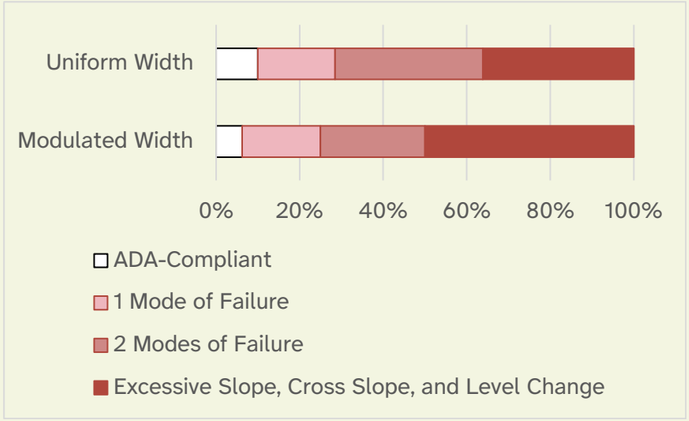
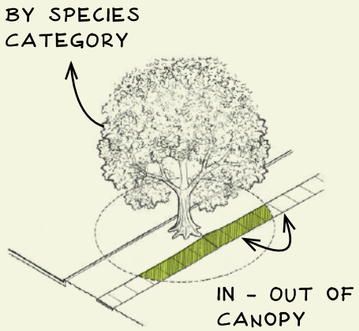


Figure 2.4.14
Accessibility of Sidewalks with and Without Modulated Width
100% Stacked horizontal bar chart showing the accessibility of sidewalks with vs. without modulated width to widen the plant bed at the tree showing that sites with modulated width had more accessibility failures, rather than less as may be expected.



accessibility thresholds with any vertical soil displacement, which is likely to occur if tree roots grow beneath the sidewalk. Level changes at sites with modulated width were typically found between old and new concrete pours, implying that the tree is lifting the entire new (or young) portion of concrete upwards. The increased modes of failure at modulated sidewalks do not imply that the modification encourages root heave, but they do seem to suggest that **the way root heave was handled at these locations did not prevent recurrence**.

Figure 2.4.15
Example of Modulated Width
Photo taken in the field showing an example of modulated plant bed width with annotations noting common trends at similar sites.



SPECIES CATEGORY

To evaluate the impact of tree species, specimen trees were divided into (58) Bigleaf Maples, (69) other deciduous trees, and (19) evergreens. Tree species as a factor was found to have a significant correlation with root heave severity, but only Bigleaf Maples had a significant sample size. More research is needed to make conclusive statements, but **Bigleaf Maples were found to have more root heave than other deciduous tree species and substantially more root heave than evergreen trees**. Across species there were measurable differences between the maximum slopes measured in vs. outside of tree canopies (see figure 2.4.16); this was calculated by subtracting the slope outside

the canopy from the slope within the canopy. Evergreen trees were found to have the least slope difference, with all deciduous species, including Bigleaf Maples, having a higher mean slope difference value and wider range. Bigleaf Maples appear to have an elevated impact on slope and more outliers than other deciduous species. Cross slope difference (figure 2.4.17) shows similar results with a greater difference for Bigleaf Maples than other deciduous species and wider ranges for all three categories. Bigleaf Maples were also found to have a higher mean and a wider range for max level change height (see figure 2.4.18). The result is that Bigleaf Maples had sidewalks with more modes of failure and fewer ADA-compliant sidewalks (see figure 2.4.19).

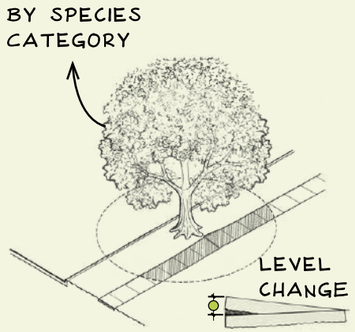


Figure 2.4.16
Difference in Max Slope In - Outside Canopy
Box and whisker charts reflecting the difference in slope within vs. outside the tree canopy by species category.

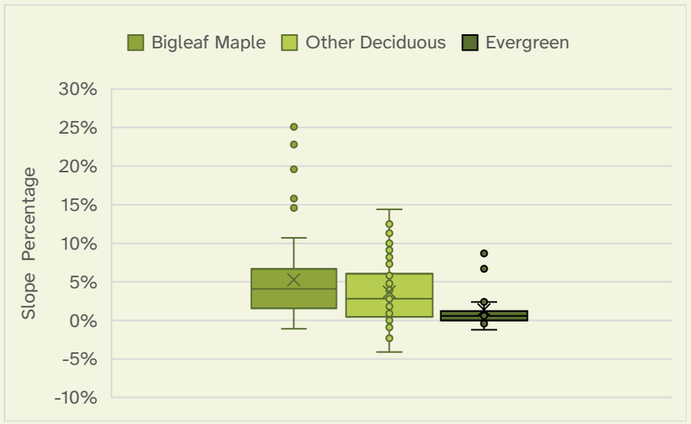


Figure 2.4.17
Difference in Max Cross Slope In - Outside Canopy
Box and whisker charts reflecting the difference in cross slope within vs. outside the tree canopy by species category.

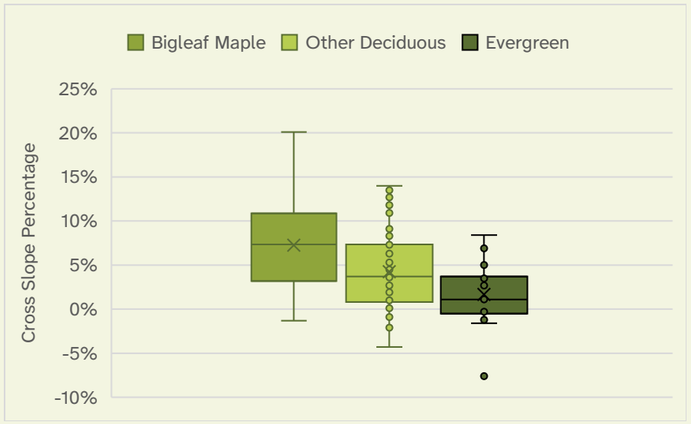


Figure 2.4.18
Level Change Height by Species Category
Box and Whisker chart illustrating the common range of level height by species category.

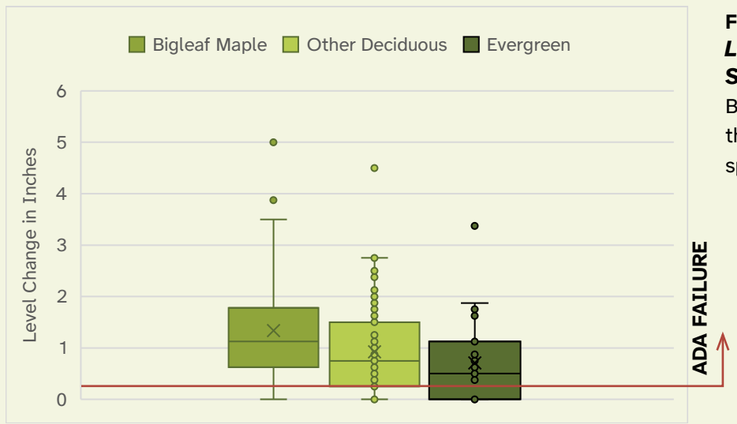
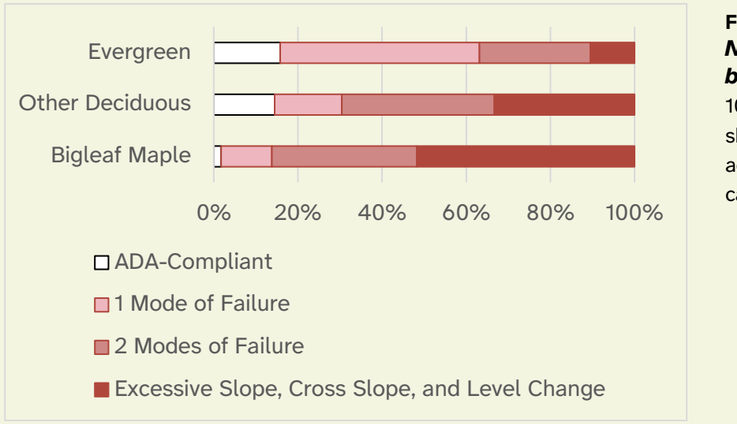
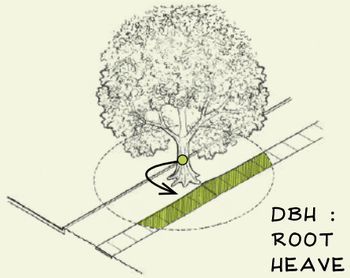


Figure 2.4.19
Number of Modes of Failure by Tree Species Category
100% stacked horizontal bar chart showing the number of modes of accessibility failure by tree species category.





TRUNK DIAMETER ACROSS ALL TREES

This study found an unexpectedly weak correlation between DBH and the maximum slope (figure 2.4.20), cross slope (figure 2.4.21), and level change (figure 2.4.22) within the tree's canopy.

The trend lines in the scatterplots below are close to flat, which would imply no measurable relationship. And the R^2 values next to the trend lines are all below 0.1. R^2 values range from 0 to 1 and imply the proportional relationship between one variable and another. A value of 1 would imply a complete, direct relationship, meaning that it would be possible to predict the amount of root heave next to a tree based solely on its diameter. With R^2 values below 0.1 it is

not possible to predict root heave severity based on tree size. There appear to be an increased number of modes of failure at larger trees (see figure 2.4.23); this shows some connection between DBH and root heave, but the relationship is looser than expected. It appears that a 26" DBH tree could have an apparently similar degree of root heave to a 52" DBH tree.

These results primarily apply to trees that fit the research scope, meaning trees over 25" DBH, but these findings warrant further research to determine the actual relationship between tree size and root heave severity. The low R^2 values imply many other factors play a significant role, possibly including random chance of where tree roots grow.

Figure 2.4.20
Relationship between Slope Within Canopy and Tree DBH Across All Species
Scatterplot showing the relationship between trunk diameter at breast height and measured maximum slope within tree canopy.

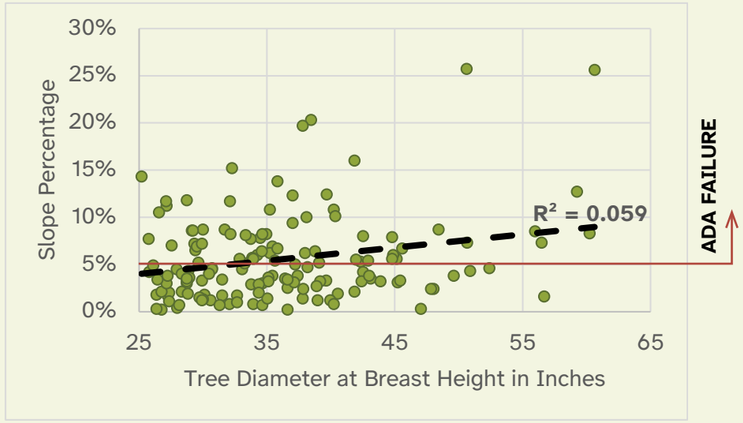


Figure 2.4.21
Relationship between Cross Slope Within Canopy and Tree DBH Across All Species
Scatterplot showing the relationship between trunk diameter at breast height and measured maximum cross slope within tree canopy.

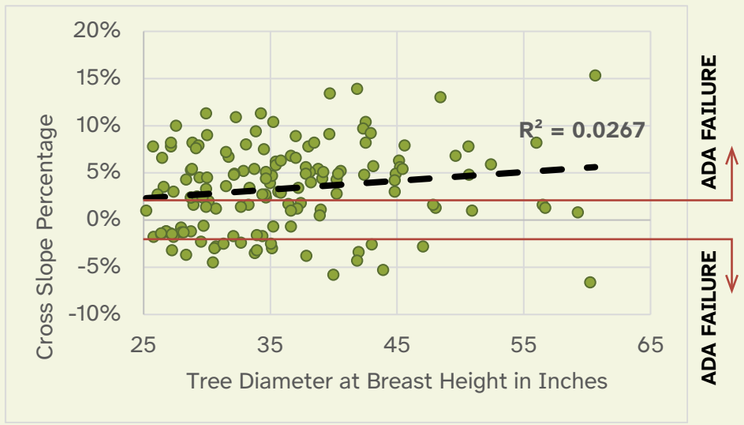


Figure 2.4.22
Relationship between Level Change Height and Tree DBH Across All Species
Scatterplot showing the relationship between trunk diameter at breast height and measured maximum level change height within tree canopy.

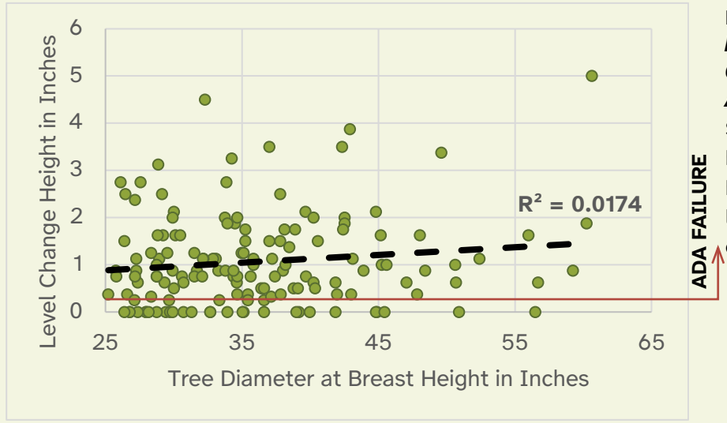
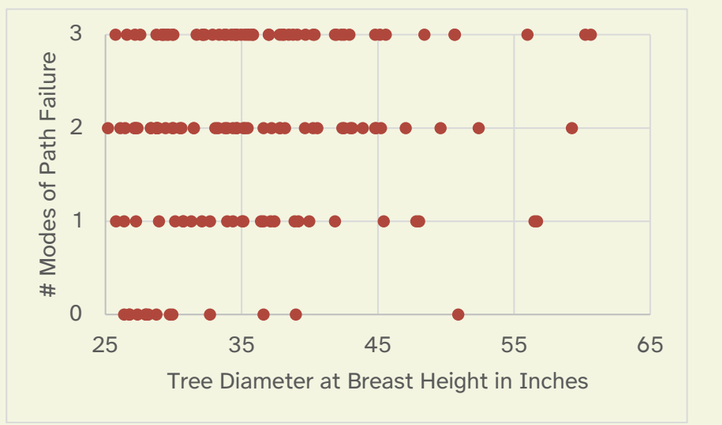
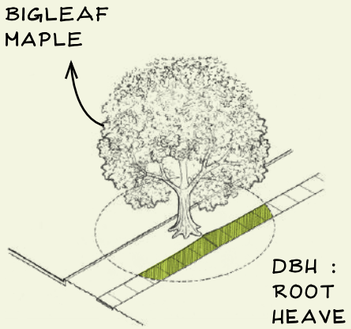


Figure 2.4.23
Number of Modes of Failure by Tree DBH
Scatterplot showing the number of modes of accessibility failure by tree diameter at breast height.





BIGLEAF MAPLE TRUNK DIAMETER

One of the most expected variables at play is tree species, but controlling for species by solely analyzing results from Bigleaf Maples does yield increased R^2 values compared to analysis across species, but not to the degree expected. The relationship between Bigleaf Maple DBH and maximum slope within the tree canopy (figure 2.4.24) shows the strongest correlation, with an R^2 value of 0.1406. DBH and max cross slope (figure 2.4.25) appear to have a weaker relationship, with an R^2 value of 0.0997. And level change height (figure 2.4.26) had the weakest correlation with an R^2 value of 0.0339.

Because all but one of the Bigleaf Maples measured had some degree of root heave that exceeded accessibility tolerances, and that tree was larger than many with substantial root heave (see figure 2.4.27), there is no reference point within this study to show when root heave tends to happen with Bigleaf Maples. However, these results show that there are **many other factors besides DBH that influence the severity of root heave, even within a single species**.

Figure 2.4.24
Relationship between Slope Within Canopy and Tree DBH for Bigleaf Maple
Scatterplot showing the relationship between trunk diameter at breast height and measured maximum slope within tree canopy.

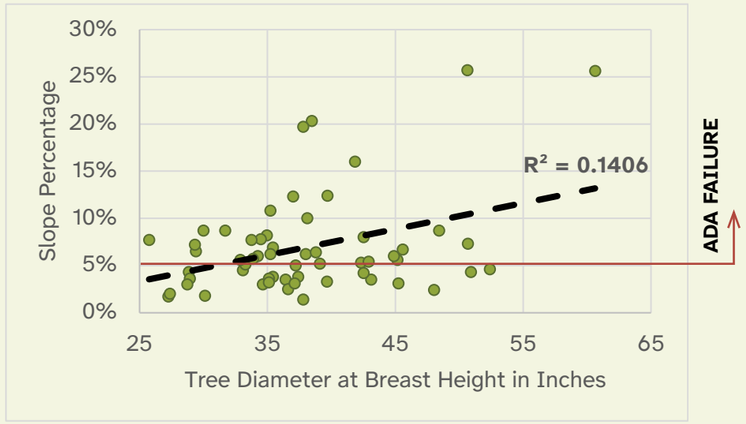


Figure 2.4.25
Relationship between Cross Slope Within Canopy and Tree DBH for Bigleaf Maple
Scatterplot showing the relationship between trunk diameter at breast height and measured maximum cross slope within tree canopy.

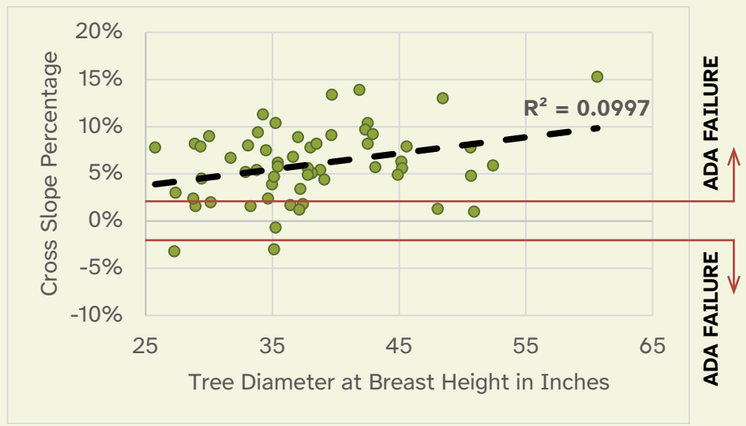


Figure 2.4.26
Relationship between Level Change Height and Tree DBH for Bigleaf Maple
Scatterplot showing the relationship between trunk diameter at breast height and measured maximum level change height within tree canopy.

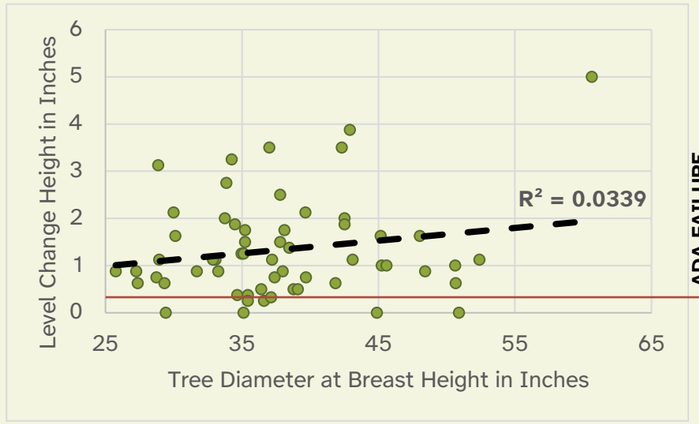
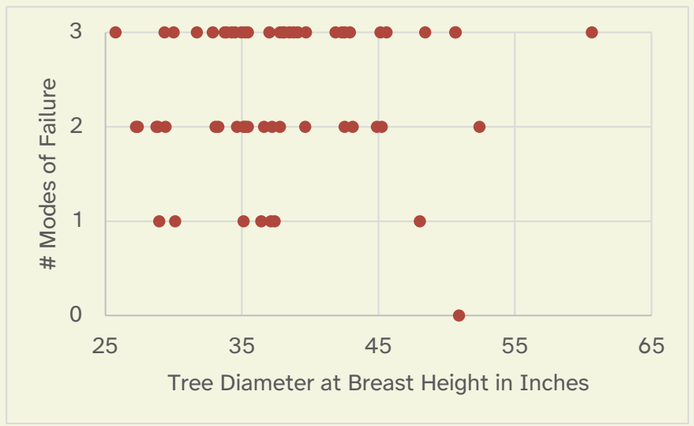
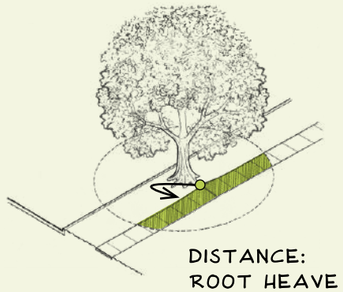


Figure 2.4.27
Number of Modes of Failure by Tree DBH for Bigleaf Maple
Scatterplot showing the number of modes of accessibility failure by tree diameter at breast height.





VISIBLE ROOT TO SIDEWALK DISTANCE

One factor that was expected to have a clear, strong relationship with root heave was the distance between visible surface roots, burls, and trunk bases and the adjacent sidewalk. In theory, the closer a visible surface root is to the sidewalk the closer it will be to the pavement beneath the surface, which seems likely to correlate with root heave.

This was measured by taking the distance from the closest visible root between the tree's trunk and sidewalk edge, measured perpendicular to the path of travel (see figure 2.4.28). Overall, this root-sidewalk distance was found to be substantially smaller for Bigleaf Maples than any other species, varied for other deciduous trees, and greatest for

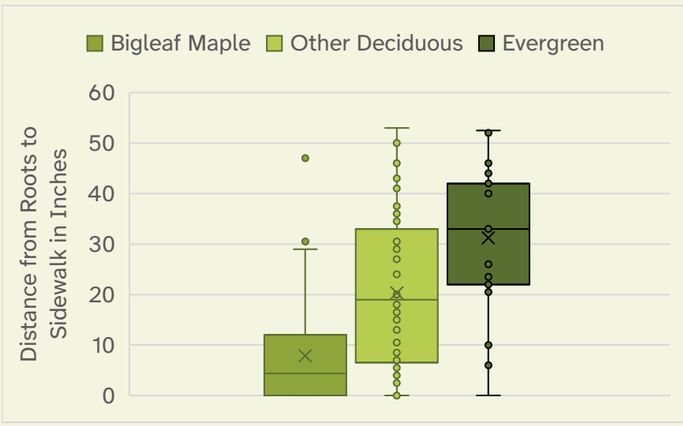
evergreens (see figure 2.4.29). Bigleaf Maples were especially likely to have a root-sidewalk distance of 0" meaning that the tree was in direct contact with the pavement on the surface.

However, **root-sidewalk distance was not shown to be a predictive factor for root heave severity**. All results were similar to the minimal relationship shown in figure 2.4.30, which reflects the relationship between root-sidewalk distance and level change height with an R^2 value of 0.0435. There was also a wide range of variance between root-sidewalk distance and the number of modes of sidewalk failure (see figure 2.4.31).

Figure 2.4.28
Visualizing Root to Sidewalk Distance
Annotated field photo illustrating the distance between visible roots and the adjacent sidewalk.



Figure 2.4.29
Distance from Roots to Sidewalk by Species Category
Box and whisker charts showing the common distance ranges between the nearest visible roots/burls and the adjacent pavement by species category.



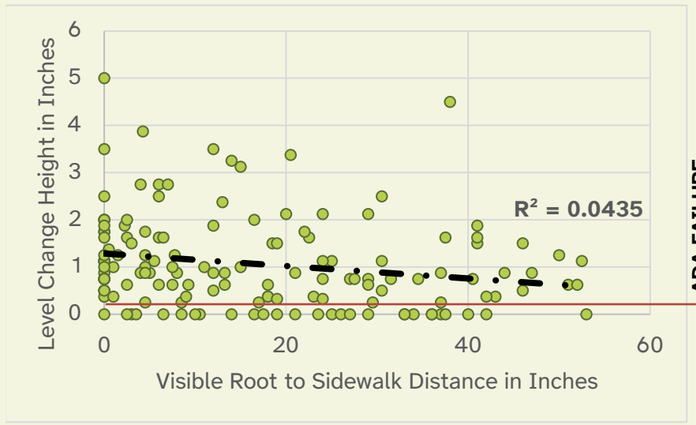


Figure 2.4.30
Relationship between Level Change Height and Root to Sidewalk Distance
Scatterplot showing the relationship between the maximum level change height within tree canopy and the distance from the nearest roots to the sidewalk edge.

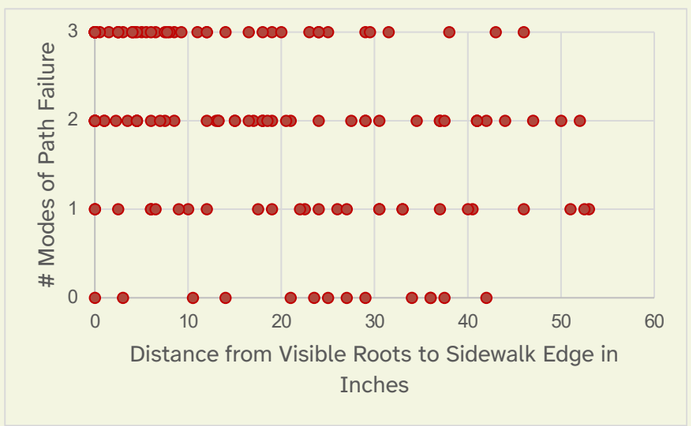
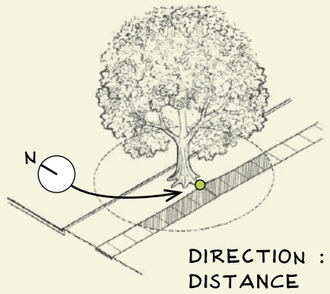


Figure 2.4.31
Number of Modes of Failure by Root to Sidewalk Distance
Scatterplot showing the number of modes of failure by root to sidewalk distance.



RELATIVE SIDEWALK DIRECTION AND ROOT-SIDEWALK DISTANCE

In addition to species, root-sidewalk distance was found to have a significant relationship with the direction of the sidewalk relative to the tree. Trees appear to grow closer to sidewalks with eastern exposure, followed by north exposure (see figure 2.4.32). They seem to keep the most distance from sidewalks that face west, followed by sidewalks to the south. These patterns were not reflected as much by Bigleaf Maples, which appear to grow very close to the sidewalk except when it has western exposure (see figure 2.4.33).

Note that these sites also include buildings of various distances and heights; controlling for other shade factors

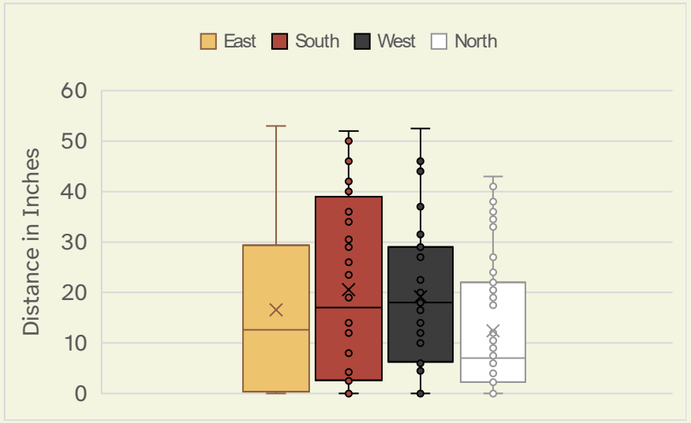


Figure 2.4.32
Distance from Roots to Sidewalk by Direction - All Species
Box and whisker chart showing the ranges of root-sidewalk distance measured across all sites within the research scope divided by the sidewalk's location relative to the tree.

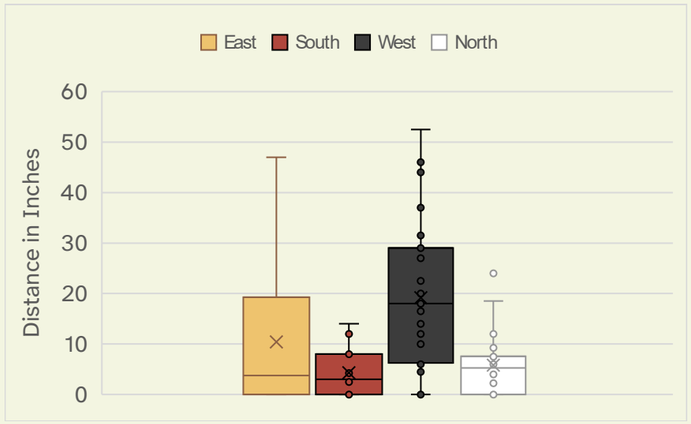
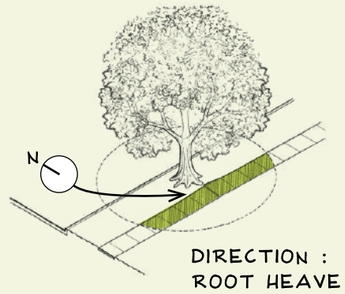


Figure 2.4.33
Distance from Roots to Sidewalk by Direction - Bigleaf Maples
Box and whisker chart showing the ranges of root-sidewalk distance measured across all Bigleaf Maples within the research scope divided by the sidewalk's location relative to the tree.

would likely lead to an even stronger relationship between direction and distance.

RELATIVE SIDEWALK DIRECTION AND ROOT HEAVE

The relative direction of the sidewalk also appears to have a substantial impact on resulting root heave that is inverted from the root-sidewalk distance and direction relationship. Figure 2.4.34 represents a common trend found across accessibility metrics, showing that maximum cross slope values were highest on sidewalks with east exposure and lowest on west-facing sidewalks. The number of modes of failure across sites by direction also shows that east-facing sidewalks were the least accessible (see figure 2.4.35).



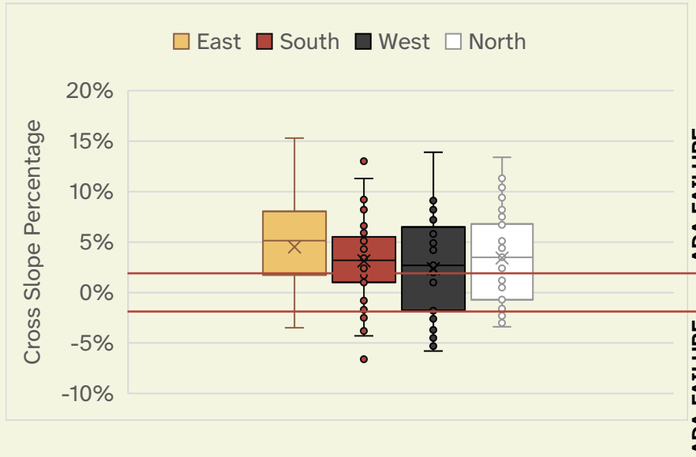


Figure 2.4.34
Maximum Cross Slope by Relative Sidewalk Direction
Box and whisker chart reflecting the range of maximum cross slopes measured at all sites within the research scope divided by the direction of the sidewalk relative to the tree.

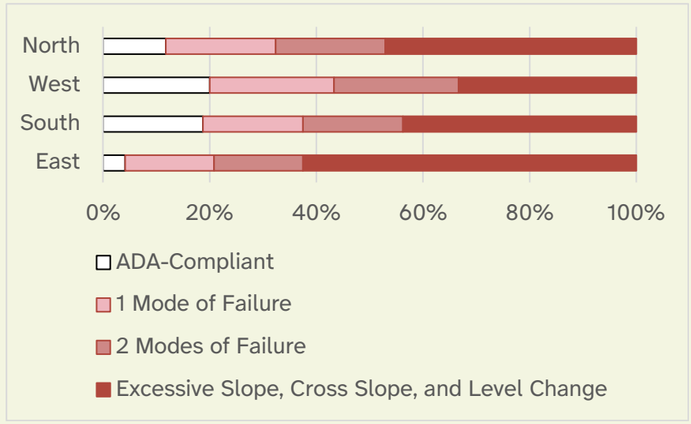


Figure 2.4.35
Modes of Failure by Relative Sidewalk Direction
100% horizontal stacked bar chart showing the number of modes of failure found at sidewalks across all sites within the research scope by the direction of the sidewalk relative to the tree.

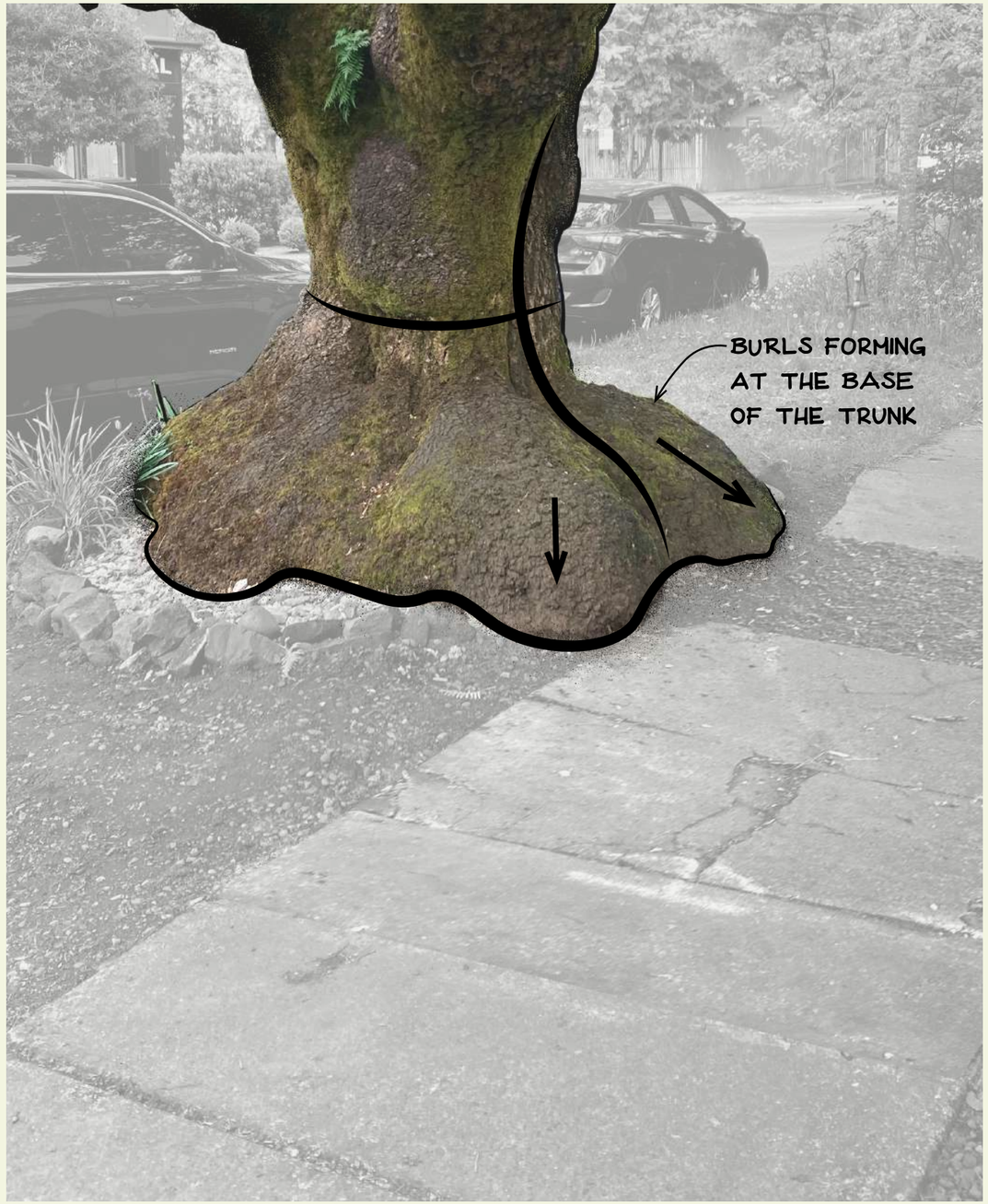


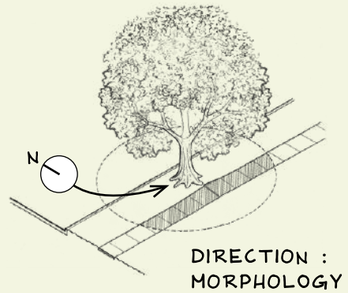
Figure 2.4.36
Illustration of Morphological Analysis
Annotated photo of a Bigleaf Maple street tree with a desaturated background and lines showing the aspects of each tree that were analyzed qualitatively in the field.

QUALITATIVE MORPHOLOGY ANALYSIS

Like the quantitative results, tree morphology was divided into three species categories (Bigleaf Maple, other deciduous, and evergreen). Bigleaf Maples were also divided by the relative direction of the sidewalk.

The qualitative analysis of tree morphology is the most subjective portion of this work, but the process yielded compelling results that encourage further empirical research documenting the exact size and angle of root flares along with overall tree form.

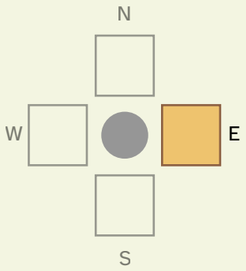
Specific investigation of Bigleaf Maple tree morphology is recommended for future research, **especially in comparison to Bigleaf Maples growing in their natural habitat.**



RELATIVE SIDEWALK DIRECTION AND BIGLEAF MAPLE MORPHOLOGY

Bigleaf Maple street trees were found to have distinctive morphological patterns characterized by basal burls (see figure 2.4.36). The qualitative overlay analysis of the field diagrams reflecting how Bigleaf Maples grew in response to the sidewalk in all four directions is reflected in the vector illustrations on the following page (see figures 2.4.37 - 2.4.40).

The overall result is that Bigleaf Maples appear to reach toward sidewalks and adjacent driveways, but in different ways and to different degrees depending on the relative direction of the sidewalk. More suckers, meaning sprouts shooting off from the trunk, were observed to the west, trees seemed more likely to lean toward the south, and they demonstrated the most sidewalk-reaching behavior to the north and east, where the sidewalk is likely cooler. This implies that sidewalks warrant site-based designs that consider solar exposure, which results in heat patterns in the soil on and around tree roots. This is particularly important for surface-rooting species like Bigleaf Maples but applies to all species.



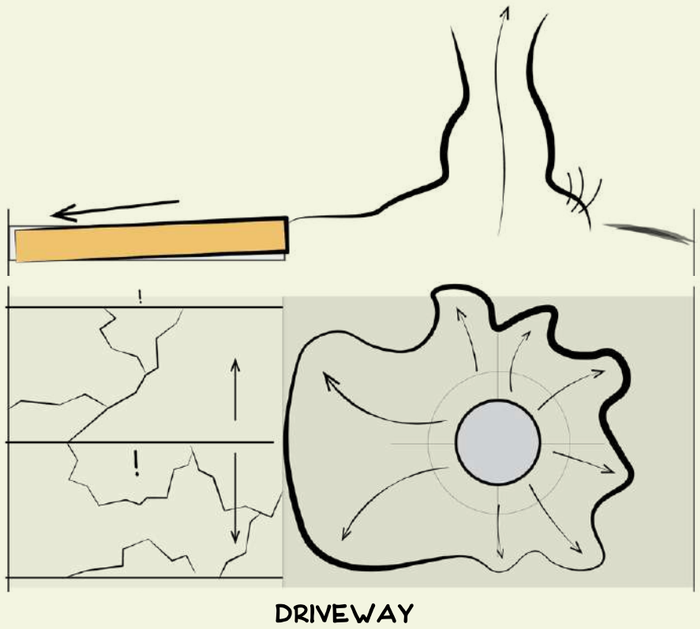
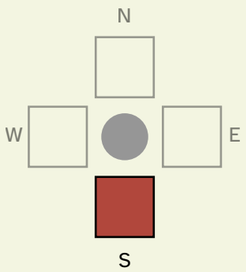
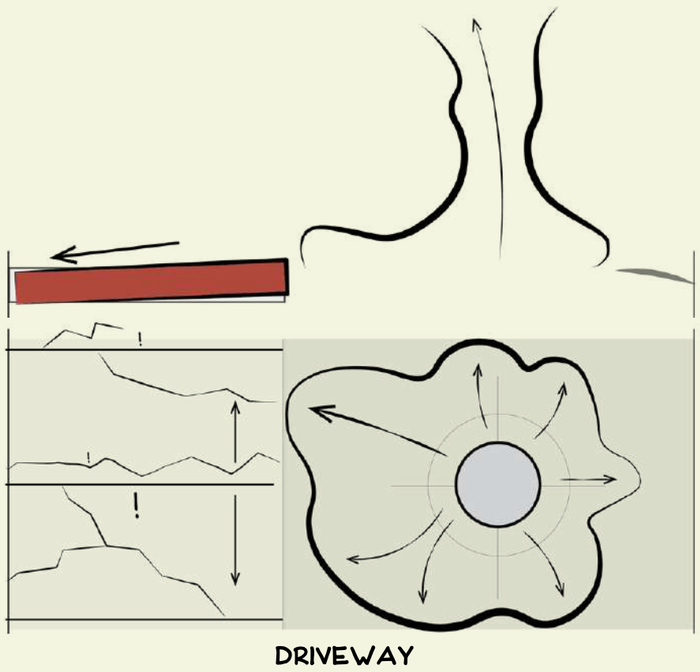
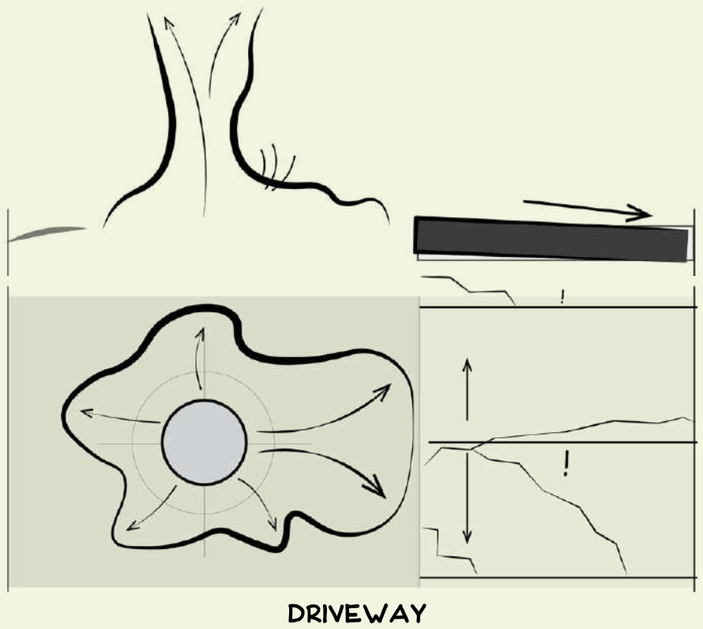


Figure 2.4.37
Observed Bigleaf Maple Morphological Trends with East-facing Sidewalks
Qualitative illustration of patterns observed in Bigleaf Maple morphology with east-facing sidewalks. Root flares appeared to fan out in all directions, while more undefined burl masses reached toward the sidewalk. And more suckers appeared on the street-facing (west) side.

Figure 2.4.38
Observed Bigleaf Maple Morphological Trends with South-facing Sidewalks
Qualitative illustration of patterns observed in Bigleaf Maple morphology with south-facing sidewalks. Broad root flares and basal burls appeared to form toward the sidewalk, reaching somewhat away from driveways. And trees seemed to lean more toward the sidewalk-facing (south) side.







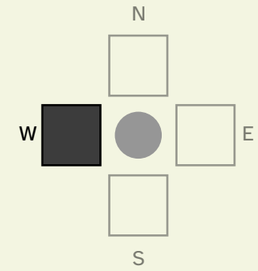
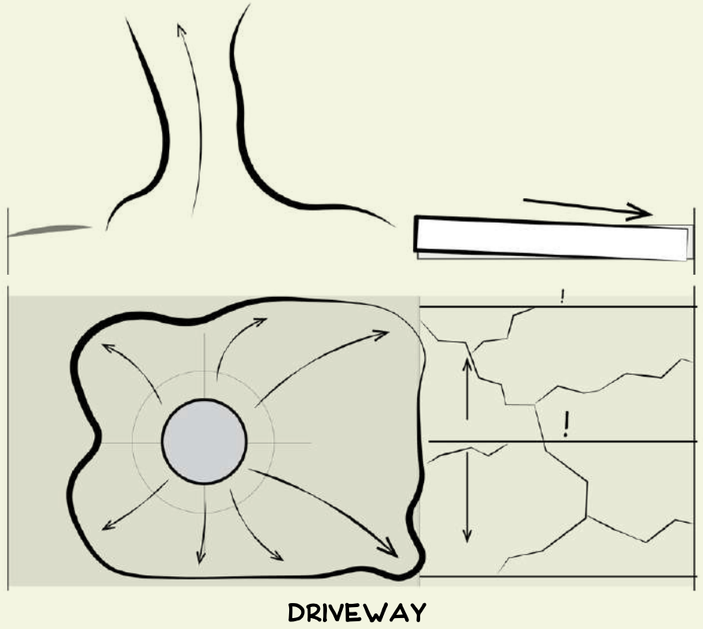
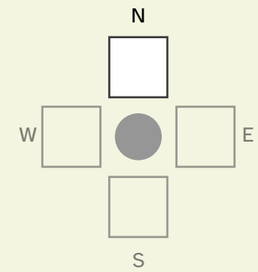


Figure 2.4.39
Observed Bigleaf Maple Morphological Trends with West-facing Sidewalks
Qualitative illustration of patterns observed in Bigleaf Maple morphology with west-facing sidewalks. Growth seemed to follow a similar pattern to trees facing east, but there appeared to be narrower stretches of burls reaching toward the sidewalk and more suckers seemed to form on the sidewalk-facing (west) side.

Figure 2.4.40
Observed Bigleaf Maple Morphological Trends with North-facing Sidewalks
Qualitative illustration of patterns observed in Bigleaf Maple morphology with north-facing sidewalks. Burls appeared to form in all directions, root flares seemed to have little definition, and trees seemed to lean more toward the street-facing (south) side.





SIDEWALK LOCATION AND MORPHOLOGY BY SPECIES CATEGORY

Across all three species categories and all four directions, **street trees appeared to reach toward sidewalks**. The overall common trend observed for Bigleaf Maples was burls spilling out at the base, particularly toward pavement (see figure 2.4.41). Other Deciduous species seemed to similarly reach toward the sidewalk and driveways, but also had a tendency to reach toward the curb and showed more defined root flares than Bigleaf Maples (see figure 2.4.42). Lastly, Evergreen trees appeared to have the fewest root flares and no burls or suckers, but they still had a tendency to reach toward the sidewalk and driveway, especially toward the corner where sidewalks and driveways intersect (see figure 2.4.43). While these results are highly qualitative and need further empirical research to make conclusive statements, they seem to align with sentiments from pre-existing literature suggesting that the conditions beneath concrete sidewalks are particularly attractive to tree roots and encourage expedited growth (Randrup et al., 2003).

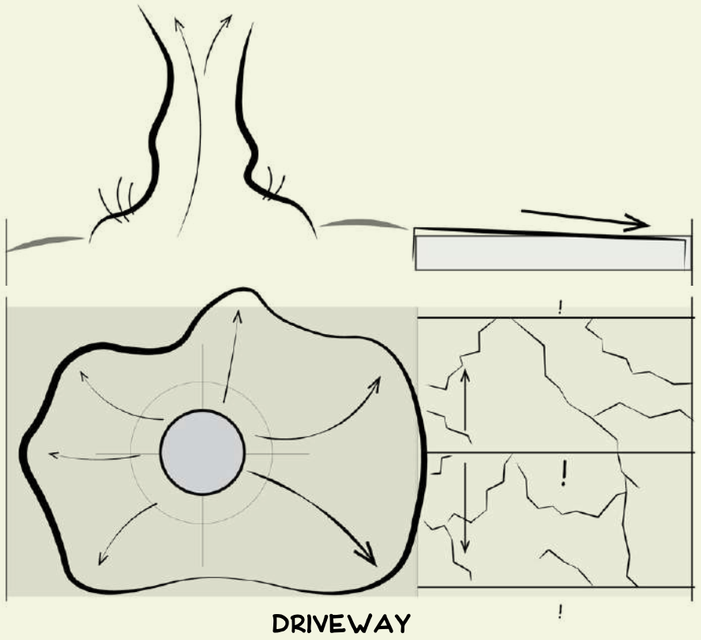


Figure 2.4.41
Bigleaf Maple Street Tree Morphology
Qualitative illustration of growth patterns observed in the 58 documented Bigleaf Maples, summarizing the most common burl and root flare growth directions and common sidewalk cracking patterns across all four directions.

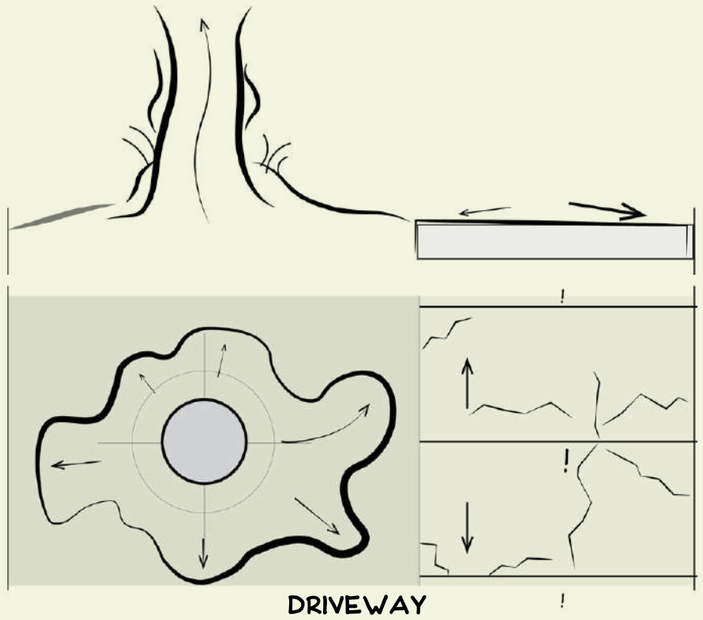


Figure 2.4.42
Other Deciduous Street Tree Morphology
Qualitative illustration of growth patterns observed across the 69 specimens of Other Deciduous species. Growth was noticeably different for this group than Bigleaf Maples and unsurprisingly this category showed a wide range of variance.

All species appeared to show some degree of sidewalk-reaching behavior, but many also reached toward the curb. Burls were somewhat common, especially for Planetrees, which developed them along the entire trunk. And suckers were also typical, especially for Lindens.

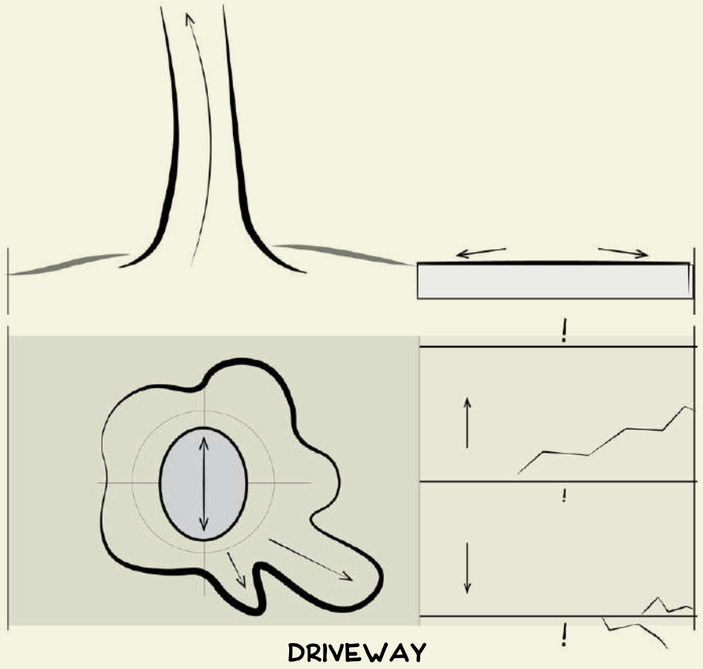


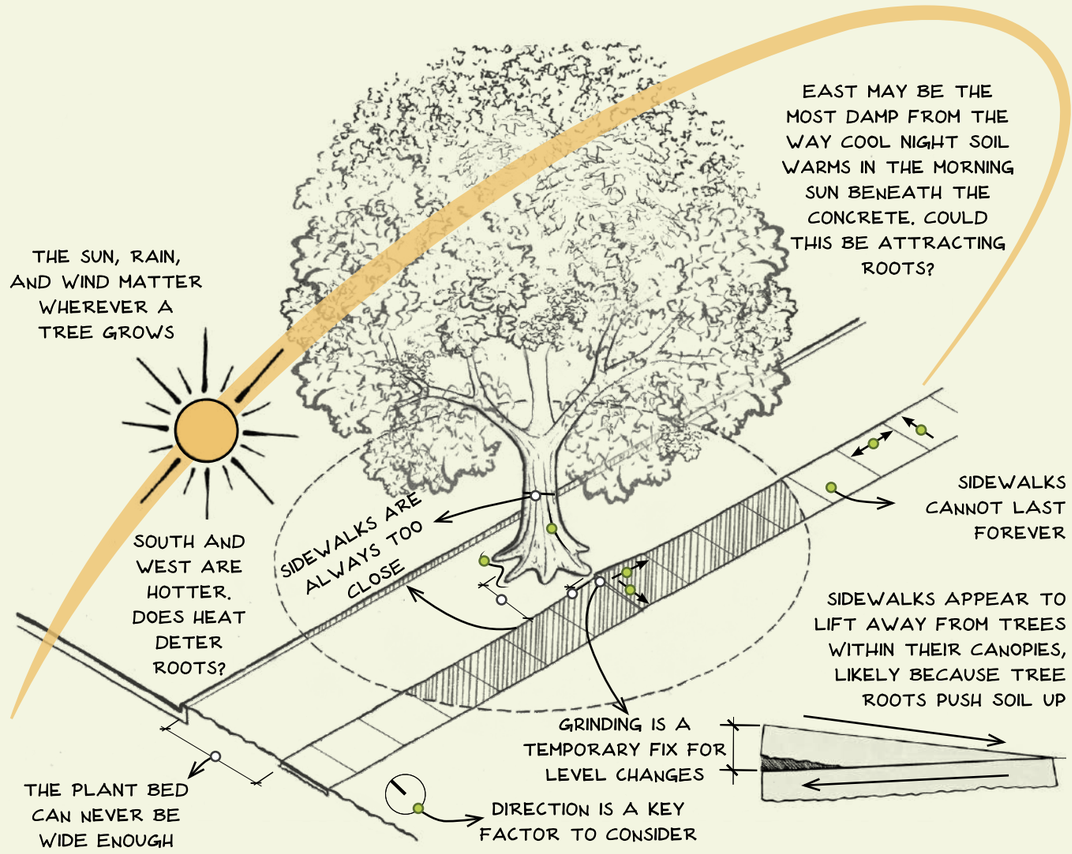
Figure 2.4.43
Evergreen Street Tree Morphology
Qualitative illustration of growth patterns observed across Evergreen trees. This group was dominated by Douglas Firs and had a small sample size, but the patterns across these 19 trees shows a more minor sidewalk-reaching pattern than deciduous trees and suggests that Evergreen street trees react differently to sidewalks than their deciduous counterparts.

No basal burls or suckers were seen on evergreen trees, only root flares and fluted trunks, which often appeared to reach toward the sidewalk. Trunks were often elliptical in shape and wider in the direction parallel with the sidewalk.

SUMMARY

When assessing these results and considering their implications for other locations, it is important to remember that all trees included within the research scope were especially **large and the most heavily represented species, Bigleaf Maple, is known for its surface-rooting nature.** Trees of smaller sizes and other species growing in different soil types, near different sidewalks, and in different climates will behave differently. However, the key discoveries in this work are expected to apply broadly.

- Sidewalk accessibility failures tend to be **worse within the canopy of large trees**, especially at the tree's centerline.
- **Sidewalks of any age can fail** from root heave, but older sidewalks appear more likely to fail and to worse degrees.
- Sidewalk **grinding is almost always a temporary fix**; it seems that sidewalks continue to lift when root heave is not addressed beneath the surface.
- Narrowing the sidewalk at the tree or ramping up the sidewalk **may also be temporary fix** that has potential detriments to accessibility in the long run.
- Trees that rely less on surface roots and tolerate more root pruning, like **evergreens, appear to conflict less with adjacent sidewalks**.
- Root heave appears to be more likely to happen near larger trees, but **severity does not necessarily correlate with tree size**, at least for trees over 25" in diameter.
- **Visible tree roots directly next to sidewalks does not necessarily correlate with more severe root heave**, implying roots maneuver around sidewalks at sharp downward angles.
- **Street trees appear to reach toward the sidewalk**, seemingly seeking out the pavement.



- **The direction of the sidewalk relative to the tree** has a significant impact on how the tree responds to the sidewalk and some impact on the degree of root heave that occurs. This is likely due to the heat patterns on the pavement from solar exposure and resulting subsurface humidity gradient.

Figure 2.4.44
Summary of Results
Isometric drawing of the noted correlations identified in this study and speculation about why solar orientation appears to be influencing root growth.

These results imply that there are **many overlapping, complex variables at every site that determine the occurrence and severity of root heave**, but the broader takeaways are simple, clear, and warrant further investigation (see figure 2.4.44).

2.5 DISCUSSION

Based on existing literature and the results from this study, **root heave seems potentially inevitable with how we build sidewalks over roots**. Sites without root heave seem more surprising than sites with root heave when we consider that all trees have surface roots, some more than others, and those roots will grow outwards and push soil upwards. It seems like trees are already working to grow around sidewalks, they simply require more room.

Given the timescale of a tree's potential lifespan, I argue that no interventions to repair or prevent root heave have been adequately longitudinally tested; **all remedies for root heave are experimental and seem effectively untested on mature trees**. It can take years for root harm to show on a tree, so it is difficult to say how trees really respond to our efforts to control root heave, but those that have spent their entire lifecycle growing in our streets communicate a bleak story with frightening implications for the future of our urban forests.

As explained in Context, mature trees are most at risk for sidewalk conflicts and more likely to have roots that are too large to cut beneath the pavement. These trees are critical for community climate resilience, so we **urgently need to reconsider how we build and maintain the sidewalks over their roots**. We can start by listening to what these trees are communicating.

STREET TREE SIDEWALK REACHING BEHAVIOR

The consistent pattern of many, if not most, street trees preferentially growing larger root flares and burls toward sidewalks implies that root heave is, at least in part, a **byproduct of trees' response to the growing conditions on-grade concrete sidewalks create** (see figure 2.5.1). Existing literature supports these findings, noting that concrete creates a warm, moist environment that may invite

















Figure 2.5.1
Sidewalk-Reaching Behavior Across Species
Example field photos illustrating sidewalk-reaching behavior.

Figure 2.5.2
Small Bigleaf Maple Cracking Adjacent Sidewalk
Photo of a Bigleaf Maple sapling in Whiteaker with a 3.6 inch diameter at breast height that appears to be cracking the adjacent sidewalk.



roots and increases their growing speed (Randrup et al., 2003, p. 215).

Concrete is an unnatural phenomenon, but it seems to inspire a **natural response that may lead to early conflict between street trees and sidewalks**. In a study conducted in 1988, larger trees are more likely to lift pavement, but root heave often begins when trees have a DBH of 11-20cm (about 4” to 8”) (Randrup et al., 2003, p. 213). Those dimensions are shockingly close to the 3.6” DBH Bigleaf Maple sapling in figure 2.5.2 that appears to be cracking the sidewalk and the 7.6” DBH Bigleaf Maple tree that seems to be lifting multiple pieces of pavement in figure 2.5.3. The entire sidewalk is already within the critical root zone of both of these trees, meaning they may already be responding to



the micro-climatic conditions concrete creates in urban soils.

Figure 2.5.3
Small Bigleaf Maple Breaking Adjacent Sidewalk
Photo of a Bigleaf Maple tree with a 7.6 inch diameter at breast height that appears to be breaking the adjacent sidewalk.

IMPLICATIONS FOR BIGLEAF MAPLES AS STREET TREES

While Bigleaf Maples do appear to lift sidewalks more than many other tree species, the difference is not necessarily dramatic enough to disqualify them as street trees. A more compelling reason to avoid planting more Bigleaf Maples in roadside plant medians is the **effect these urban street growing environments have on the Bigleaf Maples themselves**. Little can be done for the trees already growing in the streets besides improving their conditions, such as reducing heat on their roots, but we can listen to Bigleaf Maples by comparing mature specimens that are likely kin



Figure 2.5.4
Mature Bigleaf Maple in a Traditional Forest
Photo of a mature Bigleaf Maple growing in a traditional forest. Shrubs obscure the base of the tree's trunk, which connects the multiple trunks pictured in the larger image.

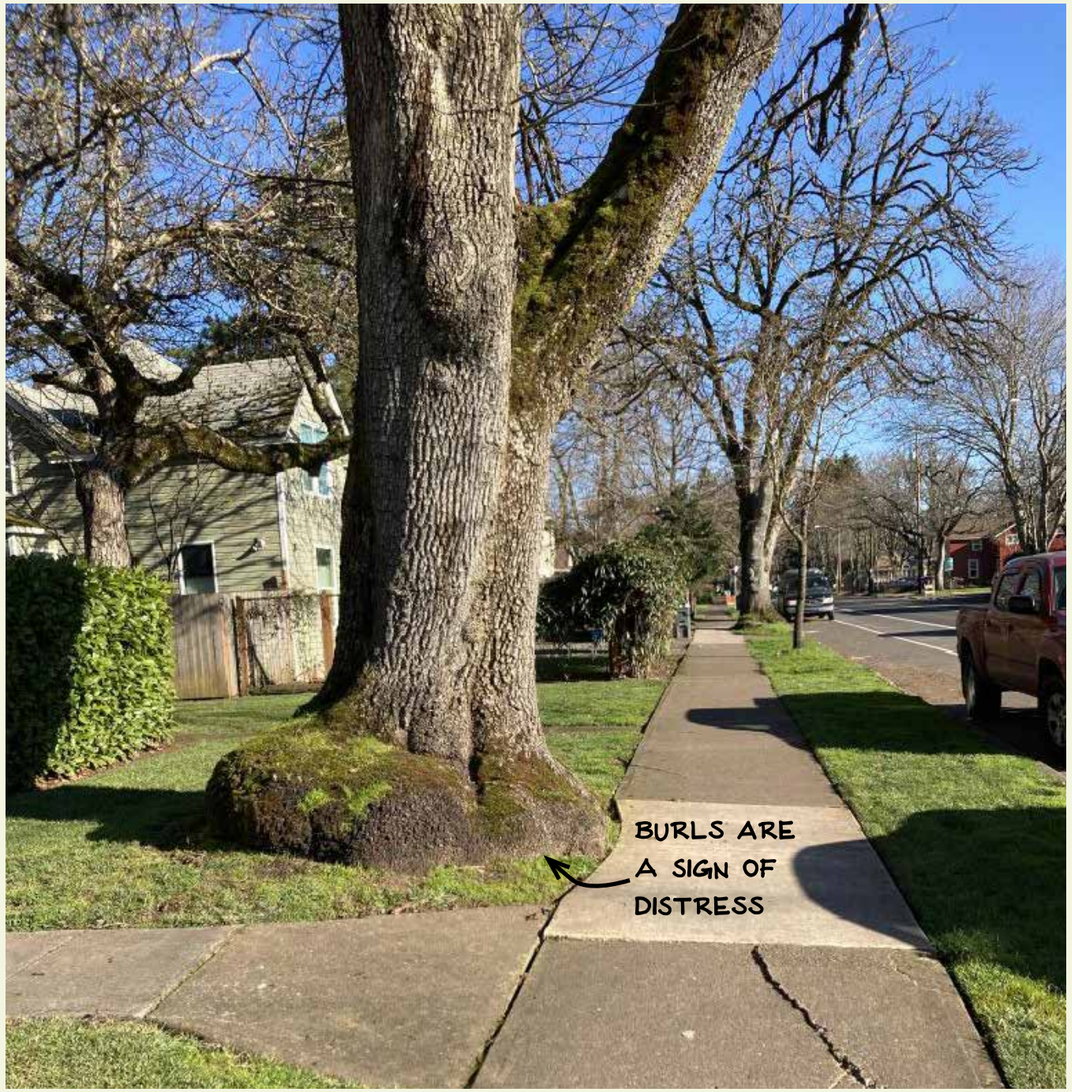


Figure 2.5.5
Mature Bigleaf Maple in an Urban Forest
Photo of a mature Bigleaf Maple growing in an urban forest.

in the riparian forest along the Willamette River with those in the streets of Eugene. Compare the Bigleaf Maple in figure 2.5.4 surrounded by Snowberries to the Bigleaf Maple in figure 2.5.5 surrounded by turf grass. Consider that they could have sprouted alongside one another when the City of Eugene was young and they are not far from one another today.

Notice the swollen base on the street tree and compare it

to the swollen bases forming on the young trees pictured in figures 2.5.2 and 2.5.3. These basal burls signify distress. That may be from the sidewalk's heat, damage from weed whacker strings scarring the base of the tree, lack of root volume space, a sense of instability from a lacking root network, or factors we have yet to consider. No matter the cause, **it seems like the street is an unkind place for these trees to grow**. Listening to these trees would mean improving the growing conditions we provide them and considering whether the street is the right spot for these trees.

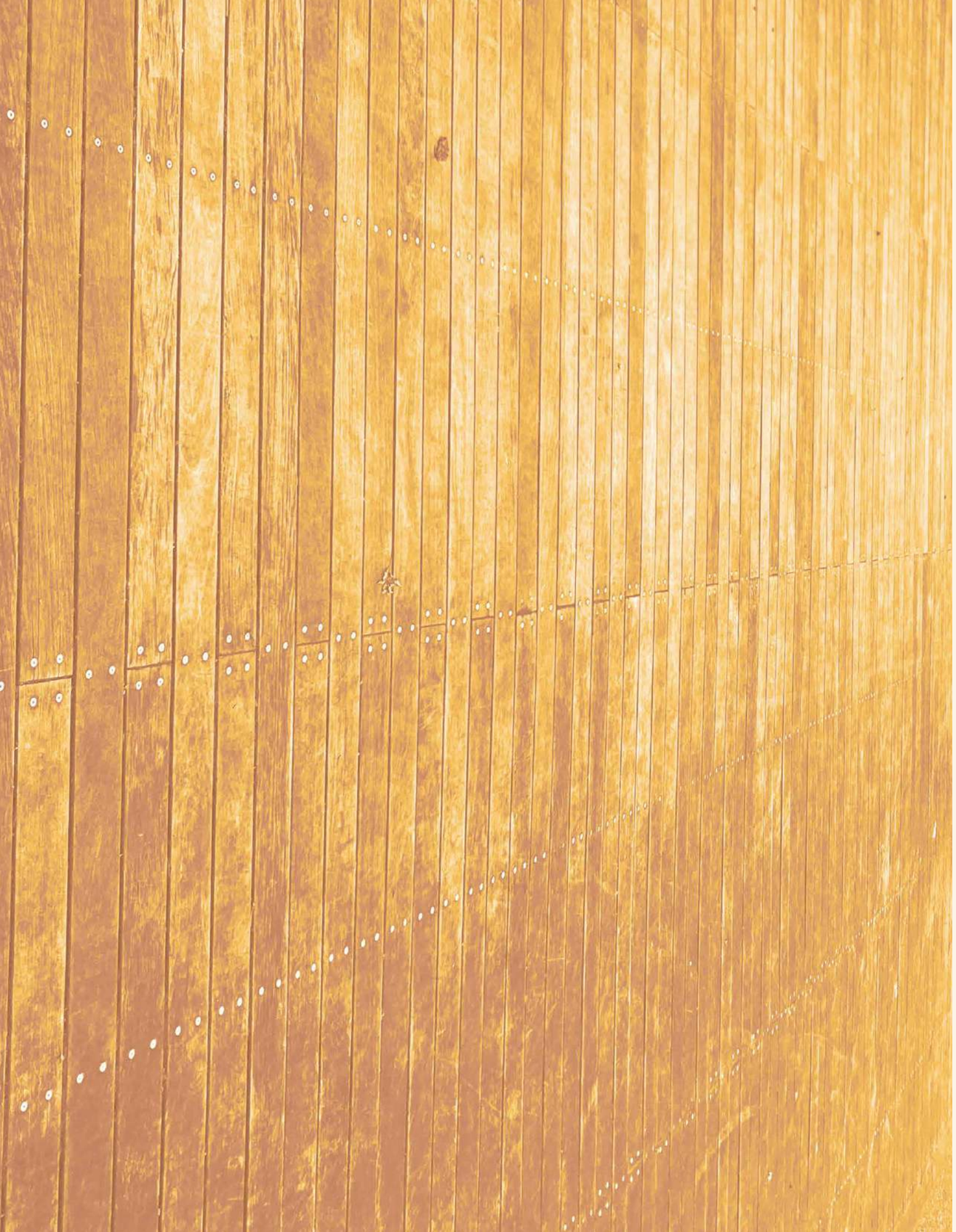
IMPLICATIONS FOR SIDEWALK DESIGN

Sidewalks as we know them put **tree root growth in direct conflict with path accessibility**. They also seem to encourage root growth, expediting root heave, making it potentially impossible to keep up with sidewalk repairs while retaining large mature urban trees. The additional urban heat sidewalks press onto tree roots also seems to have a detrimental impact on trees, especially those with surface roots. And given that root pruning is often the only way to preserve trees that lift sidewalks, **many may not survive widespread repairs**. This evidence implies that sidewalks need to be elevated to cooperate with tree roots.

- If the entire street and sidewalks on both sides are within large street trees' critical root zones, there is **no way to provide trees with enough lateral space while constructing a sidewalk within their canopies**. The only direction the sidewalk can meaningfully move is up, but even if the sidewalk is ramped up with dirt, the tree is still likely to lift it with time and a ramped sidewalk is closer to code-required slope thresholds thus more likely to exceed them in a shorter timeframe. Given these considerations, modulated width sidewalks seem to be temporary fixes and ramped sidewalks are likely to result in excessive slope.

- If **roots are bound to displace soil upwards**, sidewalks need to separate the walking surface from the soil surface. This also allows tree roots to access air, avoid heat transfer from pavement, and have more access to naturally percolating water.
- Providing clear air space over roots is effectively air pruning, which means **naturally training the roots to avoid the sidewalk without manually cutting them**.

Implementing this critical change would separate root growth from accessibility. It may also increase tree health, structure, and longevity, as well as likely reducing urban heat, strengthening community flood resistance, and improving accessibility, even when compared to sidewalks unaffected by root heave since soil shrinking and swelling are enough to break on-grade concrete sidewalks.



3.0



SIDEWALK DESIGN

The findings from the mature street tree study affirm the notion presented in related literature that sidewalk root heave is a **complex, multi-factored problem that threatens the lives of mature street trees and the safety of all pedestrians**, especially those who can't see tripping hazards. Root heave is a design problem because it seems the way we construct sidewalks places tree root growth in direct conflict with path accessibility.

This evidence-based historic revival sidewalk design proposal seeks to rebalance the demands of public works and urban forestry to **identify options for resilient accessible path construction that do not pit roots and routes against one another**.

3.1 *Reframing the Sidewalk Design Problem*

3.2 *Design Precedent Analysis*

3.3 *Case Study Site Design*

3.4 *Proposed Design System*

3.5 *Next Steps*

3.1 REFRAMING THE SIDEWALK DESIGN PROBLEM

TREES AS CLIENTS

We plant trees to benefit from the ecological services they provide, which we often quantify with monetary value to justify tree-planting and preservation efforts. The effective profit that we have from growing trees is owed in significant part to the people who care for these trees and maintain them, but the trees themselves also deserve credit. **They are paying us every day with the only currency they have** and benefiting our lives by simply existing.

If we think of street trees **less as objects and more as living beings whose habitat we are wholly responsible for**, it makes perfect sense to consider them as our clients. They inhabit the streetscape more than any being that can move, so they should be considered a primary user group for our streets.

Trees are more than just the canopies that provide shade and beauty we tend to appreciate. Roots are a necessary, vital part of trees that support them structurally, allow them to absorb stormwater, gather nutrients, and breathe. They spread out beyond the canopy, up to two or three times as far as the branches, and often prefer to grow near the surface for the tree's health and wellbeing. Sidewalks are constructed within the tree's innermost critical root zone, so it is **advisable to tread lightly and avoid cutting the roots if possible**.

The best sidewalk for a tree would be one that does not exist; the street is not a good place for trees to grow in comparison to any of their natural habitats. **We plant trees in streets for our own benefit and urgently need to increase and preserve tree canopy for our own health, safety, and resilience in the face of climate change**. They also mitigate the negative impact our cities have on broader ecosystems, bridging gaps for local wildlife and supporting

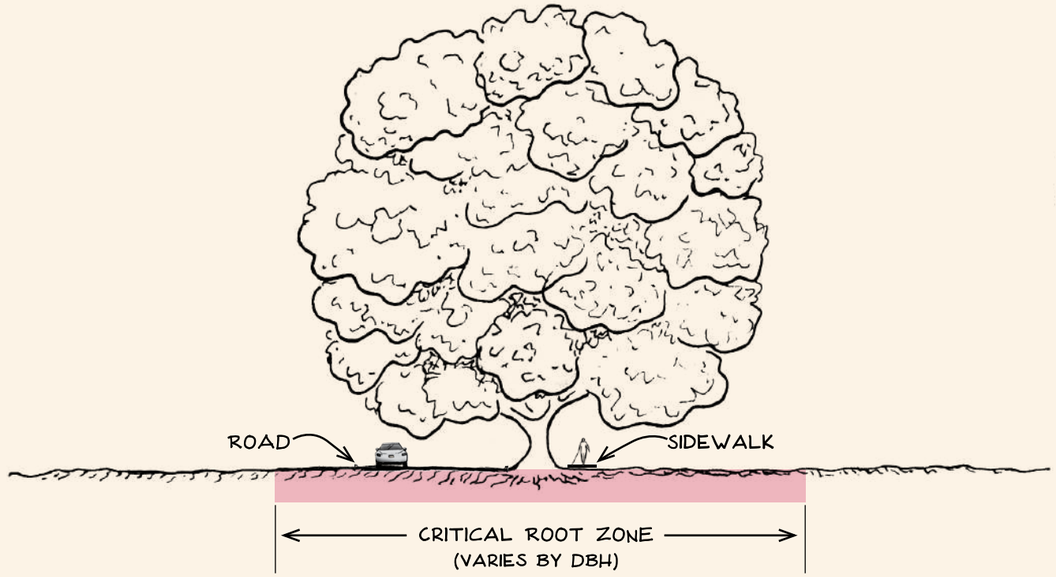




Figure 3.1.1
What We Ask of Street Trees
Diagram of a Bigleaf Maple's natural root span compared to a residential street and sidewalk. Zoomed in illustration of a street tree and pedestrian with a disability mutually struggling due to spatial conflicts in the urban streetscape.

entire ecosystems on their bark. Prioritizing our trees' needs is what we can do now to repay them for how much they are already compromising and sacrificing to grow in our streets (see figure 3.1.1).



Figure 3.1.2
Other Places to Put the Sidewalk
Illustration of options for laterally relocating the sidewalk, showing none of them address the core problem of root heave.

PREVENTING CONFLICT BETWEEN TREE AND HUMAN NEEDS

Sidewalks absolutely must separate root growth from path accessibility because they need to be accessible, especially in core "walkable" areas of cities, but the current system is failing and everyone is losing.

We have very limited options within reason besides lifting the sidewalk (see figure 3.1.2). Given that even a sidewalk across the street is almost certainly in a large tree's critical root zone, there is nowhere to move it, and removing sidewalks entirely is not a solution from a public safety perspective. Streets also rarely meet accessibility standards, experience root heave themselves, the edges of roads are designed to flood when it rains too much, and **pedestrians are at risk in the street**. Sidewalks are elevated for people's protection, included on both sides of the street to serve all properties, and must be accessible as public infrastructure. So, **how can we redesign our sidewalks to keep them accessible near trees?**

3.2 DESIGN PRECEDENT ANALYSIS

Boardwalks are the most applicable precedents for truly root-resilient sidewalk design, and have local precedent in the historic Eugene boardwalks, which may have been the original walkways installed alongside trees included within the research scope, as well as the local modern boardwalk in Eugene's Downtown Riverfront Park, which provides a strong contemporary parallel that demonstrates how wood boardwalks hold up in the local microclimate.

While these precedents can inform the design approach, it must diverge from them by necessity given that **no other system was created with the intent of functioning as sidewalks while providing substantial air exchange over roots on residential-scale streets without concrete.**

HISTORIC SIDEWALKS OF EUGENE

Historically, Oregon's sidewalks were made of many materials, especially wooden planks. Early Oregon roads were just wide dirt paths, but separate paths for bicycles and pedestrians were established at the turn of the 20th century with wooden planks or gravel (oregon.gov). These boardwalks did not appear to include clear space above tree roots, but they provide valuable context about the trees' history and aesthetically connect with Eugene's historic character. These assemblies were not necessarily accessible, especially because they lacked edge protection, but they were a much more environmentally friendly (and more tree friendly) option than modern on-grade concrete walkways.

There is limited remaining documentation of these boardwalks; most photos of them were taken to document historic events and include sidewalks circumstantially, but it generally appears like these boardwalks were elevated considering how they are visible while the surrounding area is submerged (see figure 3.2.1).

Aesthetically, these historic boardwalks resemble docks on a lake and elevated paths through state forests. They also match the contemporaneous wooden boardwalks that wove through the University of Oregon early in its history. Adapting these historic boardwalks to meet modern accessibility codes would **connect with Whiteaker's historic nature while preserving historic trees**, strengthening the neighborhood's identity, and providing improved, root-resilient sidewalks.



Figure 3.2.1
Historic Eugene Boardwalk
Photo of Downtown Eugene in 1881 after a historic flood. Wood boardwalks were commonly used during this time, alongside gravel. (Register-Guard Archive)



Figure 3.2.2
Downtown Riverfront Boardwalk
Photo of the boardwalk along the Eugene Riverfront under construction.
(Pietsch, 2021)

MODERN WOODEN BOARDWALKS

There is an extensive, fairly new modern wooden boardwalk in Eugene along the riverfront that supports pedestrians and bicyclists. This boardwalk functions as an alternative to the street, is engineered for durability, and features an elevated steel structure with wooden planks (see figure 3.2.2).

The boardwalk is substantially elevated, lit with closely spaced human-scale lights along the park edge, and protected with a cabled guardrail on the side that overlooks the river. A wooden curb provides edge protection on the park-facing side and the boardwalk appears to slope toward the river, which has no curb to allow for drainage but meets edge protection requirements by including a fairly low bottom cable as a toe rail (see figure 3.2.3).

The intensive, sturdy engineering for this boardwalk seems unnecessary and **too costly for a residential sidewalk**, but it could be scaled down. Given the boardwalk's location along the Willamette River and short walking distance to



Whiteaker, this precedent is also important design context. The sun-bleached wood decking appears to be withstanding Eugene weather, but it is unclear how long the boardwalk will maintain its rigid, stable surface without creaking or differential swelling across the boards.

There is an older wooden sidewalk boardwalk in Portland, OR that provides valuable insight about the longevity of wood in Oregon cities and serves as the most direct precedent for this project. The Jamison Square boardwalk was designed by Peter Walker and constructed circa 2000 with ipe wood planks (Helphand & Way, n.d.). This material seems to be generally stable, but is showing **signs of warping and buckling, especially at the supporting concrete beams** (see figure 3.2.5).

The Jamison Square boardwalk provides landmark spatial presence and a beautifully inviting historic revival aesthetic (see figure 3.2.4). This boardwalk was inspired by Portland's historic wooden sidewalks and docks along the Willamette

Figure 3.2.3
Modern Eugene Boardwalk
Photo of modern wooden boardwalk at the Downtown Riverfront in Eugene.
(eugene-or.gov)



Figure 3.2.4
Jamison Square Boardwalk
Wide wooden boardwalk in Jamison Square in Portland, OR. Boardwalk is on-grade and encloses trees with grates. The main circulation route appears even and accessible, but there are some visible level changes along the sides, particularly between tree grates.

River. The path connects three parks in Portland's Pearl District that have a shared theme of water and incorporates an allée of honey locusts for shade and spatial definition (Helphand & Way, n.d.). This design provides a **gentler pedestrian experience and different sensory input than a standard concrete sidewalk** that may be especially pleasant for blind users. The airspace beneath the planks creates a soft echo reminiscent of a dock on a lake that subtly increases awareness of others walking nearby and the forgiving wooden surface reflects much less heat than concrete. The path also includes fully accessible curb ramps with the required tactile pavers (see figure 3.2.6). Walker's careful detailing is evident along the edge of these ramps, where the boards seamlessly transition into concrete with no level change, even after over twenty years of wear. The boards appear to be supported by sub-grade concrete beams along these edges and terminate into the ramps, which were likely poured before the planks were installed.







Figure 3.2.5
Jamison Square Wear and Tear
Close-up views of the boards at Jamison Square warping, likely through moisture/heat expansion and contraction, causing level changes, and images of sections with heterogeneous age, indicating recent repairs.



Figure 3.2.6
Jamison Square Curb Ramp
Photo demonstrating how the Jamison Square Boardwalk connects to curb cuts.

From a human perspective, the Jamison Square Boardwalk is the perfect precedent for this project. However, Walker's tree well design does not appear especially inviting for the Honey Locusts planted within them (see figures 3.2.7 and 3.2.8). While they have pockets of airspace, the sub-grade concrete beams surrounding them that are constructed within their critical root zones seem problematic for their health. The restrictive grates around the trees could be eliminated with curbs or rails as edge protection, but the sub-grade beams seem harder to avoid.



Figure 3.2.7
Jamison Square Tree Grate
Photo of a tree grate installed in Jamison Square, demonstrating how the product is constraining the tree's base.

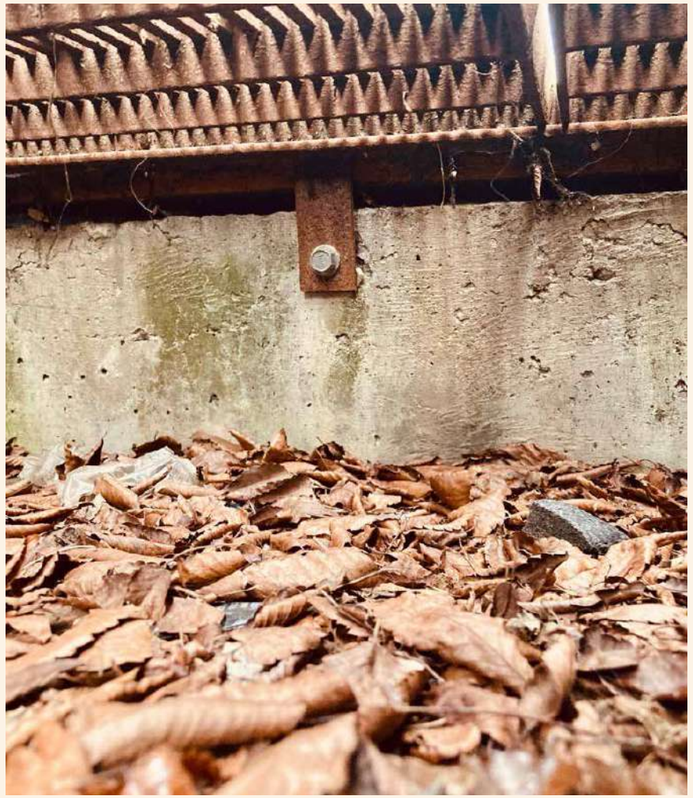
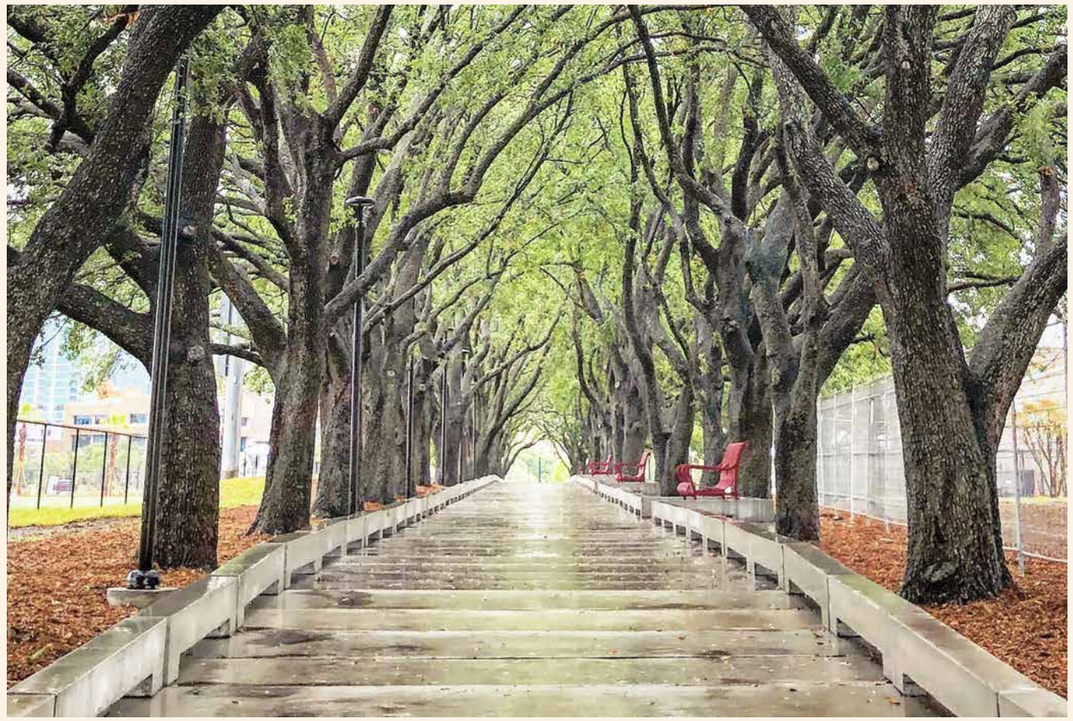


Figure 3.2.8
Inside Jamison Square Tree Grate
Photo taken below grade inside of a tree grate, showing that the grates and apparently the boardwalk itself are secured onto concrete beams, which provide some air space between them, but clearly occupy the space trees' roots prefer to grow, enclosing the trees planted in Jamison Square.



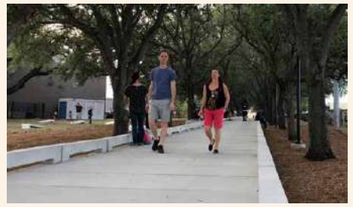


Figure 3.2.9
Julian B Lane
Precast concrete boardwalk project in Florida.
(permatrak.com)

PRECAST CONCRETE BOARDWALKS

The precast concrete boardwalk system by PermaTrak is a precedent that incorporates arborist insight and seems like a **fantastic design solution from the tree's perspective**. This system was developed with the full recognition that trees need airspace above their roots, it is intended for the CRZ of trees that are especially significant, and is built with durable construction (permatrak.com).

The most common application for the PermaTrak system is new construction sites where there are heritage trees that have grown without adjacent sidewalks. The reason this is frequently required is that trees naturally grow vital roots in the space where we typically construct sidewalks and that area is far within the tree's critical root zones. This means extensive root pruning on trees actively relying on the roots growing where the sidewalk would be installed, which is far worse than root pruning trees that grew with restricted access to root space.



The root-preserving benefits of an elevated boardwalk system are the only option for installing new walkways in these circumstances, but they would benefit all trees, including those who have grown to accommodate sidewalks. The nature of root growth also means that **elevated walkways installed at saplings cannot be replaced with on-grade sidewalks later on**, meaning that any elevated system needs to be heavily tested before being used with saplings to avoid dooming the tree in case of path failure.

The PermaTrak precast boardwalk system treats existing tree roots with care while aesthetically elevating pedestrian spaces. The system also considers accessibility, providing adequate edge protection to keep pedestrians, particularly those with low/no vision, safe (see figures 3.2.9 and 3.2.10).

PermaTrak's descriptions of the benefits of their concrete system over a wooden boardwalk are convincing, particularly because they point out concrete's inherent slip resistance,



Figure 3.2.10
Davis Field Project at Wake Forest University
Precast concrete boardwalk project at a university in North Carolina.
(permatrak.com)

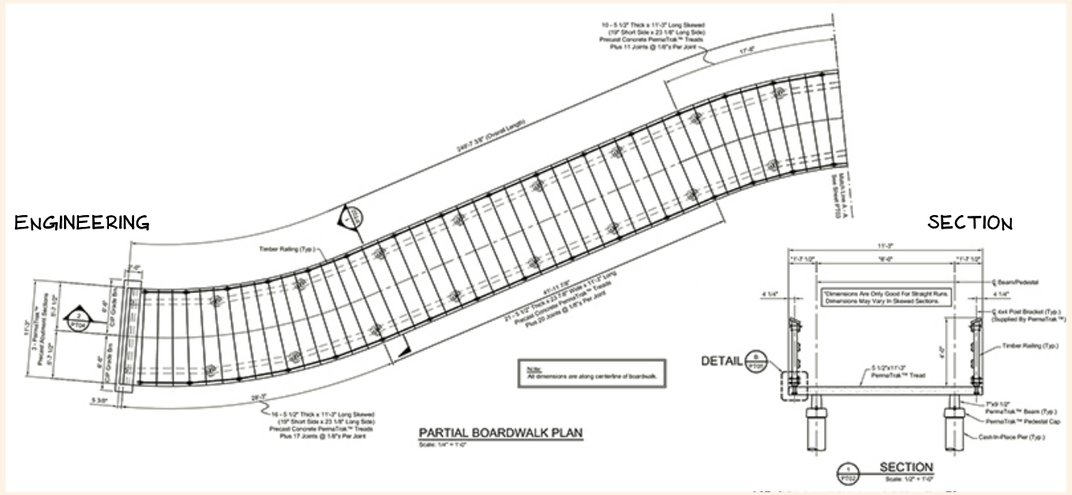


Figure 3.2.11
Main Street Tree Root Crossing in Broussard, LA
Example of a precast concrete boardwalk spanning over tree roots between sections of a standard sidewalk.
(permatrak.com)

rot resistance, and substantially longer life than wood (permatrak.com). Considering that these boardwalks are completely separated from soil expansion and tree roots, it seems likely that these boardwalks could last for a century (see figure 3.2.11).

Unaffiliated sources confirm that wood boardwalks often become slippery due to algae, moss, mold, and mildew (americantrails.org). These factors are manageable with proper maintenance, but the risk of slippery surfaces must be carefully considered when selecting a boardwalk material because relying on residents to routinely clean sidewalks is not ideal.

Most importantly, PermaTrak **advocates for collaborating with arborists, recognizing the value of their expertise when designing a sidewalk**. Their previous projects are



ABUTMENT



PRECAST CONCRETE



HELICAL PILE



a collection of elevated aesthetically pleasing walkways that range from public sidewalks and parks to university walkways. This tree-preserving system has many clear applications, but a precast plank boardwalk system still has **drawbacks** and it is worth investigating alternative materials for future boardwalk design innovation.

- Precast concrete boards seem prohibitively expensive for many private homeowners and cities that manage sidewalk repairs likely cannot afford to install these systems in most residential areas.
- The weight of a precast concrete boardwalk requires a great deal of support from the foundation, which leads to foundations with large members or tight spacing, increasing tree root disturbance and cost compared to lighter systems (see figure 3.2.12)

Figure 3.2.12
PermaTrak Construction System
Engineering drawings and construction photos of the PermaTrak precast concrete system.

The system typically uses abutments at the connections between the boardwalk system and other path types and often uses precast or cast-in-place concrete pier foundations.
(permatrak.com)

- The required thickness for edge protection with precast concrete is so large that there is often not space to accommodate it in addition to an accessible path width within the public right of way in residential areas. This is the likely reason PermaTrak projects are found in large urban areas and typical path widths are at least 8 feet.
- All concrete has a significant carbon footprint. An elevated concrete boardwalk uses significantly more concrete than an on-grade sidewalk, increasing a city's carbon footprint.
- Concrete acts as a thermal mass and contributes to the urban heat island effect; these drawbacks of concrete may not be altered by elevating the material, particularly if the assembly increases concrete mass.

Luckily, there are many material alternatives to wood and concrete, ranging from FRP to the plastic and rubber lumber assemblies (see figure 3.2.13). The main challenge these systems have is their **slip resistance**. Material specification must carefully consider integral material friction and avoid topical slip resistance that will wear down.

BOARDWALK PRECEDENT APPLICATION

The evidence-based design proposal in this project learns from inaccessible historic boardwalks and builds off of the framework established by PermaTrak, adapting the concept for a wider variety of **lighter, less carbon intensive, and less expensive materials than precast concrete**. The aesthetic goal is to relate to the beautiful park boardwalks along the Riverfront, but the material assemblies will be **more similar to the FRP boardwalk in Spencer's Butte forest and the plastic lumber boardwalks across the country**.

This proposal pushes the envelope relative to all precedents by advocating for more air space over tree roots based on their response to other suspended products like tree grates. The goal is to allow the tree to breathe comfortably, using evidence-based dimensions.

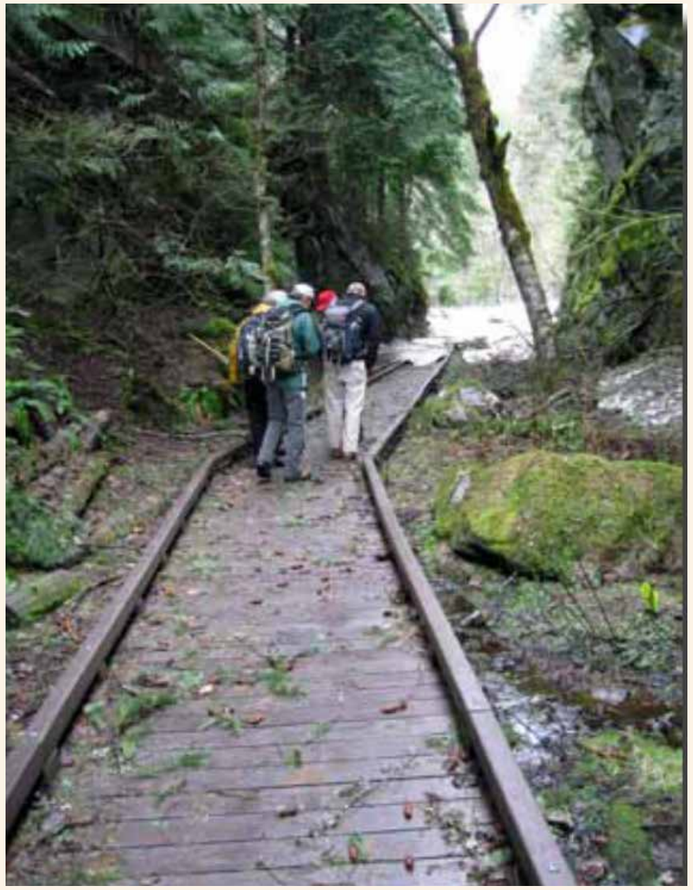










Figure 3.2.13
Plastic Lumber Boardwalks
Photo examples of plastic and rubber lumber options for boardwalks.
(Willbee, 2011)

3.3 CASE STUDY SITE DESIGN

The design portion of this project begins by examining a particular case study site, recognizing the stakes surrounding the representative design client, and evaluating available design options using the standard sidewalk system before proposing an alternative system of design experimentation.

REPRESENTATIVE CLIENT

Given the pervasiveness of sidewalk root heave as an issue, it is unsurprising that the data collection process for this project intersected with a tree that was at risk of removal due to a sidewalk conflict, but the story of this particular Majestic Maple (see figures 3.3.1 and 3.3.2) had an unexpected influence on the trajectory of this work.

Even more than the other trees within this project's scope, **this Majestic Maple is beloved and cherished by its community** thanks in part to its unique, sculptural form, which is clearly burled, expanding toward the sidewalk,



Figure 3.3.1
The Majestic Maple's Crown
Photo taken by Tim Lewis on June 5, 2026.



Figure 3.3.2
The Majestic Maple in Peril
Photo taken in the field on January 10, 2026 of the Bigleaf Maple the community was afraid of losing.

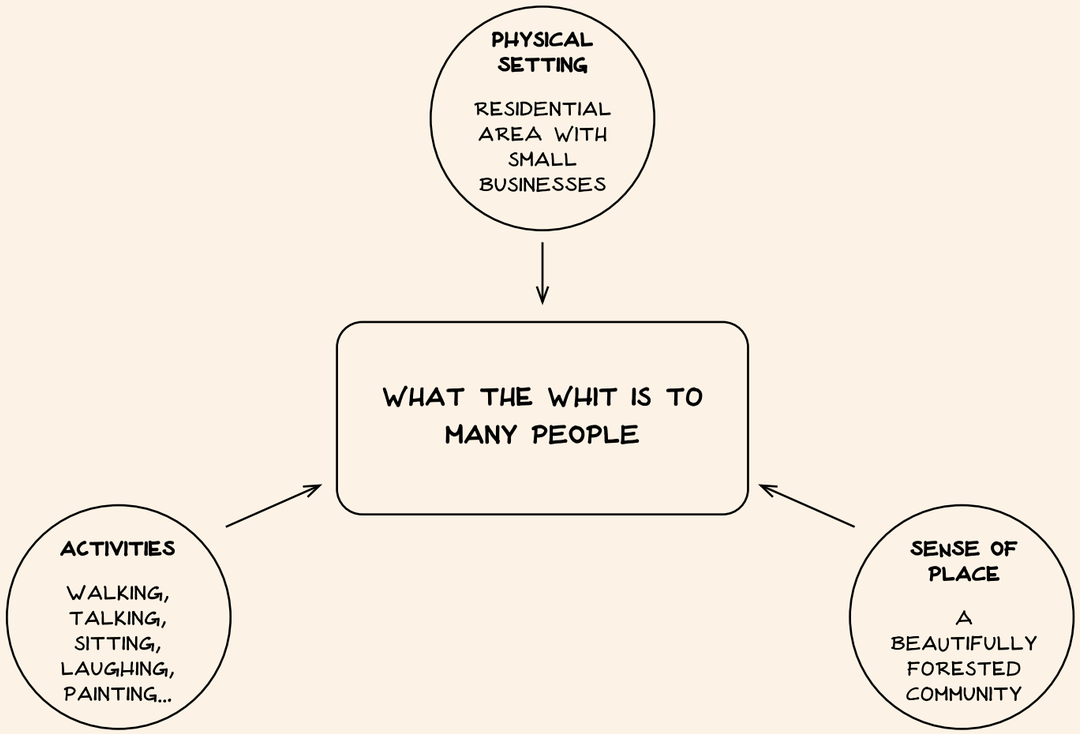


Figure 3.3.3
How a Tree Makes a Place
Adaptation of Dr. Stapleton's diagram of the cross-disciplinary tripartite model of place, using Whiteaker as an example.

"IF THAT TREE WERE CUT DOWN I WOULD HAVE HAD TO MOVE."

LEE FELDMAN-REDICK, 2026



Figure 3.3.4
Lee and the Tree
Photo by Tim Lewis of Lee Feldman-Redick in his home, looking out at the tree hoping it will survive the upcoming sidewalk repair.



Figure 3.3.5
A Neighbor in Peril
Field photo of the smaller Bigleaf Maple adjacent to the Majestic Maple that had greater conflict with the adjacent sidewalk.

and modified into a hand-like shape due to extensive crown pruning for overhead powerlines. This representative client presents a challenging design problem due to its constrained site, but it is also a reminder of why these kinds of design problems need solutions. This tree is a placemaker (see figure 3.3.3), and part of people's home that makes Whiteaker what it is, particularly for Lee Feldman-Redick (see figure 3.3.4). The same unique form that summarizes the tree's distress signal responding to its growing conditions shapes the space around it in a way that **cements this particular location in people's memory**.

The tree down the block, which was also at risk, got less attention despite having more years ahead of it, possibly because it stands out less (see figure 3.3.5). But it's more likely because the large Majestic Maple outside Lee's window is his dear friend who he's spent most of his time with for the past nine years. He watches people approach and admire this tree day in day out and **it is what makes his apartment a home**. The Majestic Maple survived in the end, but the



Figure 3.3.6
Initial Photogrammetry Model
Image of the photogrammetry model of the Majestic Maple, courtesy of Ignacio Lopez Buson. Intended as either a memorial for or a realistic reference for designing around the tree's burled base and low-hanging branch.

ten day period between discovering the tree in the field and learning it would be preserved demonstrated **the perilous situation many, if not most of the Bigleaf Maples studied for this project are facing**.

SITE DOCUMENTATION

Out of particular care for this tree and a **desire to**

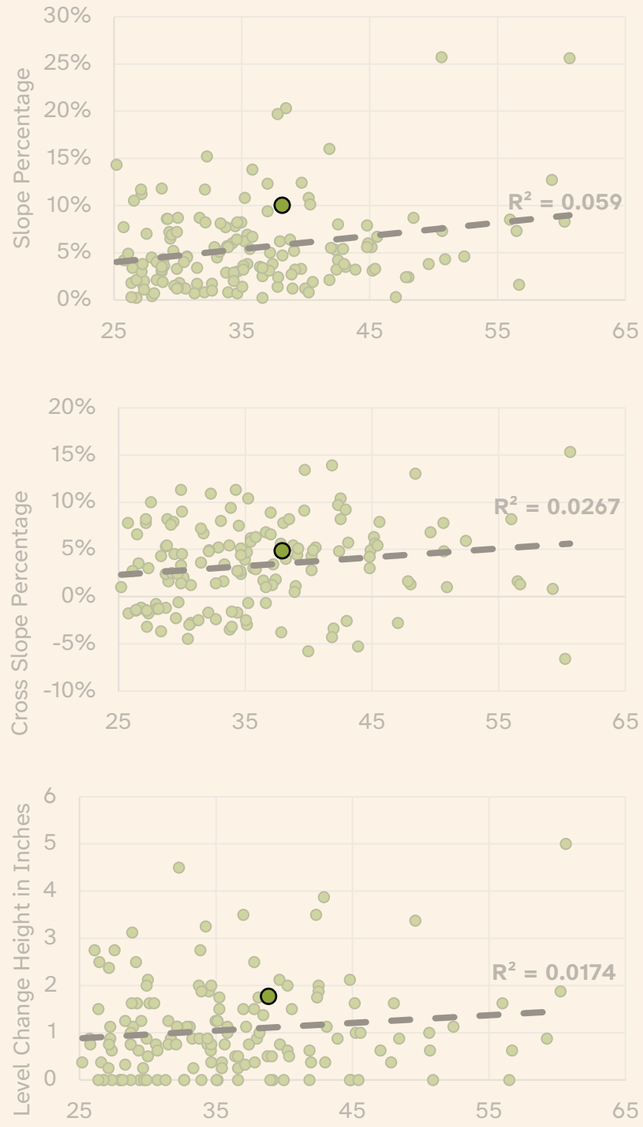


Figure 3.3.7
The Stakes at this Site
Scatterplots showing the relationship between tree DBH and root heave with this tree's location noted, showing the local sidewalk obstruction relative to other trees within this project's scope.

preserve its memory, even if it hadn't survived, it was documented through overlapping photos used to create the photogrammetry model (figure 3.3.6).

Along the way this tree was examined in detail and compared to the rest of Whiteaker's oldest trees. This tree was substantially obstructing the adjacent sidewalk, but not to an excessive degree (see figure 3.3.7). This tree was not at

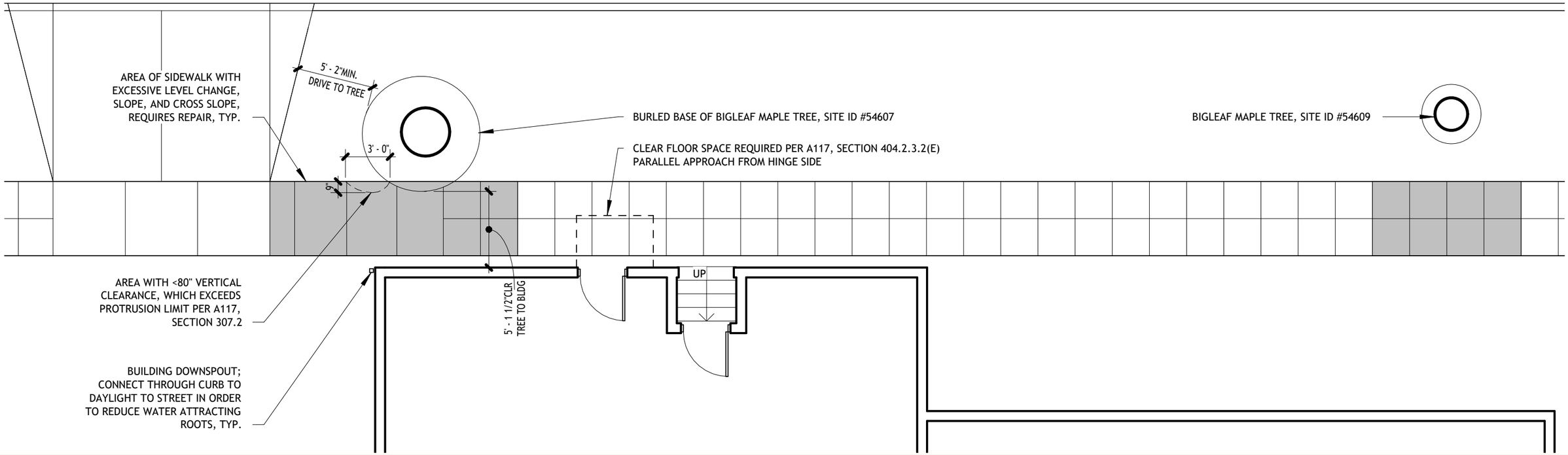


Figure 3.3.8
Conditions Measured in the Field
Drafted plan illustrating existing conditions surrounding the trees at this site.

risk because it was the worst offender, it's just that this site was reported to the city and thus required a response. The sidewalk was inaccessible and served as a tripping hazard, so the report was justified. But even the possibility the repair may lead to this tree's removal was **devastating and unacceptable to the community**.

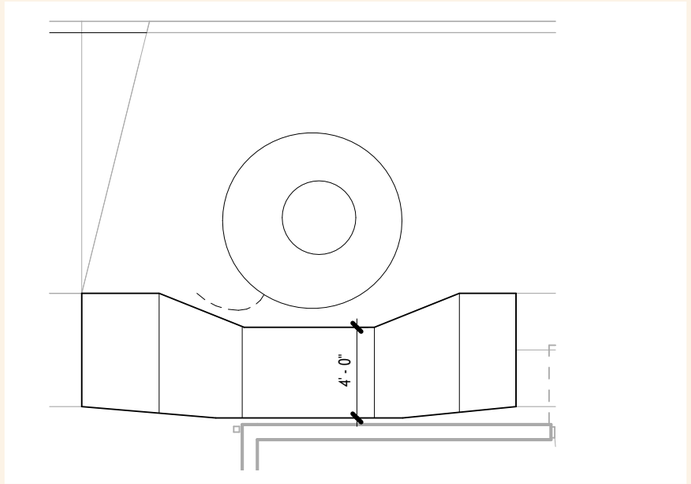
To better understand the real design challenge of sidewalk root heave, **prior to processing data from the street tree study**, this site was assessed in plan view, seeking places to move the sidewalk laterally.

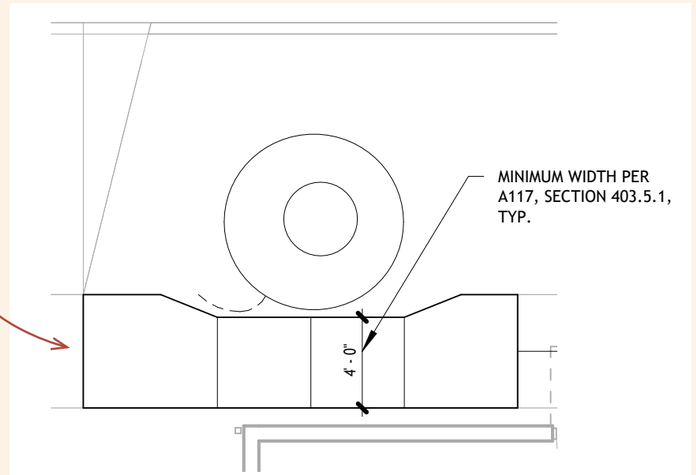
First, existing conditions were documented in detail. The distance from the adjacent driveway, ground-level doors, and the tree's basal burls were measured and sidewalk panels requiring repair were noted (see figure 3.3.8). The adjacent road also requires repair, in addition to the driveway; ideally these projects could have been coordinated as a unit to improve the area while limiting root disturbance. However, policy requires the sidewalk to be repaired within a certain timeframe and fixing the entire area is often not realistic, so design solutions solely focus on the sidewalk.

PROCESS DESIGNS

The drafted plans in figures 3.3.9 and 3.3.10 show how few options are available within the current system, which **only really allows for increasing lateral separation between sidewalks and trees**. This is overwhelmingly the most ubiquitous type of sidewalk construction, but it is limited when managing root heave. As the redlines on these drawings express, reducing the adjacent path by 1' - 0" limits accessibility, constraining people to the minimum accessible width. The reason that narrowing the sidewalk here was a necessary and beneficial adjustment is because the tree is growing too close to the building and needs more free space to move. Other adjustments, like moving the sidewalk out

Figure 3.3.9
Possible Scalloped Walk Options for Repairing the Sidewalk within the Current System - Redlined Post Analysis
Drafted plans of ways to scallop the sidewalk illustrated January 2026 while waiting to hear the determined fate of the Majestic Maple with redlines added after data analysis.





THIS IS THE MOST WORKABLE OPTION - BUT IT'S NOT ALWAYS POSSIBLE AND REDUCES ACCESSIBILITY. AND WHAT IF IT JUST RESETS THE CLOCK ON A RECURRING PROBLEM?

toward the curb, **provide little benefit and are wasteful uses of concrete**.

More radical suggestions, like an aluminum panel spanning over the tree roots like a utility box, seem both more and less realistic than relying on the existing sidewalk system to withstand root heave. The aluminum would need a supporting structure to span, which would have to be elevated significantly above tree roots and span across even a couple of feet, so there are some technical concerns. Aluminum is also slippery and reflective, thus suboptimal for a sidewalk walking surface.

OUTCOME

The city designed and constructed a new accessible sidewalk through their own means and were able to preserve both trees at this site (see figures 3.3.13 and 3.3.14), but the smaller tree had to endure significant root pruning to make sidewalk reconstruction possible (see figures 3.3.11 and 3.3.12). This is an example of how **urban forestry management requires a lot of compromise** to

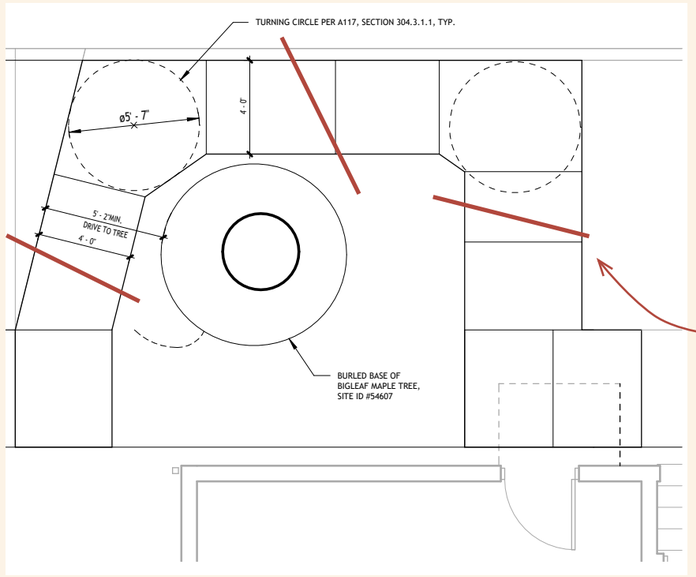
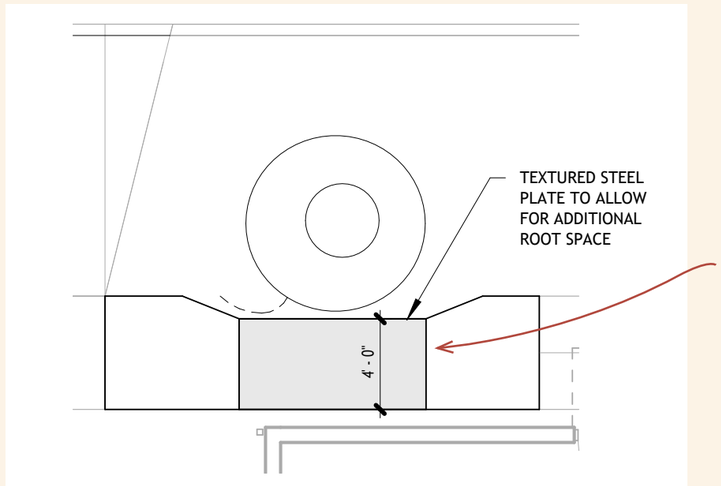


Figure 3.3.10
Theorized Radical Sidewalk Renovation Options- Redlined Post Analysis
Drafted plans of potential radical sidewalk changes illustrated January 2026 while waiting to hear the determined fate of the Majestic Maple with redlines added after data analysis.

WASTEFUL USE OF CONCRETE WITH NO MEANINGFUL ADDED ROOT SPACE!



HOW WOULD THIS BE SUPPORTED?

WOULD IT REALLY PROVIDE MORE SPACE?



Figure 3.3.11
Schrödinger's Roots - The Majestic Maple Survived
Photo from the City of Eugene Urban Forestry Department showing the Majestic Maple's roots before sidewalk reconstruction.
(Lakics, personal communication, January 21 2026)

accommodate the standard way we construct sidewalks, even when it is to the detriment of our trees.

These roots were shaved down in a particular way to minimize regrowth vertically, toward the sidewalk, and rebar was used in the sidewalk to prevent root heave at the joints near the tree. In theory this will prevent recurrence.

According to the findings in this project's street tree study, it seems **highly possible the sidewalk will lift again at the joint between old and new concrete**, potentially putting these trees at risk again. Since this intervention uses almost the entire available toolkit within the current sidewalk system, it has to last as long as the trees have years left to live. Considering that accessibility tolerances allow for 3" of



vertical displacement at the absolute most, even in the best-case scenario, will the sidewalk really survive the root growth these trees will have in the future?

COMMUNITY RESPONSE

Throughout this process, the community felt powerless and waited in fear to see whether the tree would live or die. Community members reaching out to the city may have rebalanced the equation for this tree, increasing reasons to keep it despite its old age, compromised health from previous pruning, and risk of impacting its health through root pruning for the sidewalk.

The trees' survival was a **breath of fresh air**, incredible relief, and symbol for the Whiteaker community that there is **hope**

Figure 3.3.12
Root Pruning Required to Save the Smaller Majestic Maple
Photo from the City of Eugene Urban Forestry Department showing the smaller Majestic Maple's roots before sidewalk reconstruction.
(Lakics, personal communication, January 21 2026)

Figure 3.4.13
Majestic Maple - Before and After Construction
Field photos taken before and after the Majestic Maple tree was preserved with minor root pruning.







Figure 3.4.14
Majestic Maple - Before and After Construction
Field photos taken before and after the smaller Majestic Maple was preserved with more significant root pruning.

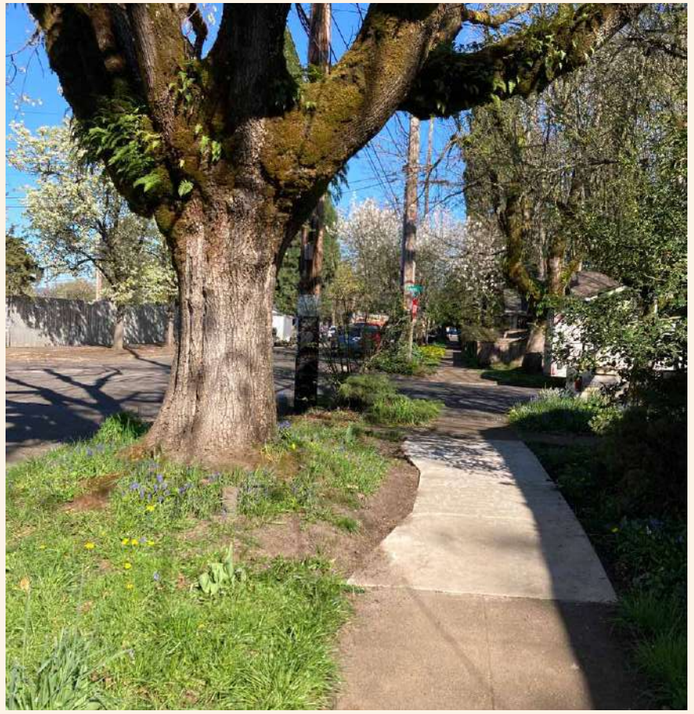




Figure 3.3.15
Save the Tree - 36” x 48” Acrylic Painting on Canvas by Lester Maurer
Painting of the Majestic Maple created while standing beneath its branches in the rain.

for the future of the urban forest they love so deeply. This tree was one of many that residents are concerned about, though it had elevated public support and attention. That symbol and the community’s passionate defense of this tree inspired the painting “Save the Tree” by Lester Maurer (see figure 3.3.15). The painting highlights light pollution around the tree’s branches, recognizing **the life-defining impact humans have had on this tree’s life**. And the tree’s hand-shaped canopy reaching upwards was noted as a symbol of defiance, wrapping around and **standing up against the constraints of the urban streetscape**.

The community held an event at a local church a couple of blocks from the tree to celebrate its survival and unveil Lester’s painting. And this story inspired a full-color Sunday article in the Register-Guard, a local newspaper that featured the photos in figure 3.3.16.





Figure 3.3.16
Register Guard Article Photos
Imaces from a local newspaper article describing the Majestic Maple’s story from the community’s perspective (Pierotti, 2026).
Photos by Chris Pietsch



Figure 3.3.17
Remember the Risk of the Roots
Photo taken during sidewalk closure prior to repair showing the Majestic Maple's roots were not growing especially close to the surface.

While the community showed a unifying love for this tree, and all trees like it by extension, it was not the city that was opposed to keeping the tree. No one appeared to be opposed to its continued existence, but public policy requires sidewalks to be fixed and **the current system restricts options for repair without risking trees' health or lives**.

The harsh reality is the tree's life was determined beneath the pavement. The tree would have lived or died entirely depending on whether the city arborists could confidently prune away just enough roots to keep it and its younger, healthier sibling down the block in check.

Given how much this tree means to the community, how central it became to this project, and how clearly it demonstrated the conflict between roots and routes, this story led to more questions. If the tree's roots had been too obstructive to repour the sidewalk and it were possible to stop time then do everything theoretically possible to find a way to save this tree, what could the city have possibly done?

Is there a solution out there that's realistic? Would it be possible to fix the sidewalk without sacrificing accessibility, the tree, or both? The answer is yes, but it requires **going back to the drawing board, drawing on the precedents cited in this project's precedent analysis, and finding a way to elevate the sidewalk** (see figure 3.3.17).

HOW COULD WE MAKE AN ACCESSIBLE PATH THAT LEAVES ROOTS ROOM TO GROW?

- ELEVATE THE SIDEWALK WITH BOARDWALK CONSTRUCTION
- USE A FLEXIBLE FOUNDATION SYSTEM THAT CAN WORK AROUND ROOT LOCATIONS
- NARROW THE BOARDWALK AS NEEDED TO LEAVE ROOM AROUND BURLS

CONNECT TO THE CURB FOR ACCESS TO PARKING

EDGE PROTECTION

SMOOTH TRANSITION FROM DRIVEWAY, SLOPE UP OVER ROOTS

3.4 PROPOSED DESIGN SYSTEM

HISTORIC REVIVAL TREE-FIRST ACCESSIBLE SIDEWALKS

The boardwalk illustrated on the previous page is the first design concept for Whitwalks, a new sidewalk system informed by historic and contemporary boardwalks, **which treats trees' needs as design requirements alongside accessibility**. This concept was developed in direct response to the Bigleaf Maples in Whiteaker, alongside the residents who asked in earnest for a solution that would allow them to fix their sidewalks without sacrificing trees. However, it could (and should) be applied and adapted to other sites that struggle with sidewalk root heave.

The only design requirement, from the tree's perspective, is to **lift the sidewalk above the roots** (see figure 3.4.1). But the specific solution and aesthetic result presented is specifically suitable to Whiteaker because of how it responds to site context. The boardwalk appearance calls back to Eugene's historic wood sidewalks. And the design intent is to tell part of the neighborhood's history, **honor the Paddle Trees** in the Whit, and provide a realistic system that could help cities peacefully and permanently resolve root-sidewalk conflicts. This system could be adapted and constructed on other sites and be made continuous across grade changes, with simple variations between on-grade and elevated construction. However, it's **necessary to start with the minimum possible intervention**.

An elevated boardwalk system is only really necessary where the sidewalk is being actively lifted (see figure 3.4.2). Whitwalks can serve as a bridge over tree roots, covering the most affected area of the sidewalk, and seamlessly transitioning to adjacent concrete with careful detailing.

This system would function best when elevated a significant amount over the soil surface, but as long as some of the soil is removed around the tree roots and there's an air gap between the bottom of the walk structure and top of the

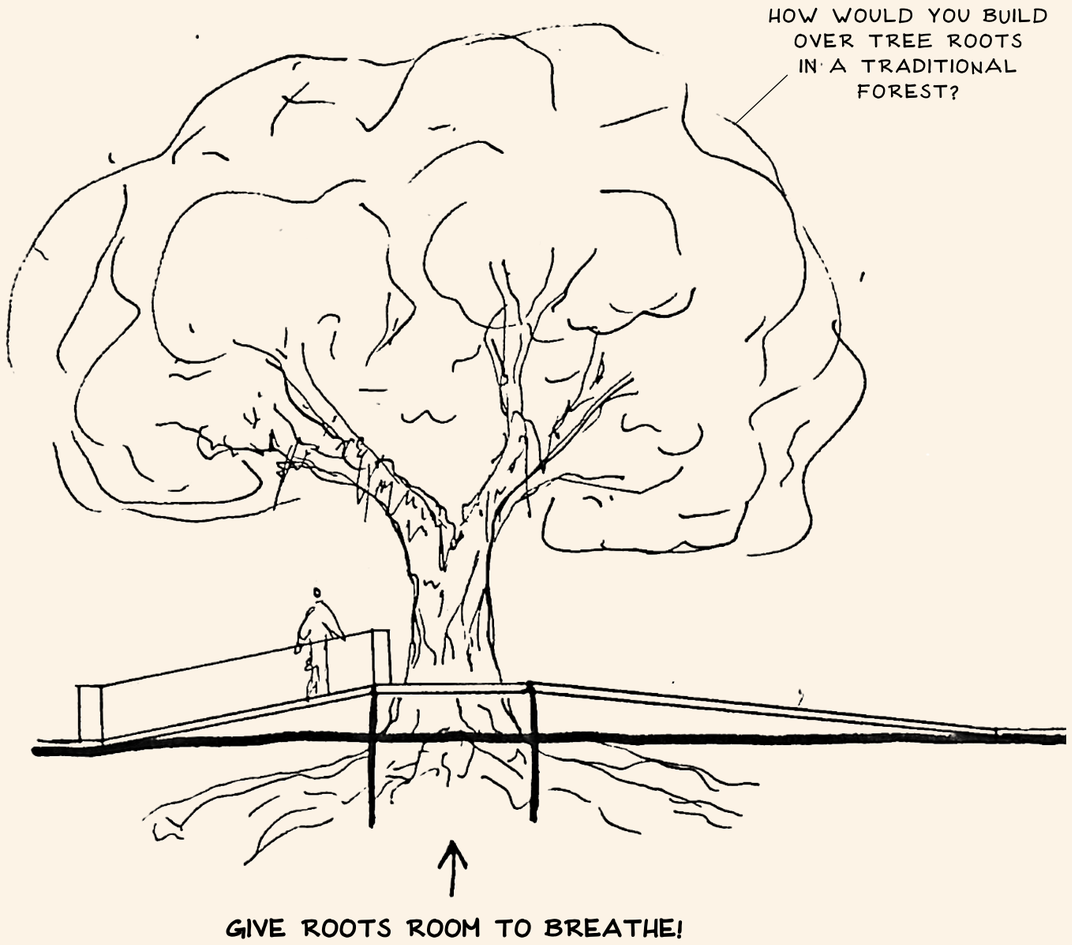


Figure 3.4.1
The Paddle Tree's Request
Illustrative sketch of an exaggerated elevated boardwalk at the base of a Bigleaf Maple tree, which asks how we would build an accessible path through a traditional forest, in other words how we would treat the tree's roots if it were growing in its natural habitat.

KEY SITE CONSTRAINTS TO CONSIDER

- ADJACENT CURBSIDE PARKING
- DRIVEWAYS
- CURB RAMPS
- CONNECTIONS TO BUILDINGS
- CONNECTING TO THE SLOPES OF ADJACENT EXISTING SIDEWALKS

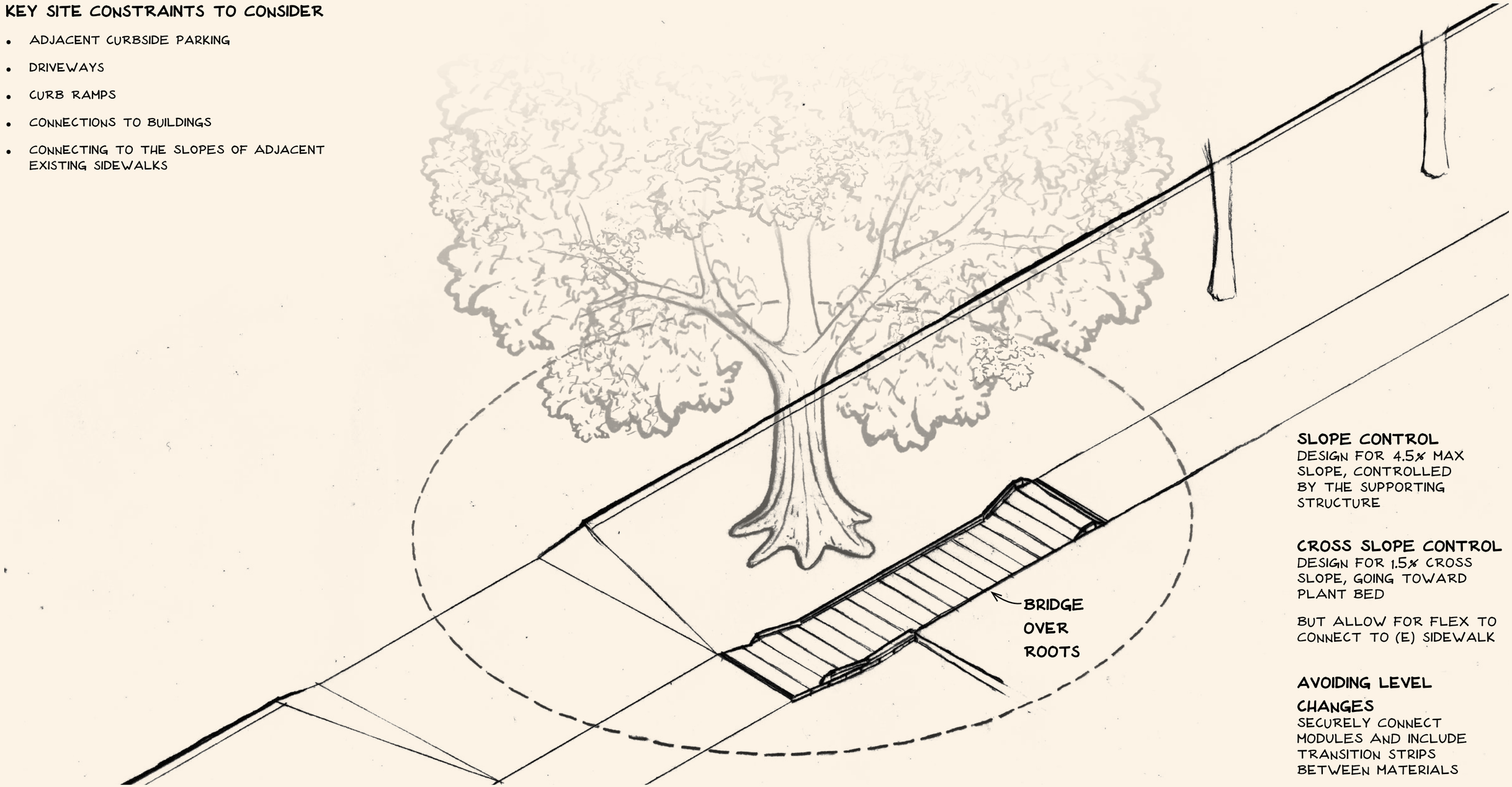


Figure 3.4.2
Minimum System Requirements
Isometric illustration of minimal intervention using WhitWalks at the base of a street tree.

roots, root heave should be avoided. This approach provides air circulation, but it's unclear if a nearly on-grade sidewalk would provide trees with enough air and separation for their roots and the space they need. Physical tests and arborist input will inform the actual design constraints, especially height requirements for space over roots.

When simplified to its basic design intent, Whitwalks are a simple design response to tree roots, though their

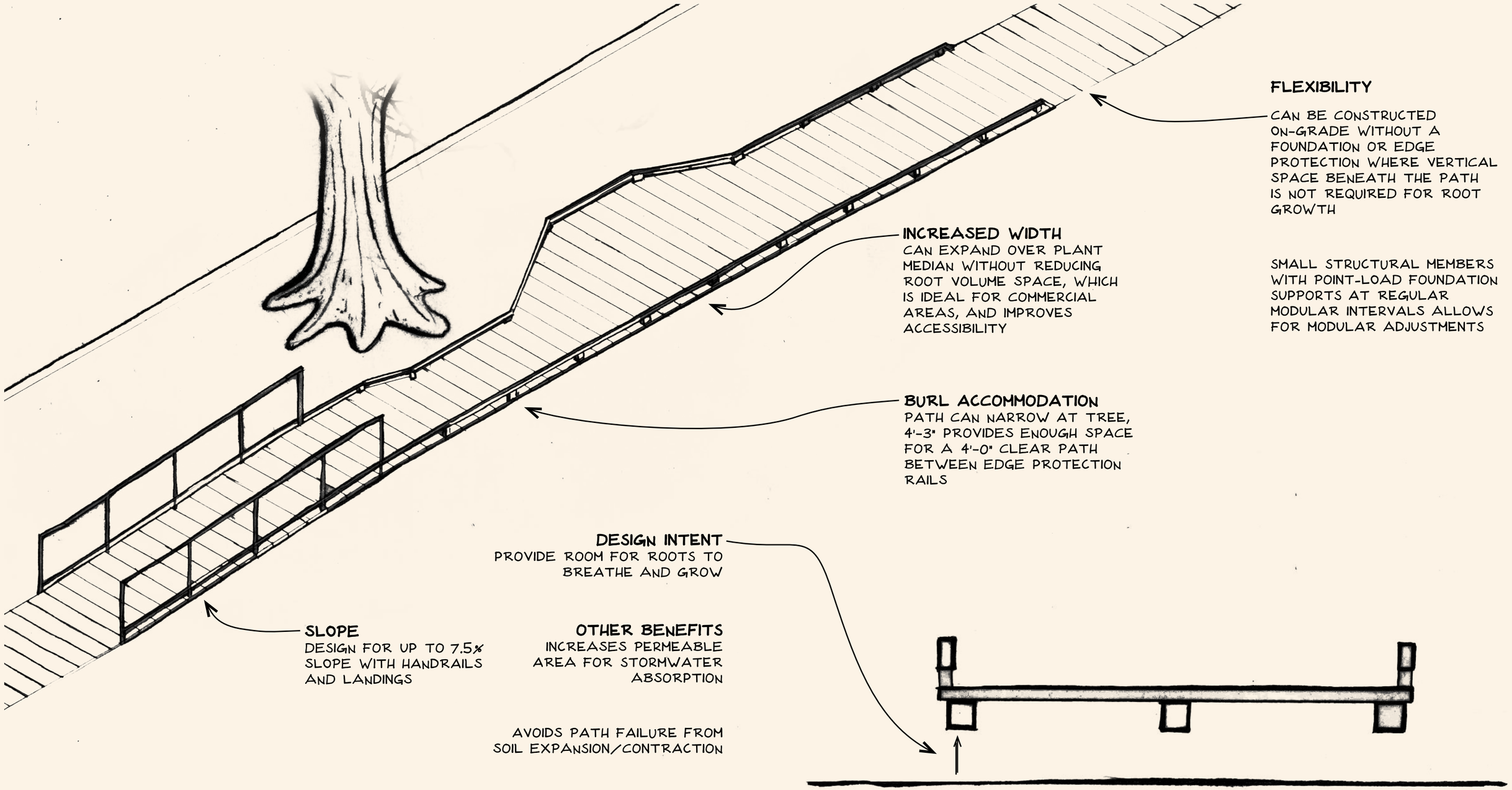
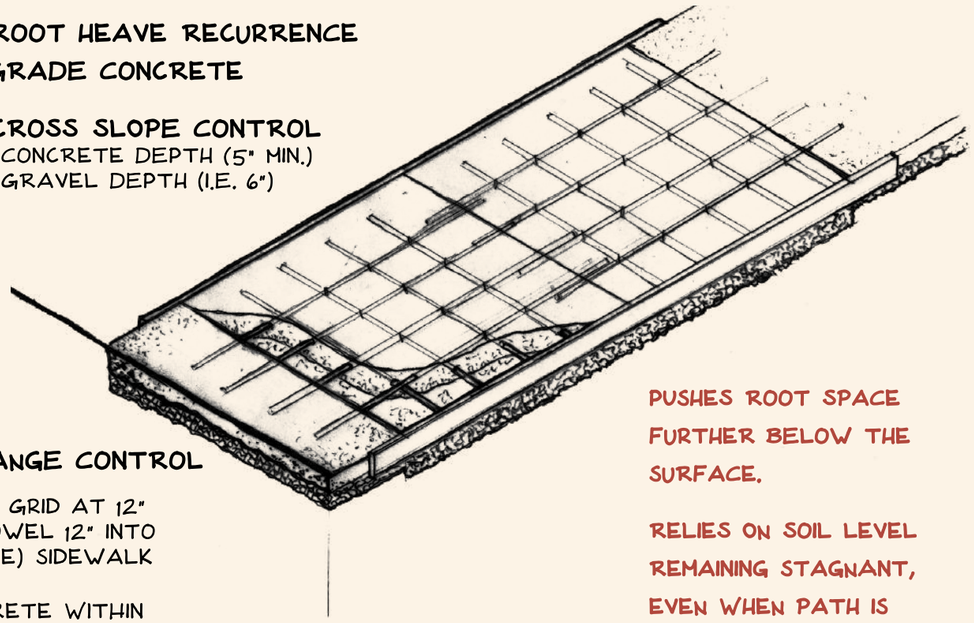


Figure 3.4.3
Potential for Expansion
Illustration of ways WhitWalks could expand and be modified to elevate sidewalks at various sites.

assembly and maintenance have additional complexities compared to on-grade concrete sidewalks (see figure 3.4.3). While sidewalk design proposals like Whitwalks need to be realistically compared to the existing concrete sidewalk system, it's worth noting that concrete sidewalks are also substantially complex, especially when trying to limit or avoid root heave as addressed previously.



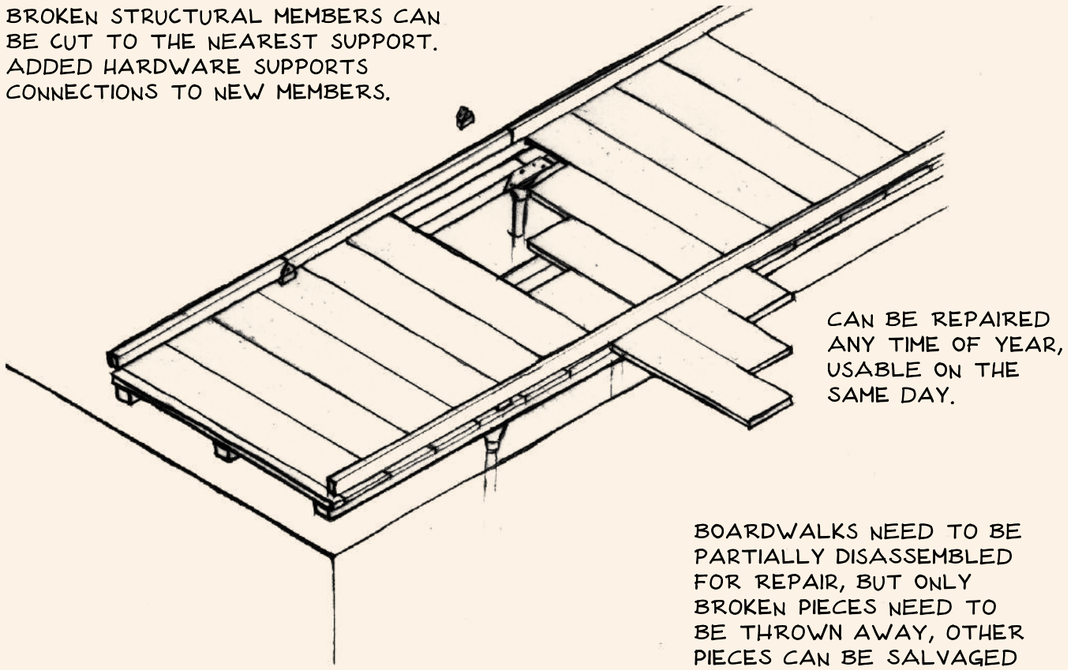


Figure 3.4.4
Means of Repair - Current System
Isometric illustration of repair required to prevent root heave with on-grade concrete sidewalks.

The reality of concrete sidewalk repair is messy, expensive, and wasteful, but a modular system could trade upfront design and installation complexity for faster, cheaper, and less wasteful maintenance long-term (see figure 3.4.4)

Figure 3.4.5
Means of Repair - Proposed System
Isometric illustration of repair required to fix WhitWalks.

3.5 NEXT STEPS

COORDINATION ACROSS DISCIPLINES

The design system proposed in this project will be developed into a realistic system with physical testing and cross-disciplinary coordination. To fill in blind spots and gather questions of concern from stakeholders, the next step for the development of this concept is **coordination across disciplines** with city staff, speaking with arborists, planners, and engineers at the same table (see figure 3.5.1). This is the recommended path for all designers looking to develop or incorporate a similar system, because **sidewalk design is a complex, important issue laden with liability risk**.

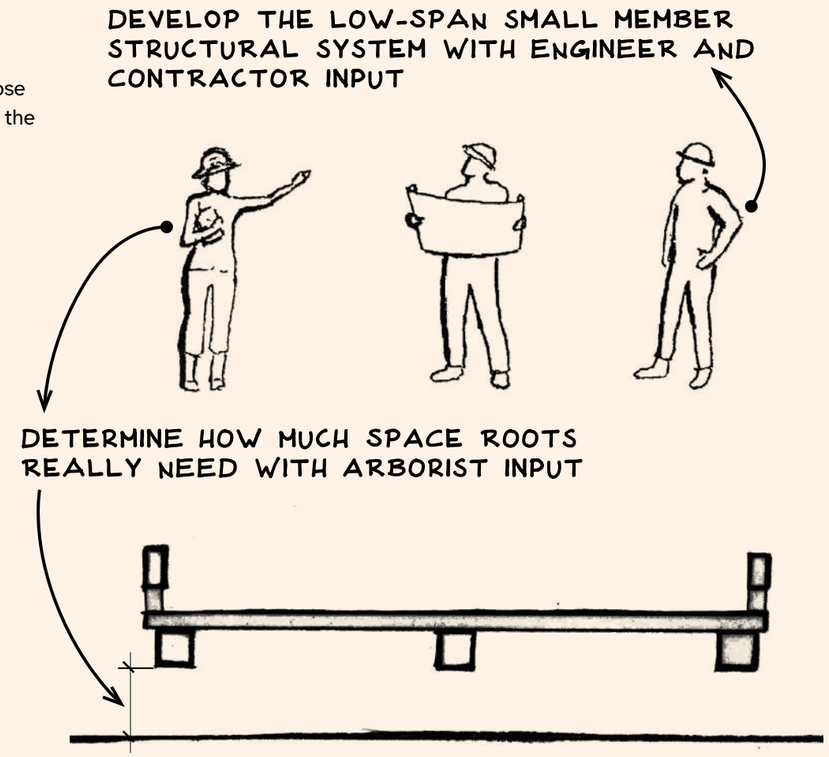
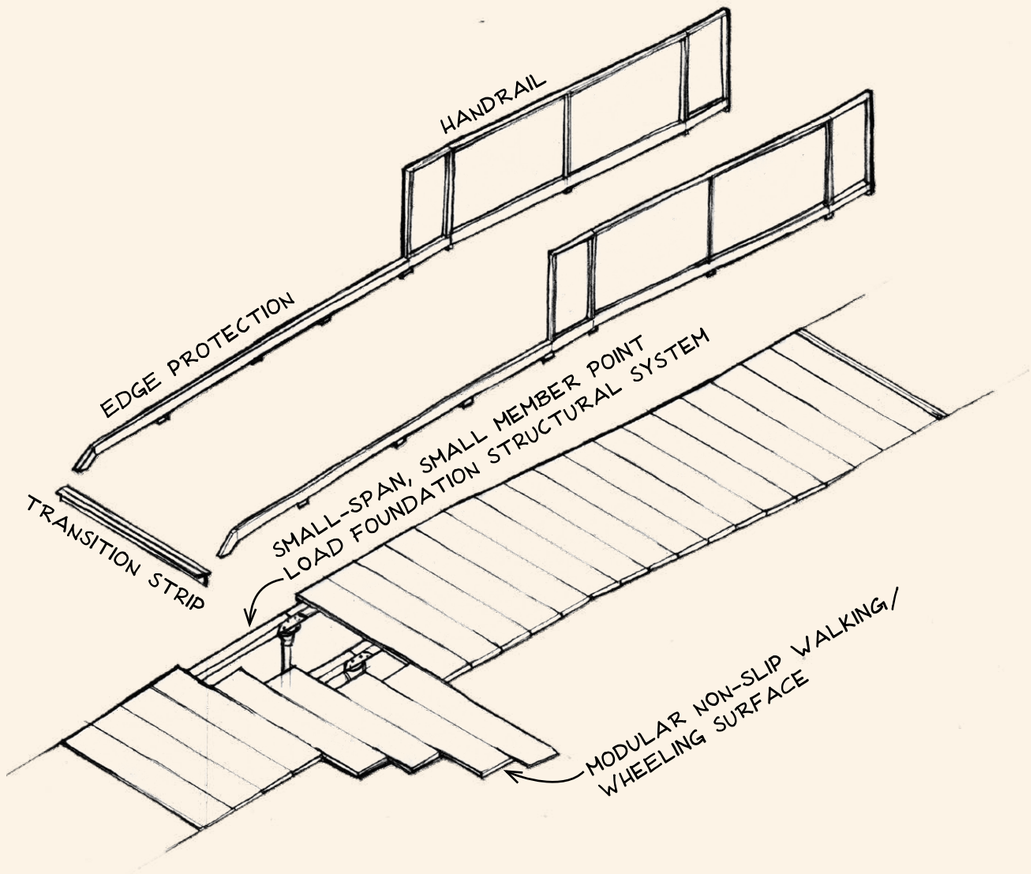


Figure 3.5.1
Design Coordination
Illustration of the people whose input is necessary to develop the proposed sidewalk system.



PROTOTYPING

To physically investigate stakeholder concerns, it's necessary to prototype this system prior to field installation. That is to protect the public's health, safety, and welfare from unforeseen problems. Even after the system has been successfully prototyped it must be implemented gradually, starting with a small number of test sites.

The prototyping process begins with identifying applicable materials (i.e. FRP, post-consumer waste plastic lumber, fiberglass, aluminum, and possibly wood with careful application to avoid slippery surfaces). The selected materials must then be translated into suitable member sizes for system components (see figure 3.5.2).

Figure 3.5.2
Assembly Determination
Isometric illustration of railings, edge protection, and a transition strip separated from the boardwalk surface.

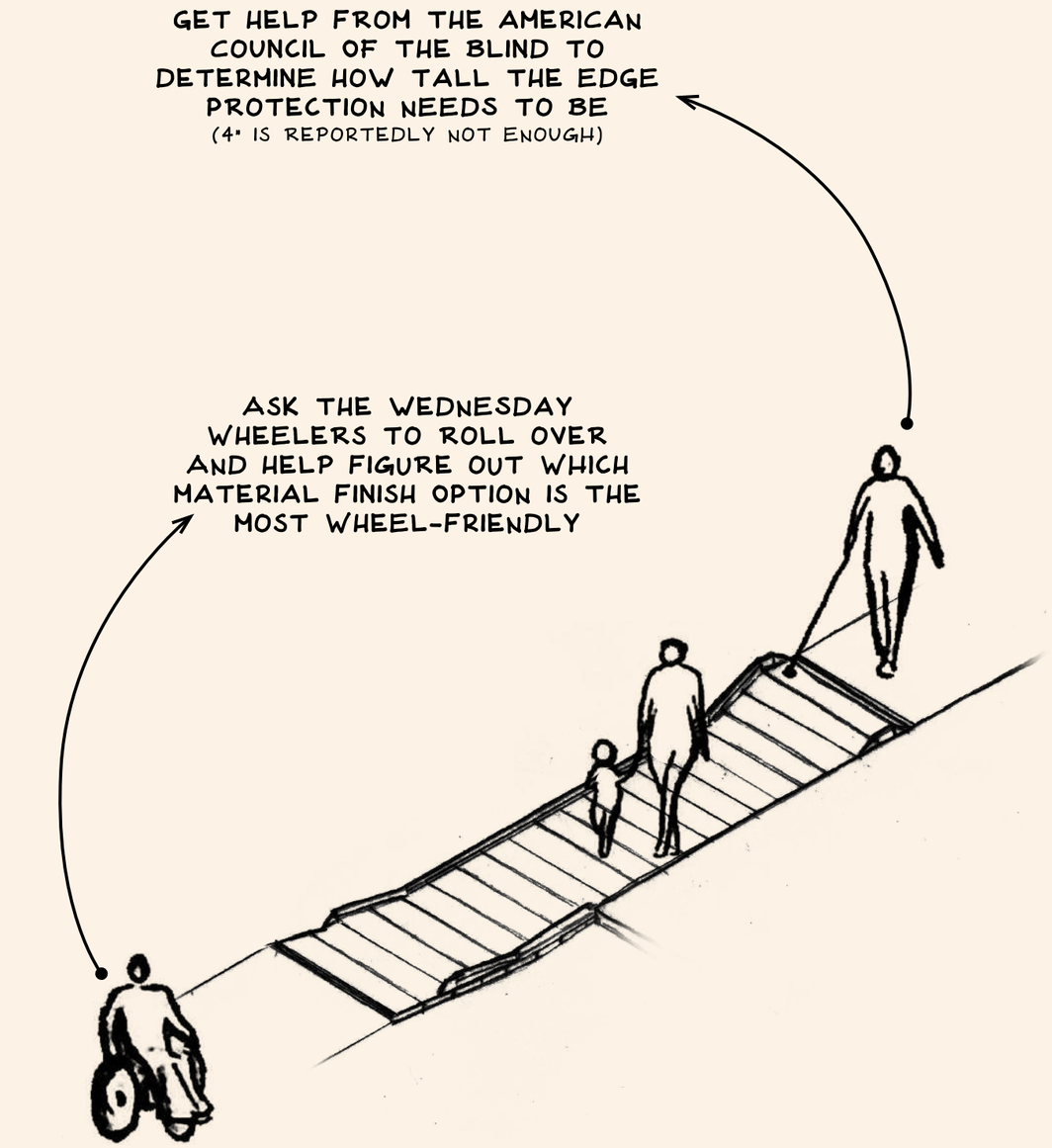


Figure 3.5.3
Testing
Isometric illustration of the user input that will be sought while prototyping the proposed system.

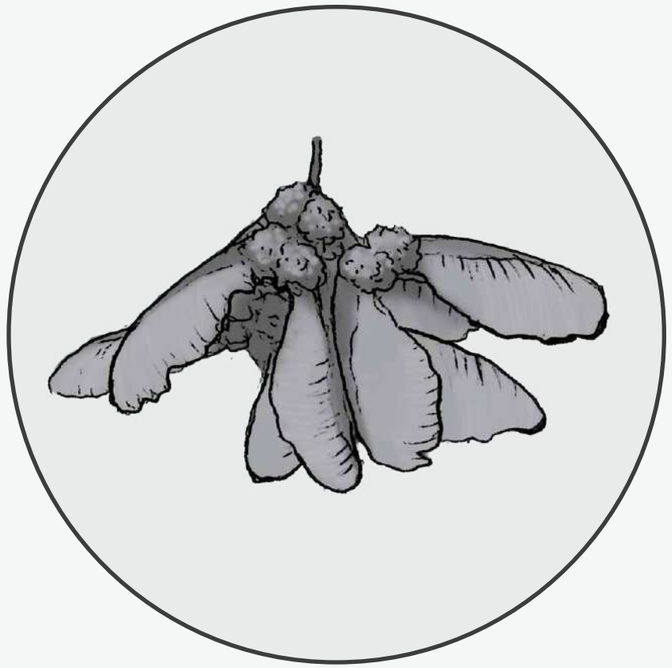
After determining the most viable assembly, a representative portion of this proposed system must be **constructed and rigorously tested for safety, accessibility, and durability**. This includes structural stress tests, sight-cane tests, and wheeling tests (see figure 3.5.3).

The main accessibility challenges with this construction are:

- Staying below maximum slopes while elevating the path.
- Using required edge protection that is the right height to be realistically detectable with a sight cane.
- Protect against slipperiness.

Overcoming these challenges will require trial and error, but I recommend that designers follow suit and work toward a solution through a system of design experimentation. After studying this issue in detail, I believe **we must find a way to separate walking surface accessibility from root growth around mature trees** and we must experiment to do so.





CONCLUSION

This project combined several layers of research, data collection, and design iteration into one broad exploration of the future of urban streetscapes, centered on **treating trees as sidewalk design clients** out of respect for the benefits they provide, their social significance, and the ways they support our cities' futures in the face of climate change.

PROJECT SUMMARY

Tree-sidewalk conflicts are so prevalent and sidewalk repairs are so urgent that this problem must be treated as an **emergency**. On the timescale of tree growth, we are out of time to understand the 'root' of root heave, particularly in the face of climate change. We must repair sidewalks to support human civil rights under the ADA along with the health, safety, and welfare of the public. However, sidewalk repairs typically require root pruning and often risk trees' lives, and sidewalk infills are dramatically riskier, often requiring extensive tree removal because vital roots naturally grow where sidewalks are normally located. Current means of resolving and preventing root heave also appear to be **ineffective**, at least for existing mature trees.

The risk of mass mature tree removal cannot be ignored or minimized; it is difficult to overstate the gravity of urban deforestation as a broad-reaching issue. Realistically, every removal harms a community's microclimate, place attachment, and climate resilience, and no amount of new saplings can truly replace a mature tree.

We don't know where we will be decades from now or if trees planted today can or will ever reach the size of our current mature trees. While public policy privileges sidewalks over trees by necessity and root heave must be immediately resolved, we can't risk deforesting our streets in the process. If we are too heavy-handed with tree removal we may reach a disastrous tipping point in our cities leading to **microclimate collapse we may never recover from**.

This project took a thorough approach to assess and treat root-heave with the complexity, urgency, and care this problem warrants, while also engaging members of the Whiteaker community on the subject through conversations and advocacy for two Bigleaf Maples at risk of removal. Losing these trees would have devastated the involved members of the community, and efforts to advocate for these trees, particularly the older of the two Bigleaf Maples,

became intertwined with this project and informed the design direction and ultimate conclusion.

This tree and community's story mirrors those of millions of other beloved trees across the country and around the world, down to the fact that it's only still standing today because **it was lucky**. That Majestic Maple is already near the end of its life, in part because of damage it's sustained over the years, but its days would have ended abruptly if its roots were growing even slightly closer to the surface.

PURPOSE OF THIS WORK

This project follows the lateral rooting pattern of the Bigleaf Maple. By spreading out in a wide, shallow network this research was able to reach a broad range of organizations, resources, and connections. While it would have been possible to pursue one of the many questions that surfaced in greater detail, rapidly investigating a wide range of issues in tandem provided faster, workable results, which is necessary to support real change in a short time frame.

By interfacing with every factor relevant to the conflict between tree roots and pedestrian routes, this work intentionally provides more questions than answers. A key aim of this project is to support future research by synthesizing these subjects and observations, specifically for the benefit of future Masters of Landscape Architecture projects as well as giving **designers, arborists, and the public** leads they can use to advocate for preserving and improving urban forests and pedestrian networks alongside each other.

Landscape architects and environmental designers are uniquely positioned to connect across disciplines, which is critical for finding workable solutions for sidewalk root heave. The legacy and history of streetscape design innovation within the discipline that began with Frederick Law Olmsted's pedestrian-centric, tree-lined parkways (figure C.1) is something that modern designers have the

opportunity to build upon today. Landscape designers need to connect with arborists, engineers, contractors, and users with disabilities to treat streetscape design with the care it requires.

The information collected, discovered, and analyzed in this project is meant to be applied in the field and adjusted as necessary to fit various locales. It can and should be applied by using figures in presentation graphics, pointing to research findings to justify **design decisions**, and serving as a guide to accurately represent the root systems of mature trees and their relationships with urban environments.

LEADS FOR FUTURE WORK

The primary discovery presented in this project is that there are complex, layered problems with how tree roots are interacting with adjacent sidewalks. Based on cursory observations during data collection, there are also unique relationships between urban street trees and their site-specific contexts. These findings present numerous options for future research, collaboration, and design (see figure C.2).

I feel the next step in advancing urban forestry management is **incorporating indigenous knowledge**, expanding on the tree-first approach presented in this project. The most compelling direction for this work is connecting street trees to the findings in The Mother Tree Project, which demonstrates the interconnection between trees that has long been recognized by traditional ecological knowledge (mothertreeproject.org).

What we see on the surface when we look at trees is equivalent to the fruiting body of a mycelium network. What we benefit from and need are the networks of intertwined roots communicating and exchanging resources in the soil. More investigation is warranted and required to understand the mycorrhizal networks in the urban forest, how this contributes to urban tree success rates, and ways we could improve these systems to strengthen our urban canopies.



It's also important that we show respect and consideration for the sacred nature of native trees when incorporating and applying indigenous knowledge, particularly in cities like Eugene where the oldest street trees standing today may have been transplanted from surrounding native habitat. We have a responsibility to recognize what those trees mean to the people whose land we inhabit, as well as acknowledging said trees would have lived much healthier, happier lives where they could have sprouted on the river than the homes we chose for them in the street. We may have taken and redefined these trees' entire lives, and we owe them respect, resources, and caring stewardship for their role in our urban ecosystems.

Figure C.1
Connection to the history of Landscape Architecture
Example of an Olmsted Parkway designed by Frederick Law Olmsted, a foundational historic figure in the field of landscape architecture, and architect Calvert Vaux.
(nycgovparks.org/)

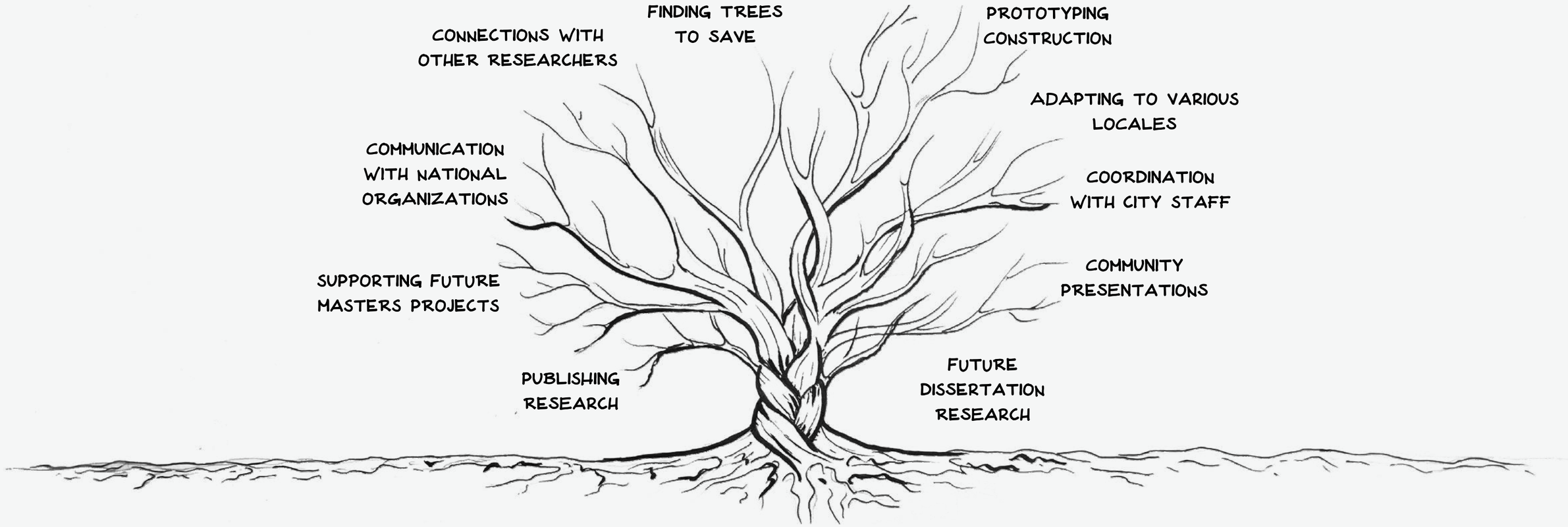


Figure C.2
Branching Off into the Future
Illustration of the future possibilities that branch off from the work presented in this document.

CONCLUDING MESSAGE TO READERS

What I learned through this project is that sidewalk root heave is complex and urban forestry management warrants more resources, staff, and consideration in streetscape maintenance. In addition to environmental concerns, sidewalk-root conflicts have a massive impact on the people around them. Broken sidewalks endanger pedestrians, but **it truly hurts communities when beloved trees are removed for sidewalk repairs**. The boundaries many people take for granted between streets and private property support all pedestrian circulation, the greenery that makes our cities livable, and important context around peoples' homes that defines residents' place attachment. There is a primal, sometimes spiritual connection between many people and their trees, which means that cutting them down feels like destroying an important part of someone's home. This was clear at West 3rd Ave and Adams St, where I met Tim and Lee, who reminded me what it is to love a tree.

While Tim interviewed me and Lee in tandem, I recall Lee turning to me to say "you and I are more than just tree-huggers" and after concluding this project I understand what he meant. Love is the spark to ignite the desire to save a forest, often one tree at a time, but it is far from the only reason. We are all more than just tree-huggers, especially those who have taken the time to read this entire document. We recognize how much we need trees, the fact that sidewalk design is the problem underlying root heave, and why we have to listen to what trees have to say. While there is a long road ahead, **we all play a role in determining the direction we go.** I hope that people from all walks of life will use this work to honor the trees they love and help others in their community work together to improve accessibility while helping urban forests thrive.



REFERENCES

The references cited in this project are organized in this section to provide a glossary of resources for future researchers and interested readers. The **sources within each section are organized in alphabetical order**. Many sources are cited in multiple sections/subsections and to avoid repeating references in this list they are **included only in the section where they were first cited**. This means later sections include more sources in the in-text citations than the reference list shown here, so those seeking a specific source should check earlier sections.

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CONCLUSION

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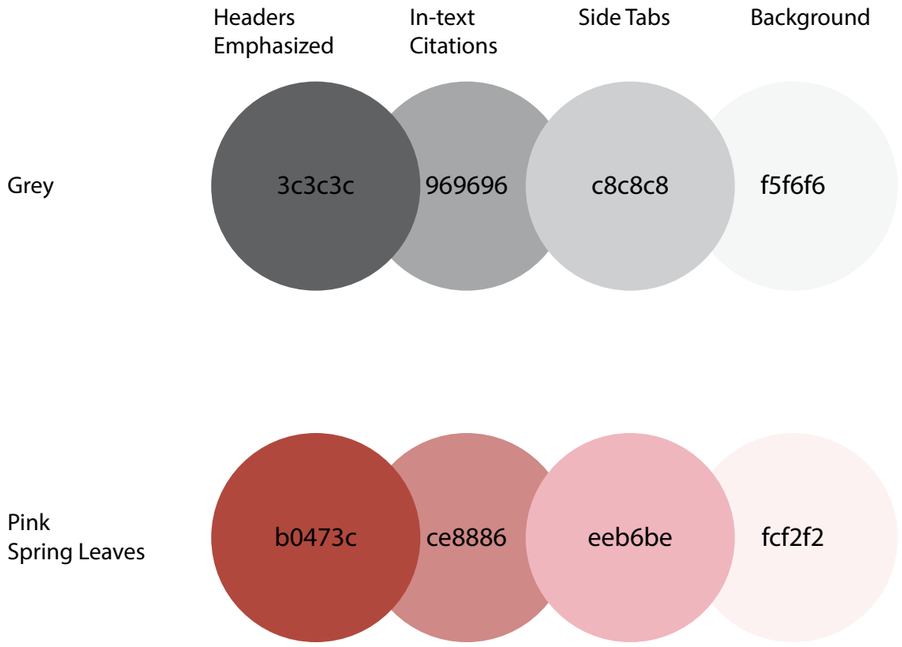
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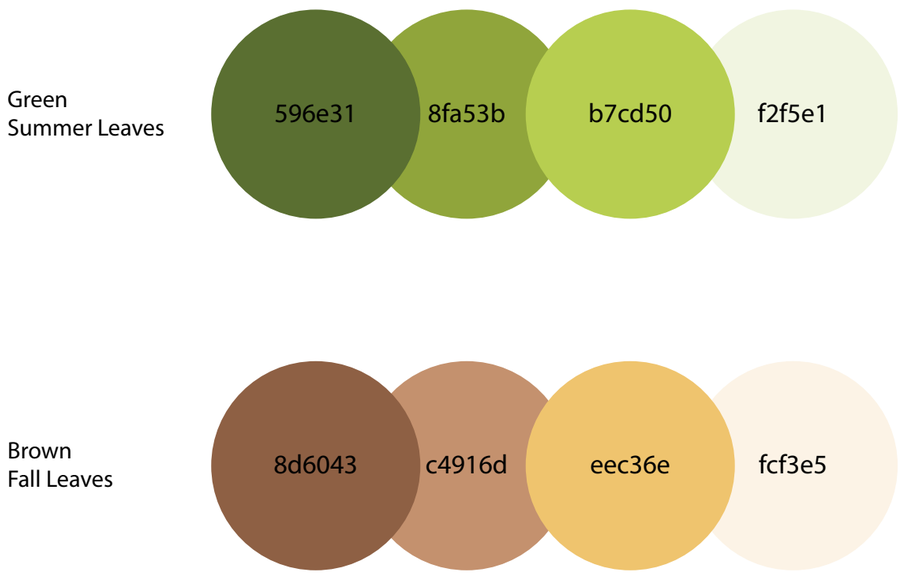
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APPENDIX





Font name: Atkinson Hyperlegible
Version: Version 1.006; ttfautohint (v1.8.3)
OpenType Layout, TrueType Outlines

abcdefghijklmnopqrstuvwxyz ABCDEFGHIJKLMNOPQRSTUVWXYZ
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12 **The quick brown fox jumps over the lazy dog. 1234567890**
18 **The quick brown fox jumps over the lazy dog. 1234567890**
24 **The quick brown fox jumps over the lazy dog. 1234567890**

Font name: Hyperreadable
Version: Version 1.006
OpenType Layout, TrueType Outlines

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24 **The quick brown fox jumps over the lazy dog. 1234567890**

THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG. 1234567890
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DOCUMENT FORMATTING

This document was formatted using Hyperreadable and Atkinson Hyperlegible, fonts designed to be dyslexia-friendly, and a font created with my own hand lettering. The graphic aesthetic is multi-media; much of the presented illustrations were hand-drawn with pencil on vellum then modified in Photoshop, the goal was to have a neo-historical appearance.

The colors were derived from the Bigleaf Maple in different seasons, symbolically connecting with the different sections, thus stages, of this project.

The color ranges were adjusted to have the same values across four color schemes, the background was made off-white for ease and comfort reading on a digital screen, and the dark-colored header and emphasized text was verified to have at least 70% contrast with the background for accessibility.

Tree Measurements and Assessment of Sidewalk Accessibility within Canopy Dripline | **Data Collection Form**

Site ID _____ Species ◯ As Expected ◯

Date _____ Tree health concerns? ◯ No ◯

Canopy Spans Entire Sidewalk?
◯ Yes ◯ No, covers _____

Another Tree w/in Canopy?
◯ Yes ◯ No
◯ Mature Tree(s)
◯ Young Tree(s)

Adjacent Property Type
◯ Residence ◯ Business ◯ Civic ◯

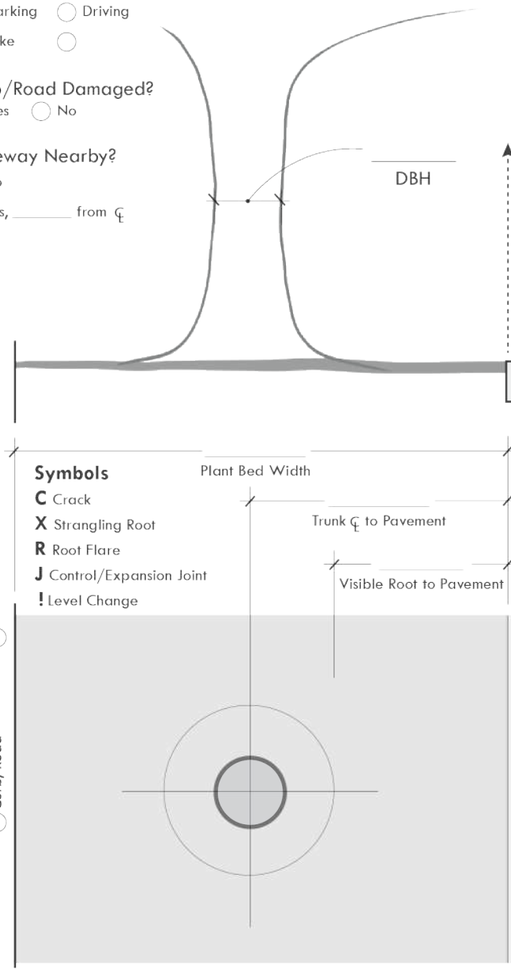
Type of Adjacent Lane
◯ Parking ◯ Driving
◯ Bike ◯

Level Change over 1/4"
_____ Max Level Change
_____ Level Change Extent

Curb/Road Damaged?
◯ Yes ◯ No

Evidence of Concrete Grinding?
◯ Yes ◯ No

Driveway Nearby?
◯ No
◯ Yes, _____ from ℄



80" Vertical Clearance?
◯ Yes ◯ No

Curb Ramp Nearby?
◯ No
◯ Yes, _____ from ℄

_____% Max Cross Slope

_____% Cross Slope Outside Dripline

_____% Max Slope

_____% Slope Outside Dripline

Plant Bed Surface
◯ Bark Mulch
◯ Bare Earth
◯ Gravel
◯ Turf
◯

Plant Bed Length
_____ Long _____ Arc
Reduced Adjacent Width?
◯ No
◯ Yes
Adjacent Width _____

Sidewalk Material
◯ Concrete
◯ Brick
◯ Asphalt
◯

Condition
◯ Even surface
◯ Pitted/spalled
◯ Cracking
◯ Crumbling
◯

Newer than Adjacent?
◯ Yes
◯ No

North

CURRICULUM VITAE

NAME OF AUTHOR

Alejandro Bechtle-Hanson

UNIVERSITIES ATTENDED

University of Oregon, Eugene

DEGREES AWARDED

Master of Landscape Architecture, 2026
University of Oregon

Bachelor of Architecture, 2021, University of Oregon
Summa Cum Laude

AREAS OF SPECIAL INTEREST

Disability Inclusive Design
Ecologically Sensitive Design
Climate Resilient Community Development

PROFESSIONAL EXPERIENCE

Landscape Architecture Intern, City of Eugene
Summer 2025
Accessibility assessments, drafting, disability-inclusive playground design

Designer, PIVOT Architecture
June 2021 – May 2024
Project development from programming through construction, focus on disability-inclusive and trauma-informed design

PROFESSIONAL LICENSES AND CERTIFICATIONS

License to Practice Architecture, Oregon, earned 2024
Passive House Consultant Certification, earned 2021

GRANTS, AWARDS, AND HONORS

Landscape Architecture Foundation Olmsted Scholar
2026 *LAF National Olmsted Scholar Finalist*
Nominated by the University of Oregon

Applied Research Award for Undergraduate Thesis
University of Oregon Clark Honors College, 2021

Native American and Indigenous Studies Award
University of Oregon
Undergraduate Research Symposium, 2021

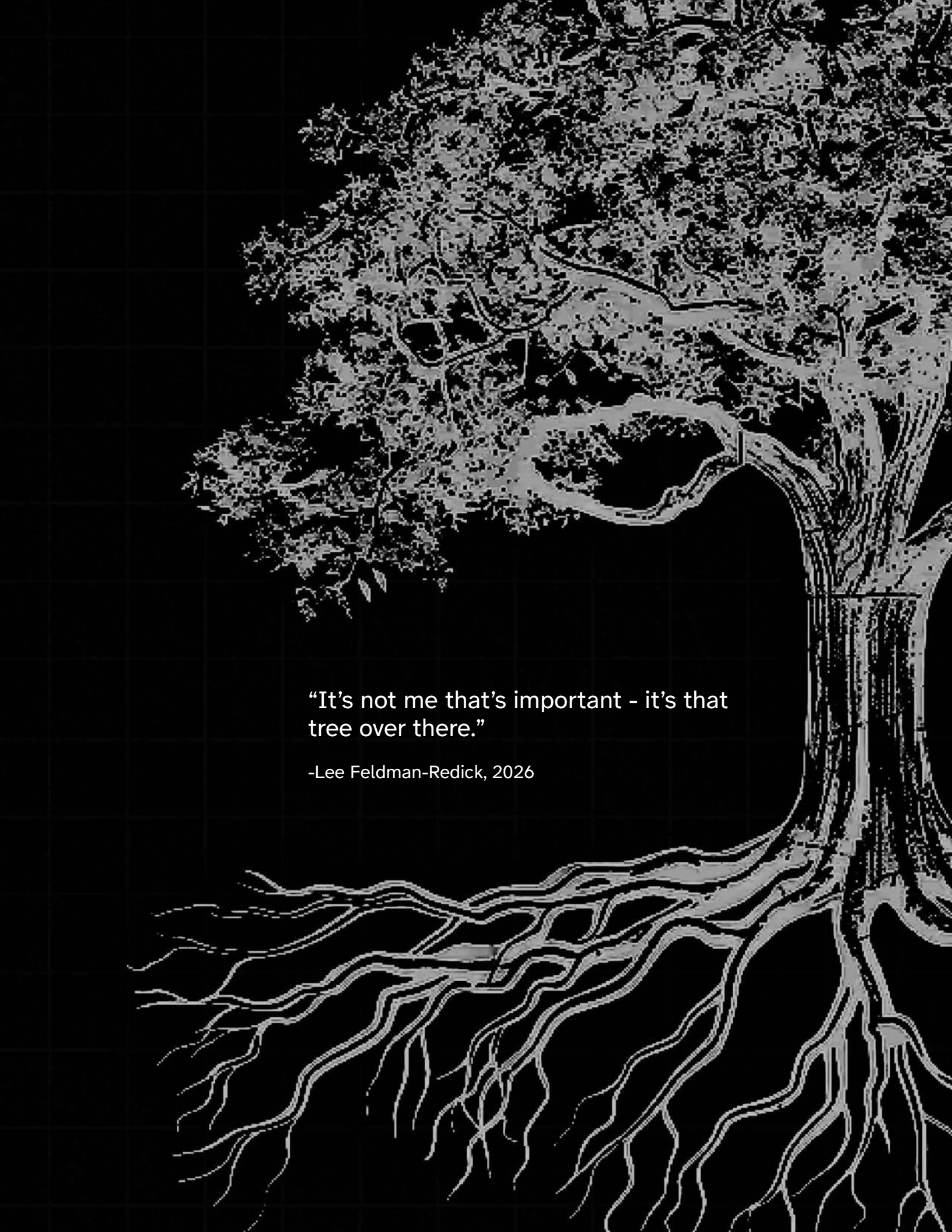
School of Architecture and Environment Award
University of Oregon
Undergraduate Research Symposium, 2021

PUBLICATIONS

Bechtle, Alejandro. “Accessible Lighting in the Workplace: Reducing the Negative Impact of Photosensitivity and Migraines.”
University of Oregon, 2021.

LECTURES

Accessible Path Design, 2026



“It’s not me that’s important - it’s that tree over there.”

-Lee Feldman-Redick, 2026