# THE URBAN TREE CANOPY'S UNDERSTORY:

# AN ANALYSIS OF THE GREEN VIEW INDEX IN WILMINGTON, DELAWARE

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the Master of Arts in Urban Affairs and Public Policy

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The Stubborn Cypress by Art Young, 1927, Public Domain

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**TABLE OF CONTENTS**

## LIST OF FIGURES

# ABSTRACT

Cities in the U.S. are growing and continue to lose tree canopy every year. City managers, already struggling to keep up with deferred infrastructure maintenance costs, must justify tree conservation and planting initiatives to a diverse range of stakeholders. Public-private partnerships provide the means to plan and fund projects collectively, but challenge traditional modes of understanding the benefits of trees. In this context, while tree inventories and structural measurement methods facilitate basic maintenance of the urban forest, a street view imagery-based analysis known as the Green View Index(GVI) can serve as a measure of the interactions that take place below the urban canopy. And by leveraging the use of machine learning to efficiently assess trees over wide geographic extents, municipalities can develop novel approaches to monitoring and maintaining their trees. This analysis demonstrates how GVI differs from inventory and remote sensing data and suggests its utility in formulating alternative urban forest policy.

## Chapter 1

## INTRODUCTION

Across cities in the United States an estimated 5.5 billion trees are growing.[1] These cities are home to over 80% of the total U.S. population and as they continue to grow, the spaces that urban trees and people cohabitate are increasingly valuable and contested. [2] While the environmental and public health benefits of trees are well documented, tree canopy cover loss is nearly ubiquitous across urban areas in the U.S.[3] New and infill development, lack of enforceable measures to protect and maintain existing trees, and tree death due to anthropogenic and natural causes are all cited as drivers of this trend.[4] Understanding the value of urban forests and the costs of these losses are often

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[1] Nowak, David J, and Eric J Greenfield. "US Urban Forest Statistics, Values, and Projections" 116, no. March (2018): 164–77. https://doi.org/10.1093/jofore/fvx004.

[2] United States Census Bureau, "Urban Areas Facts", Oct 8, 2021, https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/ua-facts.html

[3] Wolf, Kathleen L, and Alicia S T Robbins. "Metro Nature, Environmental Health, and Economic Value." Environmental Health Perspectives 123, no. 5 (2015): 390–98; Nowak, David J., and Eric J. Greenfield. "Declining Urban and Community Tree Cover in the United States." Urban Forestry and Urban Greening 32, no. November 2017 (2018): 32–55. https://doi.org/10.1016/j.ufug.2018.03.006.

[4] Kaspar, J. & Kendal, Dave & Sore, R. & Livesley, S.J.. (2017). Random point sampling to detect gains and loss in urban tree canopy in response to urban densification. Urban Forestry & Urban Greening. 24. 10.1016/j.ufug.2017.03.013.

two very different questions, and this dichotomy is rooted in the way we narrate and measure trees.

The value of trees can be defined as simply as the cost of replacement, but their ability to provide an array of benefits changes that equation. Ecosystem benefits, defined as “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life,” highlight both utilitarian and nonutilitarian concepts of value.[5] Even so, ecosystem services are typically construed as those processes “related to identifiable and measurable benefits.”[6] Specifically, the measurable, economic benefits of urban trees lend themselves to cost-benefit analyses as a way to quantify ecosystem benefits. This includes the valuation of urban trees as they relate to biodiversity and resilience as a means of mitigating the effects of climate change. This is in stark contrast to the ecological status of trees just a few decades ago; primarily valued and protected for their aesthetic and amenity value.[7] The research aimed at expanding these measurable categories of urban trees is a relatively new field, and it informs a growing profession of urban foresters.

One of my past supervisors, who oversaw forestry operations for a New York City borough, once told me that urban forestry was just one big experiment.

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[5] Alcamo, Joseph et al, “Ecosystems and Human Well-Being,” Millennium Ecosystem Assessment, 2003.

[6] Roy, Sudipto, Jason Byrne, and Catherine Pickering. “A Systematic Quantitative Review of Urban Tree Benefits, Costs, and Assessment Methods across Cities in Different Climatic Zones,” Urban Forestry & Urban Greening 11, no. 4 (2012): 351–63. https://doi.org/https://doi.org/10.1016/j.ufug.2012.06.006.

[7] Wolf, Kathleen L. “Trees, Parking and Green Law: Strategies for Sustainability,” 2004. https://www.naturewithin.info/Roadside/Trees_Parking_Green Law.pdf.

He described how unnatural it was for trees to be planted in sidewalk pits, for them to be subjected to abuses by pedestrians, motorists, developers, power companies, homeowners, and the dogs they walked on a daily basis. It was a surprising omission at the time, but I soon learned that managing trees in the city was indeed all about disturbance. While trees in their natural habitat experience competition, browsing, pests and diseases, the urban environment provides similar pressures to the extreme. Through local ordinances that penalized tree damage and removal, enforced a plan review process for new development affecting trees, and required permitting for any potential disturbance to street trees, New York City invested in the staff and infrastructure needed to protect their urban forest. I recall at the time, being in awe of the scale of these efforts.

I had been hired into that office during Mayor Bloomberg's Million Trees campaign, a large-scale campaign to plant one million trees across all five boroughs by 2017 and one of the primary goals that undergirded this initiative was reaching 30% Urban Tree Canopy(UTC) by 2030.[8] UTC is defined as "the leafy, green, overhead cover from trees" as well as a means to assess and plan "strategic, focused planting that aligns with other critical social, environmental, and economic goals."[9] UTC assessment also identifies three dimensions of UTC in terms of possible, potential, and preferable canopy. Respectively, these refer to

[8] Jarlath, J Morgan Grove, Keith Pelletier, David Nowak, and Jeff Walton. "A Report on New York City's Present and Possible Urban Tree Canopy." New York City, 2006.
[9] U.S. Forest Service. "Urban Tree Canopy Assessment: A Community's Path to Understanding and Managing the Urban Forest," 2019.

planting site criteria in terms of biophysical, economic, and social suitability.[10] Through the use of satellite imagery, LiDAR, and GIS, spatially accurate geolocation and quantification of tree canopy assist communities in understanding the current status and future potential of their urban forests. These UTC data are then typically integrated with a range of other datasets including topographic data, heat island maps, population density, socioeconomic data, property values, watershed information, transportation routes, soils, and air quality.[11] This accrual of measurements, conditions, and problems then sets the stage for the prioritization process.

By "matching known benefits of trees, to places lacking those benefits" and coordinating with "organizations positioned to manage those issues that trees help ameliorate" this alignment process connects UTC goals with those of other policy actors. [12] Identifying shared "canopy priorities" mitigates the lack of coordination that is common to resource management efforts.[13] The UTC prioritization framework is a means of understanding stakeholder values as they relate to tree canopy conditions and I highlight this process as an example of the ongoing research and implementation methods that inform urban forest policy in major cities across the U.S. This framework also serves to identify additional

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[10] U.S. Forest Service. "Urban Tree Canopy Goal Setting: A Guide for Chesapeake Bay Communities," 2006.
[11] U.S. Forest Service. "Urban Tree Canopy Assessment: A Community's Path to Understanding and Managing the Urban Forest," 10.
[12] Locke, Dexter H, J Morgan Grove, Michael Galvin, Jarlath O'Neil-Dunne, and Charles Murphy. "Applications of Urban Tree Canopy Assessment and Prioritization Tools: Supporting Collaborative Decision Making to Achieve Urban Sustainability Goals." Cities and the Environment 6, no. 1 (2013).
[13] Locke et al, "Applications", 3.

research needs, namely, the question of social-ecological factors that affect household motivations, preferences, and capacities to plant trees.[14]

My past interactions with individuals and groups validate this urgency. The diversity of stakeholders prompts many different reactions to the idea of receiving a tree adjacent to their property, to say little of their willingness to care for it. This fragmentation of interests can be defined as "the dynamic interactions between the urban forest and its stewards" and "an exchange of ecosystem services and stewardship efforts."[15] These exchanges, whether they occur at the individual or community level, are informative and efficacious, yet are vastly underrepresented in the data collected about urban trees.

Given the varied demands on tree distribution and longevity, collecting accurate information about the condition of trees is also a critical part of maintaining the UTC. This data is typically accrued in the form of a tree inventory, the general term for a data collection method and data source that includes information on trees. One prevailing question in the field of urban forestry is the utility of tree inventory data in determining policies that affect trees in cities. Traditional, forestry-based methods of collecting resource data such as species and size have given way to a sharp increase in the methods and parameters used to understand the urban canopy and make decisions regarding

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[14] Locke et al, "Applications", 18.
[15] Locke, Dexter H, Kristen L King, Erika S Svendsen, Lindsay K Campbell, Christopher Small, Nancy F Sonti, Dana R Fisher, and Jacqueline W T Lu. "Urban Environmental Stewardship and Changes in Vegetative Cover and Building Footprint in New York City Neighborhoods ( 2000 – 2010 )," 2014, 250–62. https://doi.org/10.1007/s13412-014-0176-x.

UTC.[16] This divergence of focal points has illuminated not only the economic, social, biodiversity and climate-related aspects of trees, but also the gaps that exist between canopy goals and outcomes.

Cities are growing, and the associated density increases the stakes when it comes to policies that affect the health and well-being of its residents. This tension between development and sustainability is one way of framing interactions between trees and city dwellers. Key reforms in sanitation, water, and housing have elevated the living conditions of millions of people over the past century. But as urban landscapes are redeveloped and expanded, the associated land-use changes can degrade the environment, affect consumption patterns and their resultant contributions to greenhouse gases, and increase health risks.[17] As the resolution at which information is captured about the built environment increases, planners and policy makers may be better equipped to weigh net economic and social benefits against environmental thresholds and socio-economic inequity.[18] However, even as cities commit to planting and preservation measures, the connection between municipal policies and UTC

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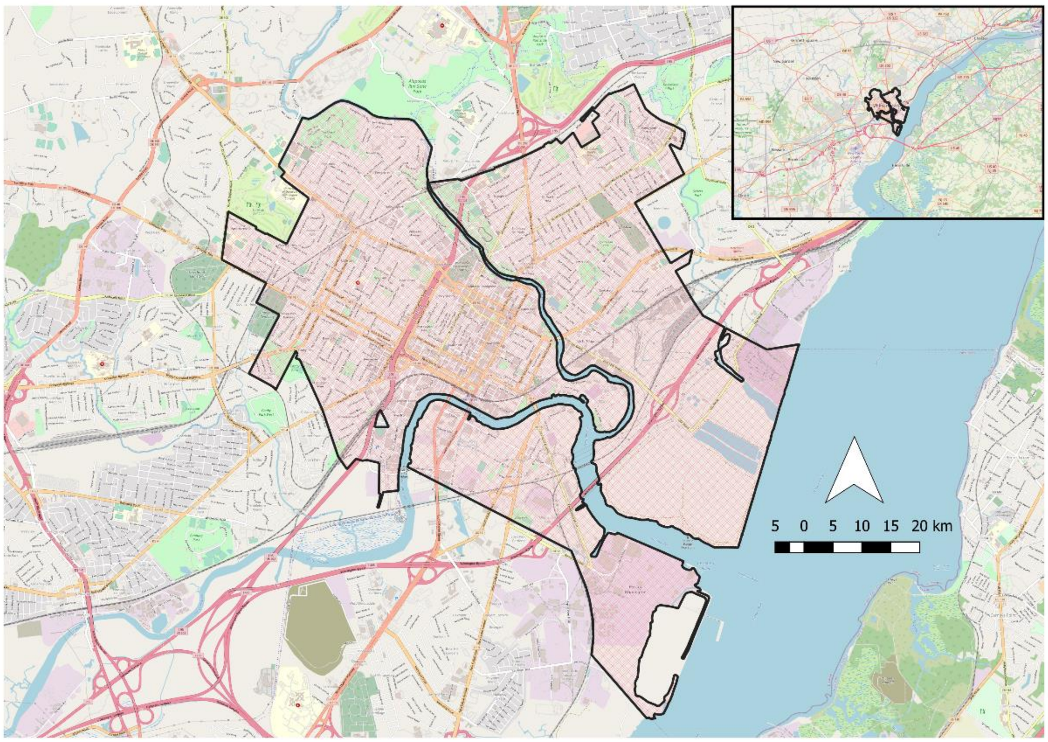
[16] Östberg, Johan. "Tree Inventories in the Urban Environment: Methodological Development and New Applications." Swedish University of Agricultural Sciences, 2013.
[17] Satterthwaite, David. "How Urban Societies Can Adapt to Resource Shortage and Climate Change." Philosophical Transactions of the Royal Society 369 (2011): 1762–83. https://doi.org/10.1098/rsta.2010.0350.
[18] Mori, Koichiro, Toyonobu Fujii, Tsuguta Yamashita, Yutaka Mimura, Yuta Uchiyama, and Kengo Hayashi. "Visualization of a City Sustainability Index (CSI): Towards Transdisciplinary Approaches Involving Multiple Stakeholders." Sustainability (Switzerland) 7 (2015): 12402–24. https://doi.org/10.3390/su70912402.

outcomes are not well understood.[19] Comparisons between cities can be problematic, and the interactions among the diversity of species within biomes and people within city blocks are a challenge for social and environmental researchers alike.

Figure 1: Wilmington Context Maps




*Source: Created by Author using QGIS*

Wilmington is Delaware's most populous city, with just over 70,000 residents as of 2020.[20] This accounts for approximately 12% of New Castle County total population, the most populous of Delaware's three counties. The city

[19] Romero, Francine S. "Logic and Effectiveness of Urban Tree Preservation: A Comparative Case Study of Charlotte and San Antonio" 53, no. 2 (2021): 142–58. https://doi.org/10.1177/0160323X211038211.

[20] United States Census Bureau, QuickFacts, April 1, 2020, https://www.census.gov/quickfacts/fact/table/wilmingtoncitydelaware,DE/POP010220

occupies 10.89 square miles of land, 46% of which is covered by buildings and paved surfaces. Over 50% of households occupy one family row houses, and 17% living in semi or detached single family homes.[21] Despite its size, Wilmington has a wide variety of urban and suburban typologies. Traditional urban development patterns include the Downtown Market Street corridor and an aging urban core still recovering from population decline experienced in the 50s and 60s. More suburban style developments characterize neighborhoods in the north and northwest. The confluence of the Brandywine and the Christina River divide the city into three portions, traversed by bridges in each quadrant. South Wilmington, with a history of heavy industry, edges into the low-lying floodplain, while the northeast includes busy North Market Street and multiple routes directly into the downtown. The West Side stretches from the I-95 corridor and encompasses many transportation corridors and dense residential development. These geographic regions are also socially descriptive regions. And while the environmental characteristics of the Delaware region have little resemblance to the average city block, ecological processes still shape the confluences of soil, water, and the movement of non-human organisms across the landscape. The largest of these are trees.

Wilmington lays on the Atlantic Seaboard Fall line, where the Piedmont and Atlantic coastal plain meet. It explains the difference in elevation between the Hilltop neighborhood and Southbridge. Native plant communities include dry

[21] United States Census, "American Community Survey 2018", Census Data API

upland oaks as well as shrubby floodplain species.[22] Delaware's climate is humid and temperate, with most trees in leaf from April to November. Wilmington's tree inventory includes over 15,500 records over 197 tree species and cultivars, not including those found in parks.

In 2007, the Delaware Center for Horticulture(DCH), in collaboration with the U.S. Forest Service convened the Trees for Wilmington coalition in order to promote the sustainable management of the city's urban forest.[23] One outcome was a comprehensive planning document outlining the risks, benefits, and recommendations for revitalized efforts in cultivating UTC. These included revising the tree ordinance, increasing per capita investment, expanding employee expertise, and tracking progress.[24] The DCH also conducted an urban forest assessment in northern Delaware, sampling trees across the region to ascertain tree cover, species composition, sewershed function, and to estimate ecosystem benefits. The study revealed that the estimated 136,000 trees in Wilmington provided an estimated $166M in ecosystem benefits through the storage of carbon, removal of pollution, savings in energy costs, and avoided carbon emissions.[25] In 2011, the tree ordinances were revised to include additional tree

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[22] Coxe, Robert. "Winter 2013 Guide to Delaware Vegetation Communities," 2013. https://www.wrc.udel.edu/wp-content/heritage/NVCS/Guide-to-Delaware-Vegetation-Communities-Winter-2013.3.pdf.

[23] Delaware Center for Horticulture, "Our Urban Forest: A Report on Trees & Community Collaboration in Northern New Castle County and Wilmington, Delaware," 2009.

[24] Ibid, *19*.

[25] Nowak, David J, Robert E Hoehn, and Gary Schwetz. "Urban Forest Assessment in Northern Delaware," 2009. https://www.nrs.fs.fed.us/pubs/rb/rb_nrs33.pdf.

protection measures and tree assistance opportunities.[26] In addition, the city hired an Urban Forestry Administrator to oversee the management of street trees. One of their primary responsibilities is to maintain the tree inventory, a geodatabase including records of street and park trees within the city limits. For cities of all sizes, the resources devoted to urban forestry activities must be a balance of planting, maintenance, and enforcement. As a public official, the UFA is also accountable for prioritizing tasks that often involve the mitigation of hazardous tree conditions, the siting and planning of planting projects, and interactions with the public and other government agencies.

As an urban forester I've had many conversations with people from all walks of life, about trees. Early on, I felt I benefited from the seemingly apolitical nature of trees. Everybody wanted to be a part of planting projects and it was hardly worth talking about the downsides of trees. But over time I began to understand that there is always some narrative at work, obscuring itself, if need be. Trees are elegantly functional and providing me with a sense of belonging. But as soon as I try and toe them into city streets, there is more to consider. As trees are increasingly recognized for their contribution to mitigating local air pollution and temperature extremes, increasing perviousness and stabilizing waterways, encouraging mental health and well-being, urban foresters, decision makers, and other stakeholders are challenged to recognize the costs of removing

[26] Wilmington, DE, "Chapter 46 Article II Secs. 46-1 to 46-25" January 6 2011.

trees and distribute these resources in an equitable manner.[27] But the costs of distribution can include disservices such as reduced solar access, carbon inputs of landscape maintenance, sidewalk damage, organic debris, and other infrastructure damage from branches and roots and tree failure.[28]

These concerns are very real and have as much to do with the nature of trees as with the quality of stewardship the tree receives. Unfortunately, tree managers and their partners are often under-resourced when it comes cataloguing these risks and funding the proactive tree care that would mitigate them. This research aims to contribute a contextual layer that might fill some of these knowledge gaps and help communities cultivate healthier and more beneficial tree canopies. The experience of advocating for trees and the people who care for them continues to motivate me. I hope to contribute a unique analysis of urban vegetation in Wilmington, DE, and in doing so provide greater understanding of the ways in which city residents experience trees.

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[27] Skoff, Jessica B Turner, Jessica B Turner Skoff, The Morton, and Nicole Cavender. "The Benefits of Trees for Livable and Sustainable Communities." Plants, People, Planet 1 (2019): 323–35. https://doi.org/10.1002/ppp3.39.
[28] Roy, Sudipto, Jason Byrne, and Catherine Pickering. "A Systematic Quantitative Review of Urban Tree Benefits, Costs, and Assessment Methods across Cities in Different Climatic Zones," 19.

# Chapter 2

## LITERATURE REVIEW

The field of urban forestry is relatively new and has its roots in traditional forestry. The somewhat contradictory term was coined in 1962 during a professor's discussion with a graduate student regarding their thesis.[29] Community forests, a term often used interchangeably today, have a long history in many countries where they served as a source for timber and local economic stability and a place for recreation. Planting trees at the southwest corner of a home has long been considered beneficial to heating and cooling functions, and this has been borne out in the research.[30] Trees were also recognized early on for their benefits for public spaces, with major U.S. cities in the 18th century touting their contribution to "increased salubrity" and mitigating the heat of summer.[31] Main streets across the U.S. were planted with the beloved elm tree, drawing a dappled shade across countless neighborhoods prior to the 1930s. And so into this appreciated, but relatively unexamined landscape, entered the humble elm Bark-beetle.

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[29] Kuser, John E, ed. Urban and Community Forestry in the Northeast, 2007.
[30] Simpson, James R, and E Gregory Mcpherson. "Potential of Tree Shade for Reducing Residential Energy Use in California." *Journal of Arboriculture.* 22, no. 1 (1994): 10–18.
[31] Kuser, Urban and Community Forestry in the Northeast, 3.

<u>Origins of Urban Forestry</u>

First reported in 1930 in Ohio, it was notable for having carried a uniquely pathogenic fungus called *Ceratocystis ulmi,* also known as Dutch Elm Disease(DED). Having already wreaked havoc in Europe's elm populations, it proceeded to kill an estimated 50 million elms across the U.S. in the span of 50 years.[32] The federal government spent millions of dollars on a variety of efforts to stop, treat, and eradicate DED. Today, the American Elm survives through the identification and breeding of DED-resistant varieties as eradication has become a lost cause. Notably, diseased elms die back, but continue to resprout and exist as understory shrubs in forest stands.[33] Similarly, the loss of landscapes and resources to DED enabled the scientific inquiries that set the stage for a burgeoning new field. Today, urban forest researchers and practitioners study trees and their cultural needs and impact specifically within the urban context. In addition to pests and diseases, competition for light, excessive light, heat, pollution, poor soils, soil compaction, and vandalism constitute the many stress factors that urban trees face. Despite the challenges and their effects on tree life expectancy, trees function in a way that alleviate those very conditions.[34]

Today, the many dimensions of urban forests are reflected in the proliferation of tools and applications used to quantify their value. Traditional

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[32] Hubbes, M. "The American Elm and Dutch Elm Disease." *The Forestry Chronicle* 75, no. 2 (1999).
[33] Karnosky, David F. "Dutch Elm Disease: A Review of the History, Environmental Implications, Control, and Research Needs." *Environmental Conservation* 6, no. 4 (1979): 311–22.
[34] Czaja, Monika, and Anna Kołton. "The Complex Issue of Urban Trees — Stress Factor Accumulation and Ecological Service Possibilities." *Forests* 11, no. 9 (2020): 932. https://doi.org/https://doi.org/10.3390/f11090932.

analyses of street trees use hedonic pricing, avoided costs, or replacement costs, and have been utilized in urban planning to raise awareness, for priority-setting and instrument design (e.g., stormwater credits and tree restitution).[35] In New York City, the valuation of trees needing to be replaced is determined by size, condition, species, and location, each exacting a multiplier for the assessed value.[36] The outcomes of these methods are harder to determine. Severe tree replacement penalties are often levied against unscrupulous homeowners or developers, leading to antagonistic disputes, as was the case in Staten Island when a homeowner was charged $170,000 to remove a tree prior constructing his new home.[37] As a result of political pressure from unhappy voters, a recent bill was passed, capping restitution fees for certain zoning districts in NYC. [38] While these kinds of measures may discourage tree removals and fund tree plantings, the financial sustainability of these regulations may indicate that developers are finding it cheaper to remove trees than to preserve them.[39]

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[35] Gómez-Baggethun, Erik, and David N Barton. "Classifying and Valuing Ecosystem Services for Urban Planning." Ecological Economics 86 (2013): 235–45. https://doi.org/10.1016/j.ecolecon.2012.08.019.
[36] New York City Parks Department, "Rules Governing Tree Replacement," https://www.nycgovparks.org/rules/section-5.
[37] Dalton, Kristen, "City's hefty tree removal fees could have cost this Huguenot resident $170K," February 16, 2021, https://www.silive.com/news/2021/02/citys-hefty-tree-removal-fees-could-have-cost-this-huguenot-resident-170k.html.
[38] Dalton, Kristen, "New law caps amount of money NYC can charge some homeowners for tree removal," November 10, 2021, https://www.silive.com/news/2021/11/new-law-caps-amount-of-money-nyc-can-charge-some-homeowners-for-tree-removal.html.
[39] Romero, Francine S. "Logic and Effectiveness of Urban Tree Preservation: A Comparative Case Study of Charlotte and San Antonio" 53, no. 2 (2021): 142–58. https://doi.org/10.1177/0160323X211038211.

The risks and shortcomings of quantifying urban trees have their roots in the ways they are measured. Traditional inventory methods and the resultant operationalizations vary globally, with tree species and stem diameter being the most commonly collected attributes and planning and the calculation of ecosystem services were the most common research objectives.[40] As the UTC process was described briefly above, another widely distributed inventory protocols is the Forest Inventory Analysis, a national data collection protocol that to "monitor long-term trends in the health and productivity of domestic forest ecosystems."[41] Established in 1928, the protocol's focus has evolved from timber resources to a more comprehensive assessment that includes wildlife habitat, sustainability, and urban trees.[42] Another established protocol is the i-Tree suite of tools, used to estimate and quantify the benefits of trees. Utilizing user-inputs on tree species and condition, local weather/pollution data is used to estimate ecosystem functions and the equivalent monetary value of those services over time.[43] Additionally, municipalities, regional agencies, and other organizations will utilize a wide range of database platforms in developing work orders, responding to service requests, and communicating the value of the urban forest to stakeholders. Ideally, tree inventories would take advantage of the necessary

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[40] Bingqian, Ma, Richard J. Hauer, Johan Ostberg, Andrew K. Koeser, Hongxu Wei, and Chengyang Xu. "A Global Basis of Urban Tree Inventories: What Comes First the Inventory or the Program." Urban Forestry & Urban Greening, no. 60 (2021): 0–33.

[41] Smith, Brad. "Forest Inventory and Analysis : A National Inventory and Monitoring Program." Environmental Pollution 116 (2002): 233–42.

[42] U.S. Forest Service. "FIA What Is Forest Inventory and Analysis?," 2022. https://www.fia.fs.fed.us/library/fact-sheets/overview/What_is_FIA_FS.pdf.

[43] i-Tree. "I-Tree: What Is i-Tree?," 2020. https://www.itreetools.org/documents/551/i-Tree_Tools_Summary_Jan2020.pdf.

resources and expertise to conduct tree health and risk monitoring, but this is not often the case.[44] A review of tree inventory methods observed that private trees, which often account for 50% of tree coverage, are often not included in inventories, and that policy implications of inventory data were rarely explored.[45]

On a related note, ecosystem disservices are an understudied and undermeasured aspect of urban tree canopy. Neglecting the assessment of ecosystem disservices in processes meant to bridge human welfare and ecosystem function is described in one study as a form of self-sabotage.[46] And finally, inventories implicitly struggle with measuring less tangible ecosystem benefits such as cognitive development, recreation, and aesthetic experiences. As such, two approaches have been suggested for the valuation of non-material benefits: disaggregating the beneficiaries and the scales at which the individual and community values a given service.[47] This involves the pursuit of “harmoni[zing] social and environmental datasets at relevant scales” through the “maintenance of long term observatories”, in the hopes that both social and environmental data can

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[44] Roman, Lara A, E Gregory Mcpherson, Bryant C Scharenbroch, and Julia Bartens. “Identifying Common Practices and Challenges for Local Urban Tree Monitoring Programs Across the United States.” Arboricultural Journal 39, no. 6 (2013): 292–99.

[45] Klobucar, Blaz, Johan Östberg, Märit Jansson, and Thomas Barfoed Randrup. “Long-Term Validation and Governance Role in Contemporary Urban Tree Monitoring : A Review,” 2020, 1–15.

[46] Lyytimaki, Jari, and Maija Faehnle. “Hopping on One Leg – The Challenge of Ecosystem Disservices for Urban Green Management.” Urban Forestry & Urban Greening 8, no. December (2009). https://doi.org/10.1016/j.ufug.2009.09.003.

[47] Small, N, M Munday, and I Durance. “The Challenge of Valuing Ecosystem Services That Have No Material Benefits.” *Global Environmental Change* 44 (2017): 57–67. https://doi.org/10.1016/j.gloenvcha.2017.03.005.

inform decisions regarding urban landscapes.[48] An ongoing effort called the Baltimore Neighborhood Indicators Alliance brings together 20 indicators for community statistical areas that track sustainability through sanitation, transportation, green space and water use, energy and weatherization, and community engagement.[49] In a recent study, researchers analyzed tree cover over 37 metropolitan areas through the lens of redlining maps, a vestige of discriminatory federal housing policies that graded eligibility for low interest mortgage loans in the 1930s, and found that D graded areas averaged 23% less tree canopy than A graded areas.[50] These observations are a reminder that trees do exist in a political landscape, where privilege and disenfranchisement are handed down through policy means.

## Perceptions of Trees

As a species, our interests in the natural world have always been tied to our patterns of consumption. The extraction of natural resources, especially wood, provide critical commodities across nations and cultures. And while this continues to be true, ideas like ‘biophilia’ or, the innate affinity for nature and living things,

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[48] Small et al., 65. “The Challenge of Valuing Ecosystem Services That Have No Material Benefits.”

[49] France, Jacob, Jacob France, Jacob France, Cheryl Knott, and Nancy Jones. 2017. “Measuring Progress Toward a Better Quality of Life in Every Neighborhood.” Baltimore Neighborhood Indicators Alliance Vital Sign (Spring).

[50] Locke, Dexter H, Billy Hall, J Morgan Grove, Steward T A Pickett, Christopher G Boone, Jarlath P M O Neil-dunne, Laura A Ogden, and Carissa Aoki. “Residential Housing Segregation and Urban Tree Canopy in 37 US Cities.” Npj Urban Sustainability, n.d. https://doi.org/10.1038/s42949-021-00022-0.

also drive our interactions with the natural world.[51] As a 2001 study documented, perceptions of adults surveyed in the Netherlands placed human health, its intrinsic value, and the value for future generations as the top three valued functions of nature.[52] How people perceive of, and experience trees is a growing field of study. Surveys of city residents have been conducted in multiple cities, covering topics such as perceptions of trees and roles of local government and citizens in the care of street trees.[53] Sentiments were generally positive, with one study showing that aesthetic qualities of trees rating highest among the positives and the accumulation of fallen leaves rating highest among the perceived annoyances.[54] Observations on the highly localized, regional and cultural factors that can affect these perceptions have also been studied. Differences in preferences for planting density, size and type of trees, and landscape types were observed among respondents from different ethnic backgrounds.[55] One novel application of technology to this personal connection to nature was piloted in Nova Scotia, Canada, whereby 15 selected trees assumed unique personalities as maintained by volunteers and interacted with the public through text messaging.

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[51] Wilson, Edward O., Kellert, Stephen R., The Biophilia Hypothesis, 1993.
[52] Lenders, H J R, and Wouter De Groot. "The New Biophilia : An Exploration of Visions of Nature in Western Countries." Environmental Conservation, March (2001). https://doi.org/10.1017/S0376892901000066.
[53] Moskell, Christine & Allred, Shorna, "Residents' beliefs about responsibility for the stewardship of park trees and street trees in New York City," Landscape and Urban Planning 120(2013): 85–95. 10.1016/j.landurbplan.2013.08.002.
[54] Schroeder, Herbert, John Flannigan, and Richard Coles. "Residents' Attitudes Toward Street Trees in the UK and U.S. Communities." *Arboriculture and Urban Forestry* 32, no. 5 (2006): 236–46.
[55] Fraser, Evan D G, and W Andrew Kenney. "Cultural Background and Landscape History as Factors Affecting Perceptions of the Urban Forest." *Journal of Arboriculture* 26, no. 2 (2015): 106–13. https://doi.org/10.48044/jauf.2000.013.

Participants surveyed reported a change in the ways they connected with urban trees as a result of the interactions.[56]

One way that urban residents make decisions about urban trees are through civic associations. Civic associations represent a variety of community-based organizations including neighborhood groups, community development organizations, tenants' councils, coalitions, and maintenance corporations. Connections between environmental stewardship groups and urban tree canopy are an active area of study, exploring the effect of location, organizational structure, and the networks between them on the landscape.[57] Associations of these sorts are important representatives of local values and potential stakeholders in urban forestry programs.

Land use policies are an important tool for policy makers' efforts in preserving or destroying tree canopy. In addition to tree ordinances, zoning ordinances were found to be highly effective in protecting existing forest tracts and improving urban canopy levels. These proactive measures can pay off in the long run as tree benefits accrue over time as trees mature.[58] Zoning has also been studied as a factor in tree population dynamics. While property owners plant trees

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[56] Sorensen, Julietta, Peter N Duinker, Melanie Zurba, and Michael Smit. "Urban Forestry & Urban Greening Testing a Novel Human-Nature Connection Model with Halifax's Urban Forest Using a Text-Messaging Engagement Strategy." Urban Forestry & Urban Greening 65 (2021): 127350. https://doi.org/10.1016/j.ufug.2021.127350.
[57] Fisher, Dana R, Erika S Svendsen, and Sarah C Low. "Under the Green Umbrella : A Census of Civic Environmental Stewardship Organizations in the City of Philadelphia." *Stewardship Mapping and Assessment Project*, 2015.
[58] Hill, Elizabeth, Jeffrey H Dorfman, and Elizabeth Kramer. "Evaluating the Impact of Government Land Use Policies on Tree Canopy Coverage." Land Use Policy, 2009. https://doi.org/10.1016/j.landusepol.2009.05.007.

for a variety of reasons, they also remove them for reasons such as hazard prevention and aesthetic preferences. Trees on private property are hard to regulate from a governance standpoint, and studies have shown that tree loss on residential parcels is associated with high canopy cover and age more than socio-economic characteristics.[59] These kinds of high-resolution assessments in conjunction with policy and demographic data allows greater insight into the multi-dimensional aspect of urban vegetation change.

## Trees and Computer Vision

The use of Big Data represents the evolution of data storage and processing, novel sources of data, and the challenge of managing said data. Also known as volume, velocity, variety, and veracity, these characteristics have contributed to the adoption of data-driven decision making across many sectors.[60] Specifically, the challenges of monitoring and modelling dynamic, spatio-temporal systems like natural and urban environments have led researchers to take advantage of sensors at and above the surface and their ability to transmit huge amounts of information.[61] The interpretation of this deluge of this information, specifically visual information, has given rise to advances in pattern recognition

[59] Ossola, Alessandro, and Matthew E Hopton. "Measuring Urban Tree Loss Dynamics across Residential Landscapes." Science of the Total Environment, 2018, 0–26. https://doi.org/10.1016/j.scitotenv.2017.08.103.

[60] Buh, Hans Ulrich, Maximilian Röglinger, and Florian Moser. "Big Data A Fashionable Topic with(out) Sustainable Relevance for Research and Practice?" Business & Information Systems Engineering 2 (2013). https://doi.org/10.1007/s12599-013-0249-5.

[61] Reichstein, Markus, Gustau Camps-valls, Bjorn Stevens, Martin Jung, Joachim Denzler, and Nuno Carvalhais. "Deep Learning and Process Understanding for Data-Driven Earth System Science." Nature 566 (2019): 195–204.

through computer vision. Computer vision is any task that involves a machine learning representation or, the set of methods that determine the visual elements necessary for classification.[62]

## The Green View Index

Conceived of in 2004, Google Street View(GSV) has now mapped 360-degree images along 10 million miles roads, trails, and everything in between.[63] This dataset is a part of the company's massive web mapping platform, supporting routing, navigation, real-time traffic conditions, and satellite imagery. And while there is a growing number of companies gathering their own street view imagery(SVI), GSV's dataset is the most comprehensive, geographically and temporally. Google's streamlining of GSV into its mapping platform has contributed to a rapid growth in the interest and usage of SVI. And as a means of understanding our sense of place, the untethered availability of context-specific imagery has reinvigorated research into the question of how people gather information about places and what characteristics of a place affect their experience, specifically the operationalization of place using geospatial tools.[64]

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[62] Lecun, Yann, Yoshua Bengio, and Geoffrey Hinton. "Deep Learning." Nature 521 (2015): 4360444. https://doi.org/10.1038/nature14539.
[63] Nieva, Richard, "Google Maps has now photographed 10 million miles in Street View", December 13, 2019. https://www.cnet.com/tech/tech-industry/google-maps-has-now-photographed-10-million-miles-in-street-view/
[64] Goodchild, M.F. "Formalizing Place in Geographic Information Systems," *in* Communities, Neighborhoods, and Health, (2011).

An emergent form of tree data is the application of the Green View Index(GVI), a means of quantifying visual representations of vegetation, through the analysis of SVI. This metric derives its value from the imagery's integration into online platforms, enabling access to highly accurate and descriptive place-based information. Since most types of remote sensing rely on aerial photography and sensing, SVI fills a typically data-poor segment of urban sensing. Researchers have established that GSV is an efficient and effective tool to observe streetscapes when comparted to physical audits.[65] For example, in 2016, the Philadelphia Parks and Recreation Department utilized georeferenced street-view imagery to map the location of every street tree in less than 5 months.[66] Furthermore, researchers have developed a model for matching geolocated trees within a municipal inventory with trees captures in SVI in order to facilitate the study of tree mortality and other tree conditions. While they were only able to achieve a 38% assignment rate to the SVI trees, the improvement of this model holds potential traditional tree inventories and their capture of temporal dynamics in tree populations.[67]

In 2018, Zhang, Zhou, Liu et al. correlated the presence of visual elements within SVI scenes to six dimensions of human perceptions, such as safe, lively,

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[65] Badland, Hannah M, Simon Opit, Karen Witten, Robin A Kearns, and Suzanne Mavoa. "Can Virtual Streetscape Audits Reliably Replace Physical Streetscape Audits?" Journal of Urban Health 87, no. 6 (2010): 1007–16. https://doi.org/10.1007/s11524-010-9505-x.
[66] Carolan, Kistine, "Mapping Philadelphia's Urban Forest", August 5, 2016. https://www.phila.gov/posts/open-data-digital-transformation/2016-08-05-mapping-philadelphias-urban-forest/
[67] Laumer, Daniel, Nico Lang, Natalie Van Doorn, and Oisin Mac. "Geocoding of Trees from Street Addresses and Street-Level Images." ISPRS Journal of Photogrammetry and Remote Sensing 162 (2020): 125–36.

beautiful, wealthy, depressing, and boring. They utilized machine learning to show that objects significantly contributed to the perceptual indicators, with trees correlating most positively to "beautiful" and "lively" and most negatively to "depressing." In contrast, walls, while inducing perceptions of safety, they correlated most positively to "depressing" and "boring".[68] These sentiments are simplistic, but the findings support urban planning and forestry research in terms of how important trees are to positive perceptions of place.

The Senseable City Lab's mission is to "speak the language of designers, planners, engineers, physicists, biologists, and social scientists…through design and science, the Lab develops and deploys tools to learn about cities—so that cities can learn about us."[69] The MIT-based research initiative developed Treepedia in order to "raise a proactive awareness of urban vegetation improvement, using computer vision techniques based on Google Street View images."[70] Developed from the work of Xiaojiang et al., it further quantifies the visual impact of street trees as a perceptual indicator by identifying levels of street tree canopy along city road networks.[71]

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[68] Zhang, Fan, Bolei Zhou, Liu Liu, Yu Liu, Helene H Fung, Hui Lin, and Carlo Ratti. "Landscape and Urban Planning Measuring Human Perceptions of a Large-Scale Urban Region Using Machine Learning." Landscape and Urban Planning 180, August (2018): 148–60. https://doi.org/10.1016/j.landurbplan.2018.08.020.
[69] MIT, "Senseable City Lab," Accessed April 14, 2022. http://senseable.mit.edu/
[70] MIT, "Treepedia," Accessed April 14, 2022. http://senseable.mit.edu/treepedia
[71] Li, Xiaojiang, Chuanrong Zhang, Weidong Li, Robert Ricard, and Qingyan Meng. "Urban Forestry & Urban Greening Assessing Street-Level Urban Greenery Using Google Street View and a Modified Green View Index." *Urban Forestry & Urban Greening* 14, no. 3 (2015): 675–85. https://doi.org/10.1016/j.ufug.2015.06.006.

In that 2015 paper, they applied the work Yang et al. on the visual effects of urban forests via a new index called Green View, they utilized the Green View Index(GVI) to analyze street trees in New York City. The method measured the proportion of green pixels in each image, which at the time was comparable to other remote sensing indices like Floor GVI and NDVI. The process by which GSV imagery is sampled has also been applied in the temporal dimension, aggregating GSV images in New York City over 10 years and analyzing local changes to GVI. The study found a slight increase in GVI across all areas, but noted the many limitations to the GSV dataset, namely, lack of coverage in backyards, parks, and tree canopies obscured by vehicles in the street, as well as the lack of regularity in time intervals between panoramas.[72]

Unlike most types of urban infrastructure, trees can be increasingly functional as they age, providing city dwellers an array of benefits over their lifespan. For these reasons, cities actively integrate trees and green infrastructure with streets and buildings. This element of change and function over time is of critical importance in describing the provision of ecosystem benefits. Understanding the indicators and causal factors of change that might affect a particular community and their access to those benefits are a means of accounting for their values. In this way, using GVI to observe the urban canopy is a form of policy scenarios over time. Each panoramic snapshot describes a scene at a

[72] Li, Xiao-jiang. "Examining the Spatial Distribution and Temporal Change of the Green View Index in New York City Using Google Street View Images and Deep Learning." *Environment and Planning B: Urban Analytics and City Science*, no. October (2020). https://doi.org/10.1177/2399808320962511.

particular time; a thousand words that might be used by those who live there, to describe the trees on their block.

Urban greening has become a ubiquitous term with many definitions, and many cases that demonstrate how different outcomes can be for different cities. Examples that share a sense of entrepreneurship, in the sense that they harness the language of sustainability and development, tie in ecology, connectivity, livability, access to open space, workforce development, and equity.[73] The idea that urban landscapes should go beyond facilitating movement and the exchange of resources, and instead sustain kinship and community ties are not necessarily new ideas, just restricted ones.[74] One restricting factor is the techniques used to document and evaluate the value of trees and urban green spaces. The utility of the methods used to model and plan the distribution of trees for maximum impact, is very much dependent on flattening and homogenizing tree function.[75] In exploring a new method for evaluating urban trees, a huge source of inspiration has come from the researchers and practitioners from all over the world, creating a diverse array of knowledge. The analysis of SVI as a rich source of information about tree-people interactions is a promising contribution to a more expansive definition of urban greening.

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[73] City of Baltimore Department of Planning. 2018. "Baltimore Green Network: A Plan for a Green and Connected City."
[74] Campbell, Lindsay; Wiesen, Anne. 2009. Restorative Commons: Creating Health and Well-Being Through Urban Landscapes. Gen. Tech. Rep. NRS-P-39. Newtown Square, PA : U.S. Department of Agriculture, Forest Service, Northern Research Station. 278 p.  https://doi.org/10.2737/NRS-GTR-P-39.
[75] Sandberg, L Anders, ed. Urban Forests, Trees, and Greenspace. Taylor & Francis, 2014.

# Chapter 3

## METHODOLOGY

This study analyzes street view imagery at points throughout Wilmington's street network, extracting the level of tree canopy from each scene. The perspective of pedestrians and motorists are approximated, with the understanding that perceptions of place are highly subjective, but also highly correlated to visual indicators. The Green View Index is aggregated at the city block level, as are demographic statistics, land cover attributes, tree inventory values, street network attributes, and the presence of civic associations. Spatial analyses and regressions are used to determine relationships that affect GVI.

## Research Questions

1. How is Green Value Index distributed across Wilmington, DE?
2. How do the Green Value Index, tree inventory data, and tree canopy cover relate to one another in Wilmington, DE?
3. How does the Green Value Index relate to other urban spatial patterns?

## Units of Analysis

Seven thousand, seven hundred and eighty-one street view panoramas and their GVI are geolocated and aggregated at 1,627 city blocks. This sample includes images from July 1, 2007, to March 1, 2020.

## Database Analysis

To understand the city's social and spatial characteristics, data is gathered in the form of GIS boundary layers including city blocks, civic associations, census tracts, zoning districts, parks, street networks, and the city's street tree inventory. These layers help us the extent of urban infrastructure and the demographic context for trees in the city.

Other map layers include a high-resolution land cover map which provides accurate descriptions of classes including vegetation, structures, paved and natural surfaces for the state of Delaware. This 2014 dataset allows us to examine tree canopy coverage and built surfaces across the city's various typologies through a combination of LiDAR and satellite imagery. In addition to quantifying UTC cover, the landcover data also provides a baseline for the SVI data I collect.

Wilmington's Public Works department maintains a tree inventory that is regularly updated, aggregating data on individual trees throughout the city. Over 15,000 trees are represented and certain elements of this database contribute to our analyses. This dataset also provided planting project categories that the DCH was involved in. This provided a variable for the presence of trees planted through the coordinated efforts of the local organization. In combination with the landcover dataset, these layers provides a resource and management background that I expect are strongly associated with the measurements taken in the following steps.

The methodology for procuring GVI data was modeled after research conducted by Xiaojiang Li et al.in 2015, utilizing Google Street View as an urban greenery assessment tool.[76] Accessing Google's image repository first required a sampling of points along Wilmington's street network at every 50m. A shapefile containing these 8,609 points were then used to query Google's API using Python and retrieve image metadata for panoramas nearest to those points. Each line contained the image's ID, date taken, and latitude and longitude of the panorama's location. This collection of images was also filtered for time taken between the months of May and September to avoid panoramas of defoliated trees. An additional filter included selecting the most recently taken image, resulting in a total of 7,781 images.

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[76] Li, Xiaojiang, Chuanrong Zhang, Weidong Li, Robert Ricard, and Qingyan Meng. "Urban Forestry & Urban Greening Assessing Street-Level Urban Greenery Using Google Street View and a Modified Green View Index." Urban Forestry & Urban Greening 14, no. 3 (2015): 675–85. https://doi.org/10.1016/j.ufug.2015.06.006.

Next, the metadata was used to acquire the images themselves. Each panorama consisted of three images taken at different headings, which were then stitched together to create a 360° panorama. At this point, the images were processed using a mean shift algorithm to segment the image by color. Soon thereafter, the processing methodology was changed in favor of a semantic segmentation algorithm utilizing pixel classification and image context, which was then trained to be able to recognize objects in urban scenes.[77] This meant that just tree canopy, and not other types of vegetation like turfgrass, will be measured. Finally, the number of "tree canopy" pixels is divided by the total number of pixels within a given panorama to determine the Green View Index(GVI). At this point I evaluate the character of this data type, including temporal and geographic coverage. This value provides the basic element for further analyses and correlations.

Each geolocated GVI value is plotted back onto Wilmington's street network and able to be summarized at boundary layers. The street network is also analyzed using OSMnx, a tool that enables the collection and analysis of street networks. By constructing data from OpenStreetMap, a widely used editable

[77] Li, Xiao-jiang. "Examining the Spatial Distribution and Temporal Change of the Green View Index in New York City Using Google Street View Images and Deep Learning." Environment and Planning B: Urban Analytics and City Science, no. October (2020). https://doi.org/10.1177/2399808320962511.

geographic database, users can access, download, and access the network topology for the purposes of measuring distances and routing paths.[78]

## Spatial Analyses

Each of the 1,627 block features are buffered by 15 meters using QGIS, which ensures the capture of 7,781 GVI points located on the surrounding roads. The overlapping blocks mean the GVI points are captured a total of 19,816 times cumulatively. The captures values are then averaged over each block.

Landcover type raster bands are combined into tree cover and built cover files, which are then joined to the block geographies as well. Tree cover includes tree cover over buildings, roads, and bare earth. Built cover includes buildings, paved roads, and other types of road surfaces.

Zoning maps from the City of Wilmington are also joined to the block layer, including 26 zoning types over the five general types: residential, commerical, open space, industrial, and waterfront. Civic association maps are joined to the block layer, which includes 86 different organizations. Wilmington parks were also processed and mapped if they were adjacent to a given block.

Wilmington's tree inventory showed wide variability of completeness. While the intial inventory was completed in 2011, many trees have have not been updated since then. The temporal mismatch is apparent here and in other variables, so the only data extracted from the inventory was diameter at breast

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[78] Boeing, Geoff. "OSMnx : New Methods for Acquiring , Constructing , Analyzing , and Visualizing Complex Street Networks," 2017, 126–39. https://doi.org/10.1016/j.compenvurbsys.2017.05.004.

height(DBH) of individual tree records. This measures the girth of the tree's trunk approximately 4.5 feet off of the ground, and is a commonly used measure of tree size. The DBH data was geolocated and joined with blocks encompassing and across the street from their location. DBH inches were summed across those within the block's buffered footprint.

Census block group data from 2018 including income per capita, total population, household density, owner-occupied percentage, and populations for white, black, and hispanic residents were also included and joined to the block layer. Finally, OSMnw was used to perform statistical analysis of the street network withn the block polygon. Total length of the street and number of intersections were used in tandem with block size to create intersection and street density variables.

*Table 1*: Variables

| Variable Name | Description | Mean | Standard Deviation |
|---|---|---|---|
| | *Vegetation and Cover* | | |
| GVI(%) | Green View Index | 17.98 | 10.59 |
| Tree Cover(%) | Percentage of Tree Canopy Coverage | 22.2 | 19.03 |
| DBH(in) | Sum of All Tree Trunk Diameters | 212.44 | 250.78 |
| Area(sqkm) | Total Square Kilometers of Block | 0.01 | 0.03 |
| Built Cover(%) | Percentage of Building/Road Coverage | 63.69 | 23.57 |
| If Plant(bool) | Tree Planting Project Occur on Block | | |
| Park Adjacent(bool) | Block is Adjacent to a Park Property | | |

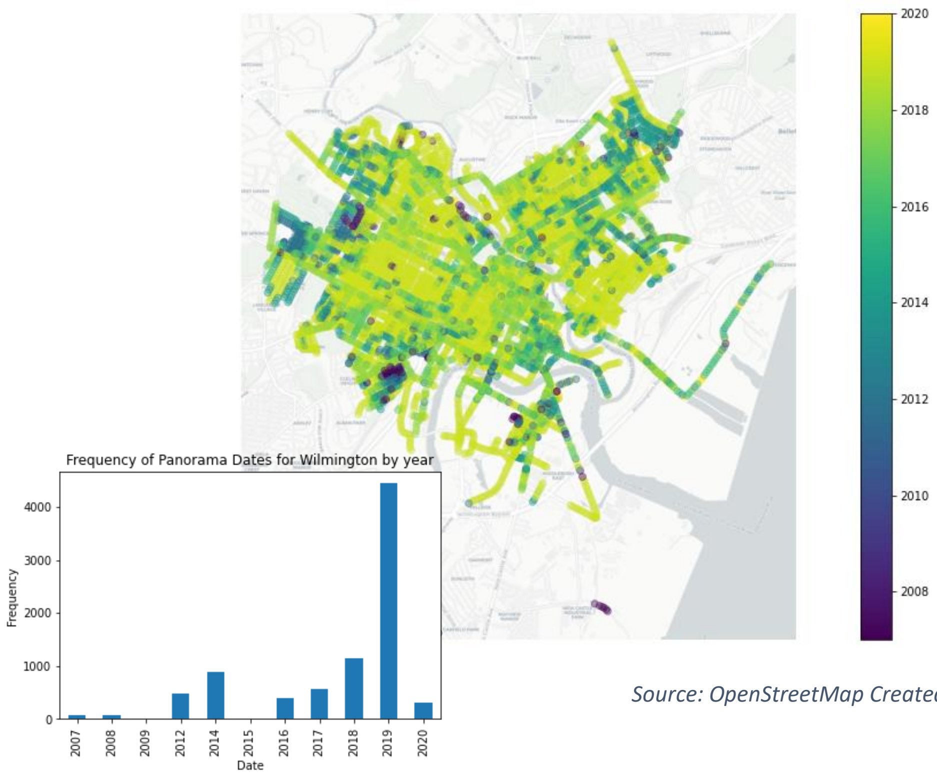
| | | | |
|---|---|---|---|
| | *Street Network* | | |
| Intersection Density | Number of Intersections / Area | 2303.79 | 7901.70 |
| Street Density | Total Street Length / Area | 182.12 | 754.12 |
| | *Census Data* | | |
| Owner-occ(%) | Percentage of Owner-occupied Units | 45.87 | 18.15 |
| Pop.Density | Total Population / Area | 5653.67 | 7435.79 |
| Income per capita | Total Income / Population | 32222.88 | 19652.17 |
| White pop(%) | Percentage of Population that is White | 38.78 | 26.31 |
| Black pop(%) | Percentage of Population that is Black | 54.85 | 26.51 |
| Hispanic pop(%) | Percentage of Population that is Hispanic | 9.53 | 9.97 |

# Chapter 4

## FINDINGS

The streetview imagery dataset gathered for Wilmington has some basic characteristics that are unique to the data form and to the particular instance when it was aggregated. One is the historical nature of each image. The resolution and regularity with which the images were captured have both increased, but have no systematic variation. While resolution was not studied in-depth, most of imagery is more recent than 2012, by which time high-resolution images were standard.

*Figure 2:* Distribution of Panoramas by Date



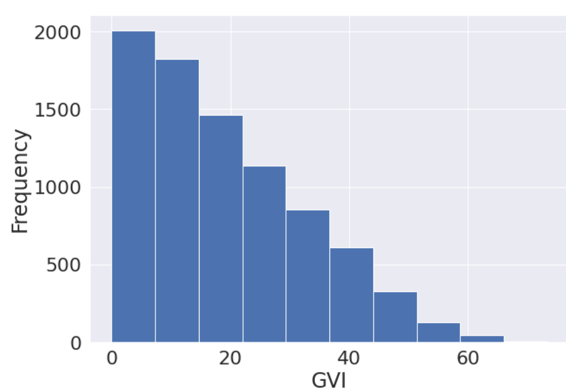

*Source: OpenStreetMap Created by Author*

## Wilmington's GVI

As indicated in the plot, the most up-to-date, leaf-on images still ranged from 2007 to 2020. Figure C reveals pockets of areas that seem to have especially out-of-date images, during which greenery values could have changed. Other cities may have more up-to-date datasets, but Wilmington's access to recent imagery may continue to be a disadvantage for research applications. The temporal distribution of GVI, if widely available has bee show to have applications for analyzing change over time. A study in NYC examined the impact of planting projects on GVI over a period of 10 years, indicating an increase in values that were unrelated to ethnic/racial status of nearby residents.[79]

Figure D indicates the frequency of GVI values across the entire city, with the mean GVI value at 19.19% and over 97% of GVI values being under 50.

*Figure 3* Distribution of GVI values in Wilmington



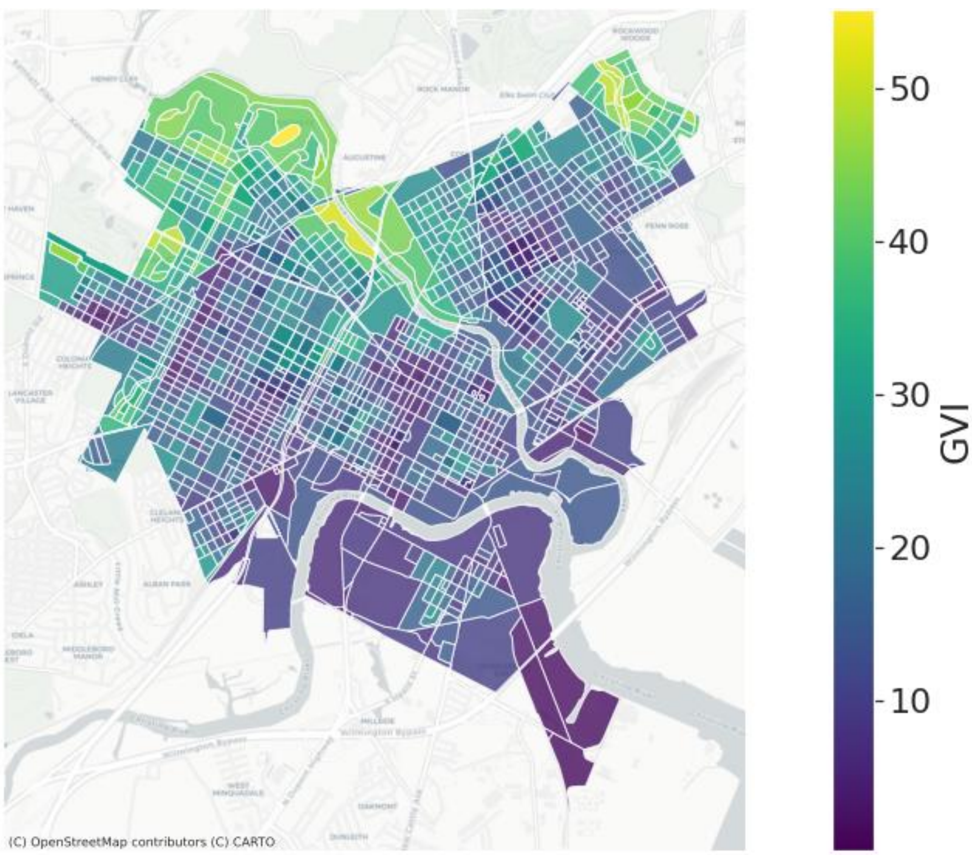

*Source: Created by Author*

[79] Li, Xiao-jiang. "Examining the Spatial Distribution and Temporal Change of the Green View Index in New York City Using Google Street View Images and Deep Learning." Environment and Planning B: Urban Analytics and City Science, no. October (2020). https://doi.org/10.1177/2399808320962511.

GVI values of global cities range from 8 to 36, as documented on the Treepedia website.[80] The average GVI of the 31 cities documented on the site was 18.75%, and the average population density was 3,764/km$^2$.

At the time of this research, I could not locate a more comprehensive database for GVI values across cities. For reference, the percentage of tree cover as extracted from the high-resolution 2018 landcover dataset is 21.04%. Taking a look at Figure 4, the spatial distribution of GVI is aggregated on the block level.

*Figure 4*: Distribution of GVI by Block




*Source: Source: OpenStreetMap Created by Author*

[80] MIT, “Treepedia,” Accessed April 14, 2022. http://senseable.mit.edu/treepedia

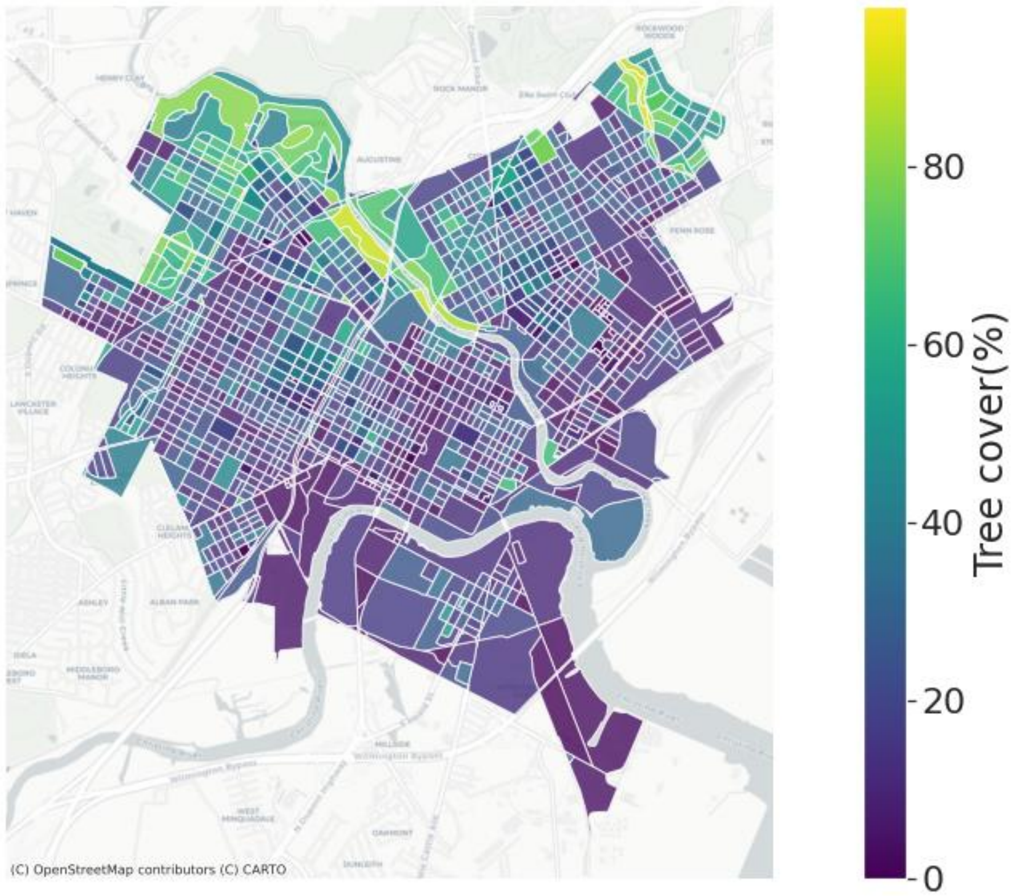
Study of the urban form at the block level have established its utility in describing urban morphology and explored it as a complement to traditional landscape ecological metrics.[81] What's significant for the applicability of GVI is the alignment of the connectivity and boundaries that drive "social engagement and ecological function". On this map, you can clearly distinguish larger regions in the north and northwest that represent high GVI along roadways within parks, parkways, and detached home residential neighborhoods. The rest of the city is highly heterogeneous, indicating only that GVI often varies from a block-to-block basis, but oftentimes with a smoothing effect. This is due to the 360-degree extent of panoramas, covering both sides of the street in its capture of visible canopy. Figure 5 shows the same block level aggregation of tree cover percentage, which you will see illustrates a more discrete measure, with no opportunities to extract vegetation outside of the block.

RQ1 asks about the distribution of GVI throughout the city. At the city level, Wilmington's GVI is comparable to other cities and does not differ unexpectedly from land cover percentage. Block-level mapping initially shows clear distinctions from block to block aside from a few concentrations of high and low values. The relation between GVI and tree cover and the tree inventory will be introduced in the next section.

[81] Brussel, Vrije Universiteit. "Developing Urban Metrics to Describe The Morphology of Urban Areas at Block Level." Landscape and Urban Planning 167 (2017): 399–409.

## Wilmington's Tree Cover and Inventory

*Figure 5*: Distribution of Tree Cover Percentage by Block




*Source: OpenStreetMap Created by Author*

While similarities in the data are apparent, it is difficult to determine where and how these differences occur based on maps. The tree cover layer provides 1 meter resolution, defining canopy as objects over 2 meters in height, based on leaf-off LiDAR data.[82] The GVI is comprised of imagery taken from the ground, but quantifies the same vegetation that comprises the tree cover layer. Tree cover concentrates over the Northwest including the Brandywine Park,

[82] O'Neil-Dunne, J. "CMS: LiDAR-derived Tree Canopy Cover for States in the Northeast USA." ORNL DAAC, Oak Ridge, Tennessee, USA, (2019) https://doi.org/10.3334/ORNLDAAC/1334

which in addition to its large size, is unique in that it has a road network through it, much of it through forested land. This amplifies the GVI values for the park. I can also see low tree cover along the east side where rail and industry continue to operate, and new waterfront developments haven't had time to accumulate mature trees. Downtown Market Street and West Center City, with the lion's share of high rises and parking lots, limits available space for trees. Northern sections including Brandywine Hills, a detached single family home community, have large yard acreages and established tree canopy that has been maintained for many years.

Block-level aggregation of tree cover percentage provides an important measurement of trees are distributed throughout the city, specifically by the extent of their canopy. The health and extent of tree canopy is related to many of the benefits conferred to urban dwellers and is an indicator of the structural and biological presence of urban trees.

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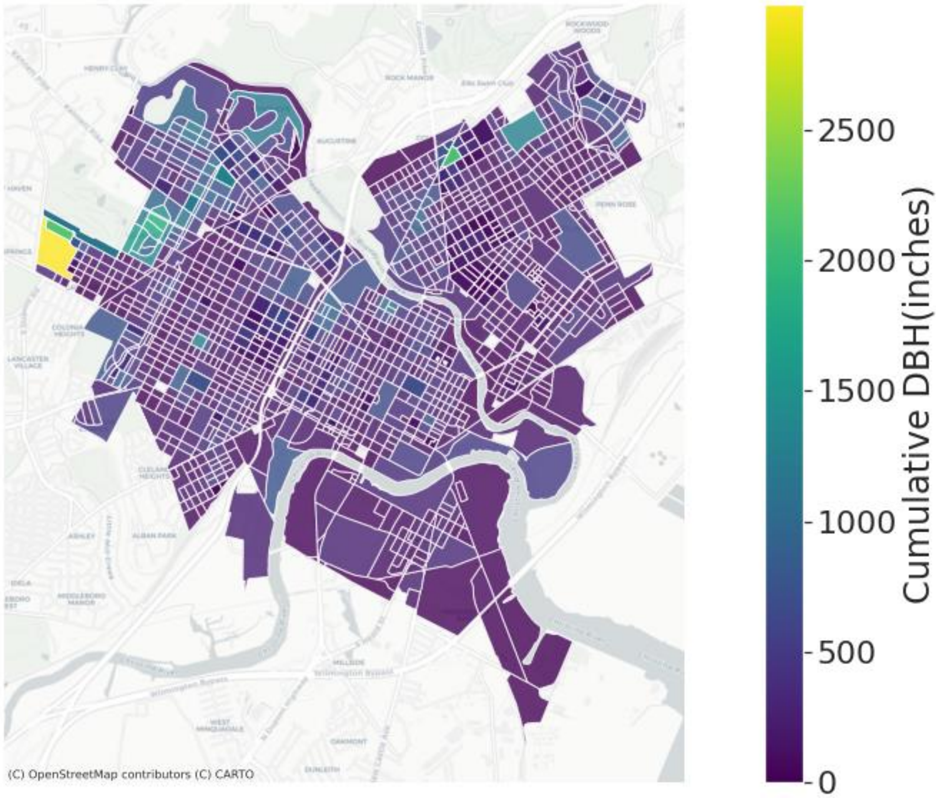
*Figure 6*: Distribution of Inventoried Tree's
Diameter at Breast Height(DBH)



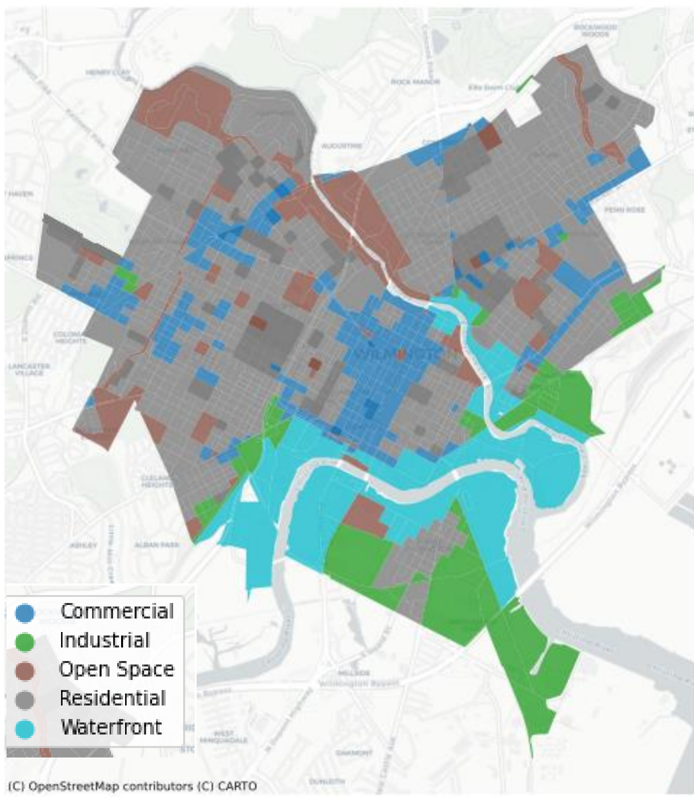

*Source: OpenStreetMap Created by Author*

Wilmington's tree inventory encompasses both planted and naturally generated trees in its public ROWs. As many trees have not been updated from the initial inventory assessment in 2011, the condition and size of these trees may be inaccurate. Location, species, and DBH, are the most complete fields and as seen in the Figure 6, high accumulation of DBH inches occur in similar geographies as high tree cover does. What I will explore in the forthcoming sections are the different factors that affect tree cover and DBH versus those that affect GVI.

## Wilmington's Zoning Districts

In order to analyze the implications of those differences and similarities, I will explore how location, and planning policy relate to each other in this context by utilizing land cover and zoning. Similarly zoned blocks will be highlighted to show what inferences can be made from a tree cover/GVI ratio.

*Figure 7*: Zoning in Wilmington




*Source: OpenStreetMap, OpenDataDE, Created by Author*

## Residential Examples

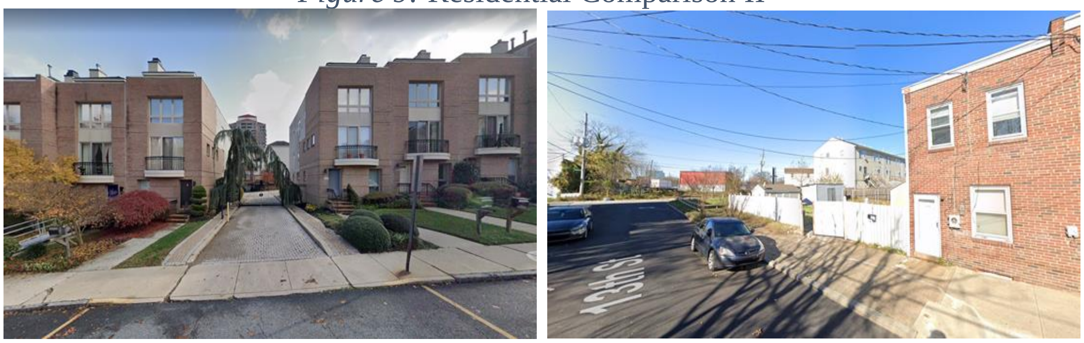
*Figure 8*: Residential Comparison I

| | |
|---|---|
| Location: Trenton Pl<br>Zoning: One Family Row Houses<br>GVI: 34.59<br>DBH sum: 942<br>Tree Cover: 56.23%<br>Built Cover: 39.97%<br>Community: Trinity Vicinity<br>Owner-occupied: 26.74% | Location: N Market St<br>Zoning: One Family Row Houses<br>GVI: 7.74<br>DBH sum: 207<br>Tree Cover: 40.71%<br>Built Cover: 51.59%<br>Community: 2500 Civic Association<br>Owner-occupied: 58.13% |

*Source: Images by Google Maps, Data: GSV, UVM Landcover, US Census, City of Wilmington*

One Family Row Houses zoning accounts for the vast majority of blocks in the city. The Trenton Place block is within the historic Trinity Vicinity neighborhood just east of the I-95 corridor. The right-of-way adjacent to these homes have been planted heavily and, combined with backyards with mature trees, contribute to high tree cover. The N Market St block is located in Northeast Wilmington on the just beyond a corrider with frequent commercial zoning. A Very large interior lot with mature trees also increases tree cover, but GVI measures low due to the lack of street trees. Both blocks are zoned R-3, and both have relatively high levels of tree cover, but differ greatly in terms of GVI. Here is a good example of how sidewalk and front yard typologies can affect street level canopy. While there is a very strong negative correlation between building and paved cover percentage and tree cover, the homes with actual space for trees in their front yards lag behind a block with no front yards and brick sidewalks in terms of GVI. With that said, GVI and DBH sum track positively with each other, but as we'll see in the following example, there are exceptions.[83]

*Figure 9:* Residential Comparison II



| | |
|---|---|
| Location: Lovering Ave | Location: Thatcher St |
| Zoning: One Family Row Houses | Zoning: One Family Row Houses |
| GVI: 34.85 | GVI: 6.65 |
| DBH sum: 373 | DBH sum: 23 |
| Tree Cover: 18.84% | Tree Cover: 0.95% |
| Built Cover: 72.76% | Built Cover: 81.85% |
| Community: Westhill | Community: 11th Street Bridge |
| Owner-occupied: 33.16% | Owner-occupied: 36.21% |

*Source: Images by Google Maps, Data: GSV, UVM Landcover, US Census, City of Wilmington*

The Lovering Avenue block is near Trolley Square and is one block removed from South Park Drive. There are homes on the interior of the block, and therefore the overall tree cover is greatly reduced. Large front yards comprise mostly of shrubs and turfgrass but in this instance, GVI increases due to the presence of Brandywine Park, which has a forested boundary along Lovering. The Thathcher Street block is just off of Northeast Boulevard, surrounded by industrial and waterfront zoning. In this case, there are open grassy lots, and very few street trees that explain low DBH and tree cover. The GVI value increases

[83] See Appendix A.

due to a nearby fenceline buffer that appears unmaintained, leading to the generation of trees, shrubs, and woody vines. In both of these blocks, the tree cover is lower than GVI, indicating the presence of trees beyond the confines of the block itself.

## Commercial Examples

*Figure 10:* Commercial Comparison I

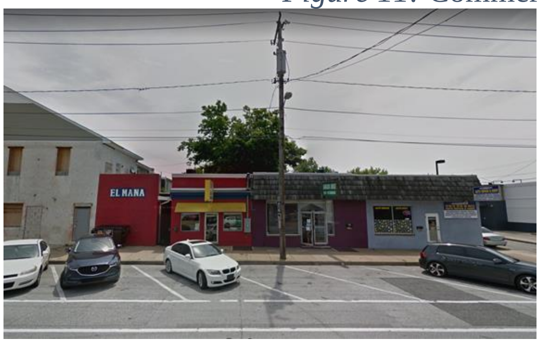

| Location: Augustine Road<br>Zoning: Secondary Business Centers<br>GVI: 26.12<br>DBH sum: 94<br>Tree Cover:9.91%<br>Built Cover: 82.35%<br>Community: Forty Acres<br>Owner-occupied:55.41% | Location: Concord Avenue<br>Zoning: Secondary Business Centers<br>GVI: 21.47<br>DBH sum: 117<br>Tree Cover: 19.95%<br>Built Cover: 63.56%<br>Community: Triangle<br>Owner-occupied: 40.12% |
|---|---|

*Source: Images by Google Maps, Data: GSV, UVM Landcover, US Census, City of Wilmington*

Secondary Business Center zoning accounts for the most frequently found commercial zone in Wilmington. The Augustine Road block is at the corner of a gateway intersection, where traffic from points north and northeast of the city enter the Forty Acres and Trolley Square neighborhoods. The parking lot and multi-tenant business plaza take up most of the parcel with a few street trees. Across the intersection is a railway and the northwest corner of Brandywine Park.

The vegetation from the nearby open space increases GVI in addition to the plantings. On Concord Avenue, a similar commercial typology exists, but without street trees adjacent to the parking lot. A designed planting from across Concord Avenue likely increases GVI, despite the block's low tree cover. In both of these cases, GVI is higher than tree cover, benefitting from nearby open space.

*Figure 11:* Commercial Comparison II




| | |
|---|---|
| Location: North Union Street<br>Zoning: Secondary Business Centers<br>GVI: 3.66<br>DBH sum: 8<br>Tree Cover:23.97 %<br>Built Cover: 72.65%<br>Community: West Side<br>Owner-occupied: 31.37% | Location: Lancaster Avenue<br>Zoning: Secondary Business Centers<br>GVI: 3.74<br>DBH sum: 2<br>Tree Cover: 6.32%<br>Built Cover: 91.58%<br>Community: Southwest Civic Assoc.<br>Owner-occupied: 48.25 % |

*Source: Images by Google Maps, Data: GSV, UVM Landcover, US Census, City of Wilmington*

The North Union Street block is near the southern end of this busy commercial area. The corridor overall has very little tree cover and in this case, there are some interior lot trees that increase tree cover and a few street trees on the North Lincoln side, but the overall GVI remains low. With very few businesses providng parking lots or nearby residences with off-street parking or garages, on-street parking congestion and above-ground utilities restrict the placement of street trees. Union Street is a state maintained road, and recent initiatives have been aimed at making the Union Street corridor more pedestrian and bicycle-friendly. The Greenhill avenue block is situated off of Lancaster Avenue, another state maintained route, in the western part of the city. Businesses in this area are more likely to have off-street parking and there are four lanes, as compared to Union streets two lanes. Larger building footprints and parking lots contribute to a much higher built cover percentage, resulting in very low tree cover. In both of these cases, GVI is lower than tree cover, indicating there are no external sources of tree canopy at the street level. These dense, motorist-heavy locations are characterized by intensive usage by larger vehicles and oftentimes very little delineation between parking lots and sidewalks. Without nearby park space or space created for street trees, the low GVI indicates a potential need for cooperation with state agencies to make room for trees in the right-of-way(ROW).

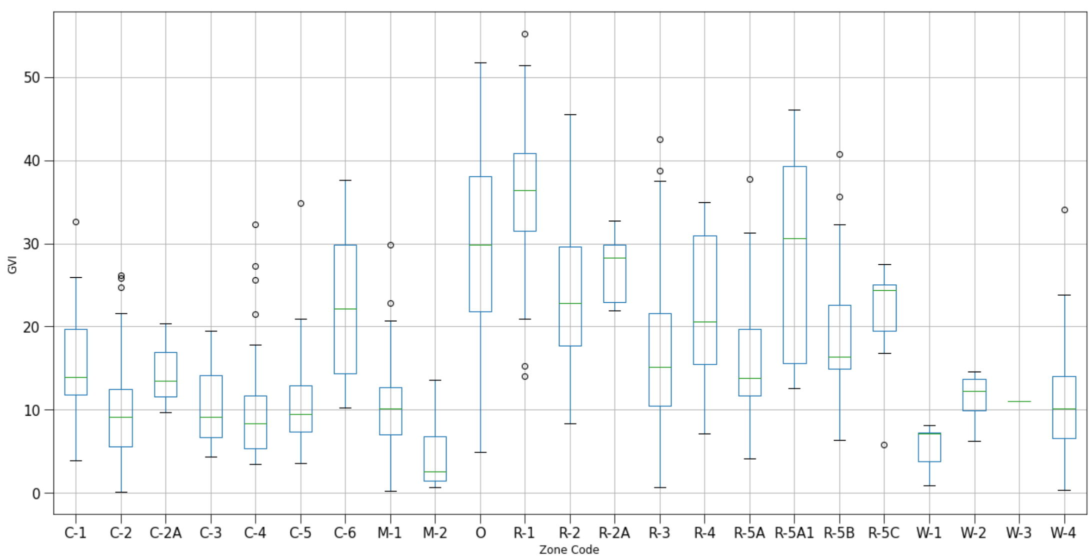
The use of GVI to quantify vegetation at the block level has provided some insights into the distribution of tree canopy within residential and commerical zones. To summarize:

- Tree cover is an indicator of tree canopy over the interior and exterior of a block. Despite having a high tree canopy percentage, residential blocks may have a low GVI due to low planting levels in the ROW and/or front yards.
- A given residential block's tree cover may be low due to buildings and pavement, but the extent of vegetated landscapes limited to turfgrass and shrubs can cause similar readings. GVI can measure higher than

tree cover due to the presence of nearby parkland or unmanaged open space.

- The same is demonstrated for commercial blocks in proximity to open space i.e. nearby open space will affect GVI even if the block itself is not amenable to trees. The opposite is likely true as well; if commercial blocks don't have design elements in place that incorporate trees and there are no nearby open spaces, GVI values will be low.

*Figure 12*: Box Plot of GVI for Zoning District Types

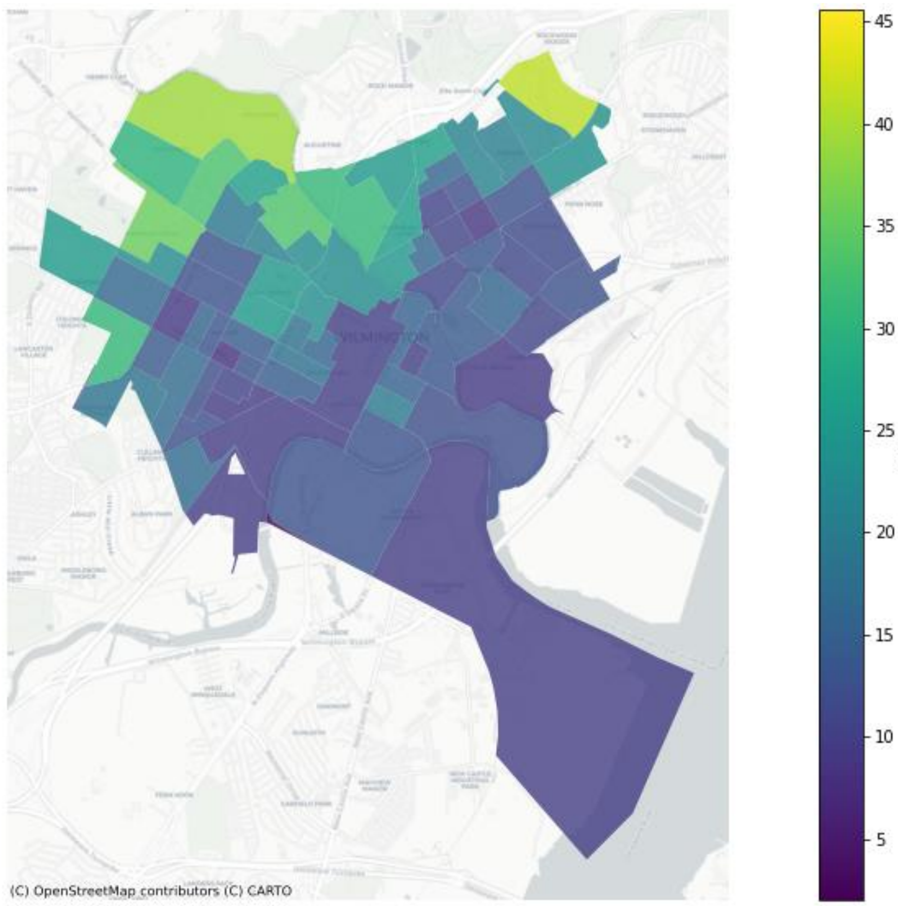



The zoning districts in Wilmington overlap, but some examples of distinguishing typologies have been highlighted. In the plot above, you can see that differences in land use policies seem to account for variances in GVI. Further research will be able to use zoning status as a starting point for understanding the limitations and opportunities for changing GVI.

## Census Tracts

Data from the 2018 5-year American Community Survey included key demographic data regarding Wilmington's populace. Statistics included population, race, income, and owner-occupied housing status.

*Figure 13*: Census Block Groups by GVI

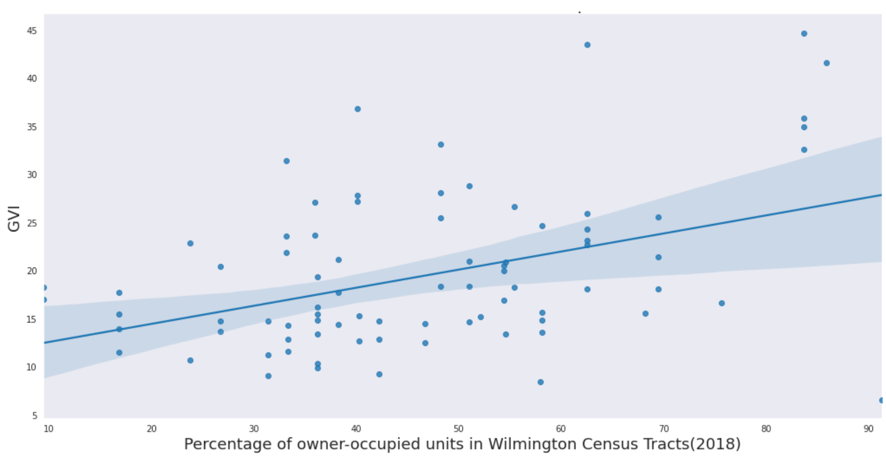



*Source: OpenStreetMap  Data: GSV, US Census*

*Figure 14:* GVI as function of Percentage of White Residents


*Figure 15*: GVI as function of Percentage of Black Residents


*Figure 16*: GVI as function of Percentage of Owner-occupied Units



The correlations between the highlighted demographic factors is notable, but not necessarily in and of themselves. Researchers have documented the tempering effect of other socio-physical factors such as housing age in tandem with race and income. One theory advances that older neighborhood whose residents have disposable income are more able to replace trees that die, conserving canopy levels to some extent.[84] Consider the case of new neighborhoods that are nevertheless made up of wealthy residents. The capacity for trees to live for long periods in the landscape seem to be affected by some of the factors examined here. While I was unable to include housing age here, the legacy of race, income, and housing is certainly a subject for further analysis. A recent study by Healy et al. explores the cycles of canopy gain and loss as correlated with periods of economic prosperity and its effect on the landscape.[85]

## Communities

Civic associations serve the community in a variety of capacities. They provide health, housing, recovery, and other social services, and as seen on the map, generally, but not exclusively, serve a defined geographic location. These

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[84] Lowry, John H, Baker, Matthew, and Ramsey, Douglas. "Determinants of Urban Tree Canopy in Residential Neighborhoods: Household Characteristics, Urban Form, and the Geophysical Landscape." Urban Ecosystems 15 (2012): 247–66. https://doi.org/10.1007/s11252-011-0185-4.
[85] Healy, Marc, John Rogan, Lara A Roman, Sabine Nix, Deborah G Martin, and Nicholas Geron. "Historical Urban Tree Canopy Cover Change in Two Post-Industrial Cities." Environmental Management, 2022. https://doi.org/10.1007/s00267-022-01614-x.

organizations are natural stakeholders in urban canopy initiatives, able to provide a localized, more disaggregated understanding of the values of local residents.

*Figure 17*: GVI of Civic Associations

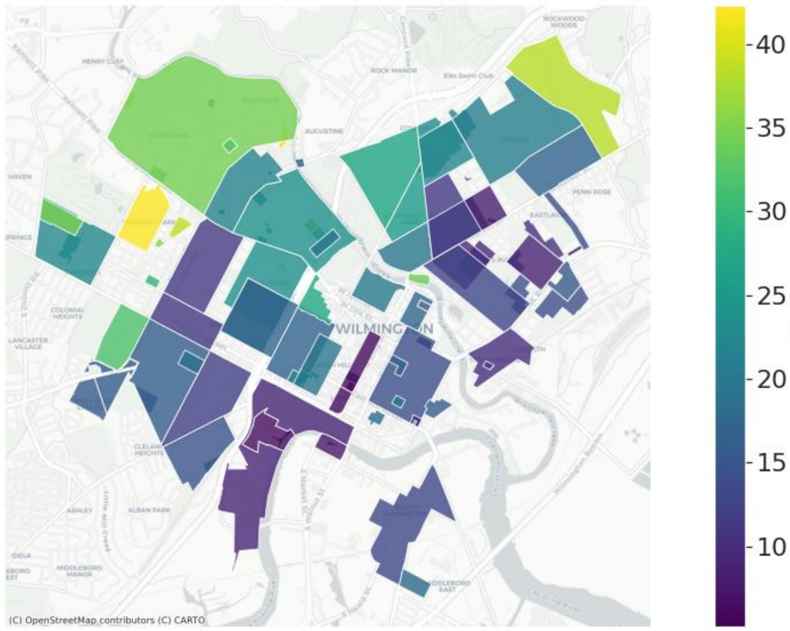
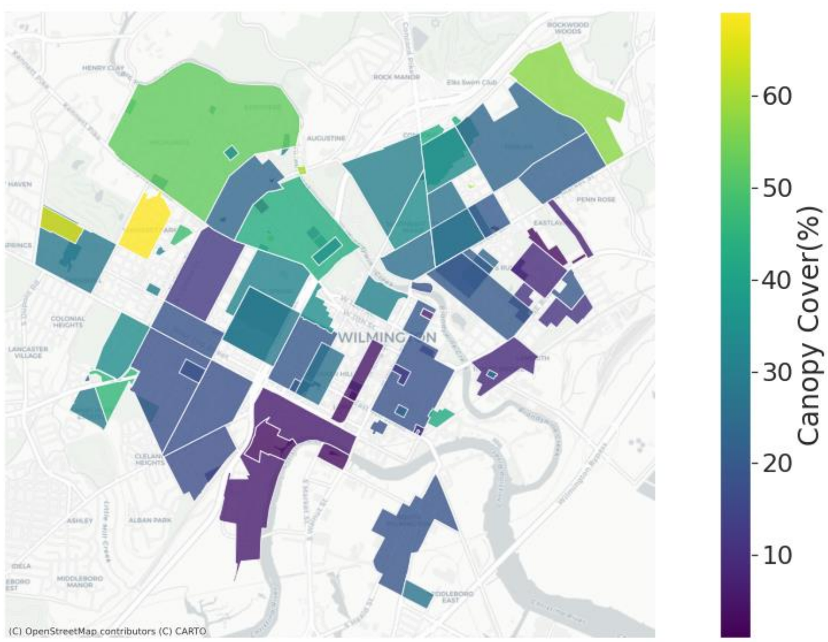



*Figure 18*: Canopy Cover of Civic Associations



From a planning perspective, a representation of local values can come in the form of comprehensive development plans. The city's 2028 Comprehensive plan suggests strengthening tree protection regulations and planting projects as referred to in other community plans. The Northeast Wilmington Community Revitalization Implementation Plan(2019) includes goals for improving streetscapes through the planting of empty tree pits, creating new pits on non-shaded blocks, and "improving pedestrian conditions" with street trees.[86] The Southbridge Neighborhood Action Plan includes the use of street trees with "smaller caliper trunks…and higher canopy…to discourage parking on sidewalks," to "reduce urban heat island effects in the neighborhood," and to "increase awareness about the benefits of trees in the community, as well as the equity implications tied to the issue." They also include an action item covering the use of fines to penalize local industries that have overgrown trees on their property, causing damage in the form of "lifting sidewalks," harboring mosquitoes, and "intrusive growth in alleyways and empty lots."[87] These descriptions include desired outcomes as well as unwanted disservices related to trees.

What stands out in these plans is the description of tree canopy on a very up-close level. Adjectives "intrusive" and "higher" define the kind of scene that GVI values represent. Therefore, while the association-wide values of GVI may not tell a very compelling story, it's a start in terms of identifying which streets,

[86] WRA. "Northeast Wilmington Community Revitalization Implementation Plan," (2019).
[87] Asakura Robinson. "The Southbridge Neighborhood Action Plan," (2021).

with which GVI values, represent the best and worst of what planning processes describe. While redlining maps for Wilmington have not been unearthed, the history of urban renewal and highway construction have played a role in displacement and the dividing of neighborhoods. Identifying priorities on a community association-basis will be the start to making GVI values meaningful.

The planning process for these communities can unearth heritage narratives that affect perceptions of street trees. In Detroit, researchers identified residents' heritage narratives or, local histories as they pertain to trees and memories surrounding the city government's disinvestment in tree maintenance the resultant decline.[88] These perceptions would oftentimes result in the refusal of free trees, reflecting an uncertainty of their impact on the neighborhood. They also observed that "the lack of resident involvement in species selection and decision on maintenance protocols is counterproductive", considering the importance of stewardship for tree survival.[89] Researchers in Baltimore studied antagonistic sentiments regarding street trees in certain neighborhoods with plantable space, determining that a generalization of preferences regarding trees across ethnic groups was problematic, and not reflective of the practical bases for the concerns of interviewees.[90] While these examples highlight the scholarship

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[88] Carmichael, Christine E., and Maureen H. McDonough. "Community Stories: Explaining Resistance to Street Tree-Planting Programs in Detroit, Michigan, USA." Society and Natural Resources 32, no. 5 (2019): 588–605. https://doi.org/10.1080/08941920.2018.1550229.

[89] Carmichael et al., "Community Stories: Explaining Resistance to Street Tree-Planting Programs in Detroit, Michigan, USA."

[90] Battaglia, Michael, Geoffrey L Buckley, and Michael Galvin. "It's Not Easy Going Green: Obstacles to Tree Planting Programs in East Baltimore." Cities and the Environment 7, no. 2 (2014).

that can be involved in exploring local experiences with tree canopy, the planning process is a promising outlet for the co-production of this kind of knowledge.

By observing the differences in tree canopy cover and GVI within community groups, I can see few potential avenues for further study. The perceptions of tree canopy as they are expressed by community members can be indicative of heritage narratives and hyper-local conditions that have changed over time. By providing different measures of canopy, researchers might better understand the factors that contribute to positive and negative perceptions of trees. SVI also provides a means of illustrating different levels of GVI and what they look like. The use of GVI in tree canopy policy scenarios could be a valuable exercise for communities looking to plan for the future.

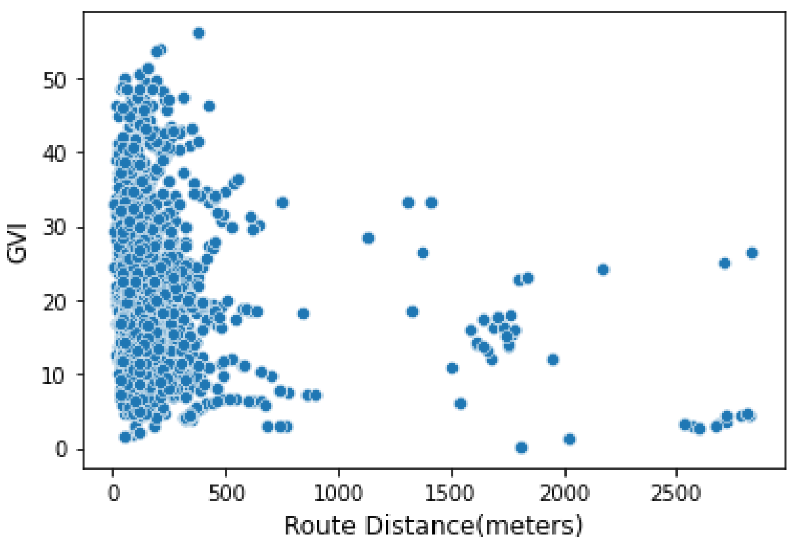
## Street Networks

The spatial characteristics of street networks is a fascinating field that won't be covered in this paper. However, the function of blocks as a transitory environment promises further applications for GVI. Pedestrians and motorists travel through blocks for a variety of reasons, and parks are one urban destination that has similar dimensions as street trees. Parks serve the purposes of active and passive recreation and can provide their own level of ecosystem benefits to users as well as those who live in proximity to parks. The nature of my assembled dataset was amenable to a transit-oriented exploration, whereby pedestrian "routes" were created through Wilmington's street network. The starting point were placed at each sample point and the end point was placed at that point's nearest park location. This resulted in 5,317 different routes, and the results can be seen in Figure 19 and 20.

*Figure 19*: GVI Averages across Park Routes


*Created by Author*

*Figure 20*: GVI as Function of Park Route Distance



The use of GVI values to quantify high resolution imagery along streets creates opportunities to explore transportation planning and modelling. These figures explore the dimensions of urban corridors as connective, green spaces. Accessibility is an important element of parks as a public good, and the experience of pedestrians on their way to those local parks can be imagined with this route data.

## Summary of Findings

The process of arranging spatial and social data layers is an exercise in looking closely. Maps hold the power to limit and train our field of vision on a particular set of boundaries and yet there is much about the urban environment that confounds pattern-setting. By using city blocks I attempted to took advantage of the smallest, discrete unit to analyze the high-resolution nature of the GVI.

The examples highlighting residential and commercial parcels with differing GVI and tree cover percentage was a means of answering RQ2. The relationship between tree cover and tree inventory data has not been explored in the literature beyond the GVI's comparison to other vegetation indexes.[91] One related application was quantification of shade through the detection of sky versus canopy and buildings in GSV imagery, which resulted in the suggestion that street trees contributed an 18.5% reduction in sky view factor in sampled locations in

[91] Kumakoshi, Yusuke, Sau Yee Chan, Hideki Koizumi, and Xiaojiang Li. "Standardized Green View Index and Quantification of Different Metrics of Urban Green Vegetation." *Sustainability (Switzerland)* 12, no. 18 (2020): 1–16. https://doi.org/10.3390/su12187434.

Boston.[92] The development of GVI as a complementary indicator of tree canopy is dependent on understanding the ways GVI values are manifested in urban landscapes. In our examples, the vistas accessible from block exteriors accounted for the capture of tree canopy outside the boundaries of the block itself. This approximation of the scale at which we perceive the landscape means that the trees visible between buildings and across roads and above fences are included.

The data's census variables showed distinct positive and negative correlations with GVI, but the literature pointed to unincluded data such as housing development age and the associated patterns of racial discrimination that excluded minorities from certain neighborhoods. The correlations might imply that differences in perceptions of the value of tree canopy at street level differ across demographic lines, but it is also likely they reflect these housing factors. The owner-occupied percentage inhabits a similar space, and the consequences of affordable housing policy, vacant land distribution, crime, and redevelopment are all documented as affecting and being affected by urban trees.[93] Including housing values was originally intended, but Delaware is in the process of updating the market values of parcels that haven't been assessed since 1983.

By examining GVI across Wilmington's urban contexts, I highlighted some distinctions in its spatial and demographic distribution. In the following

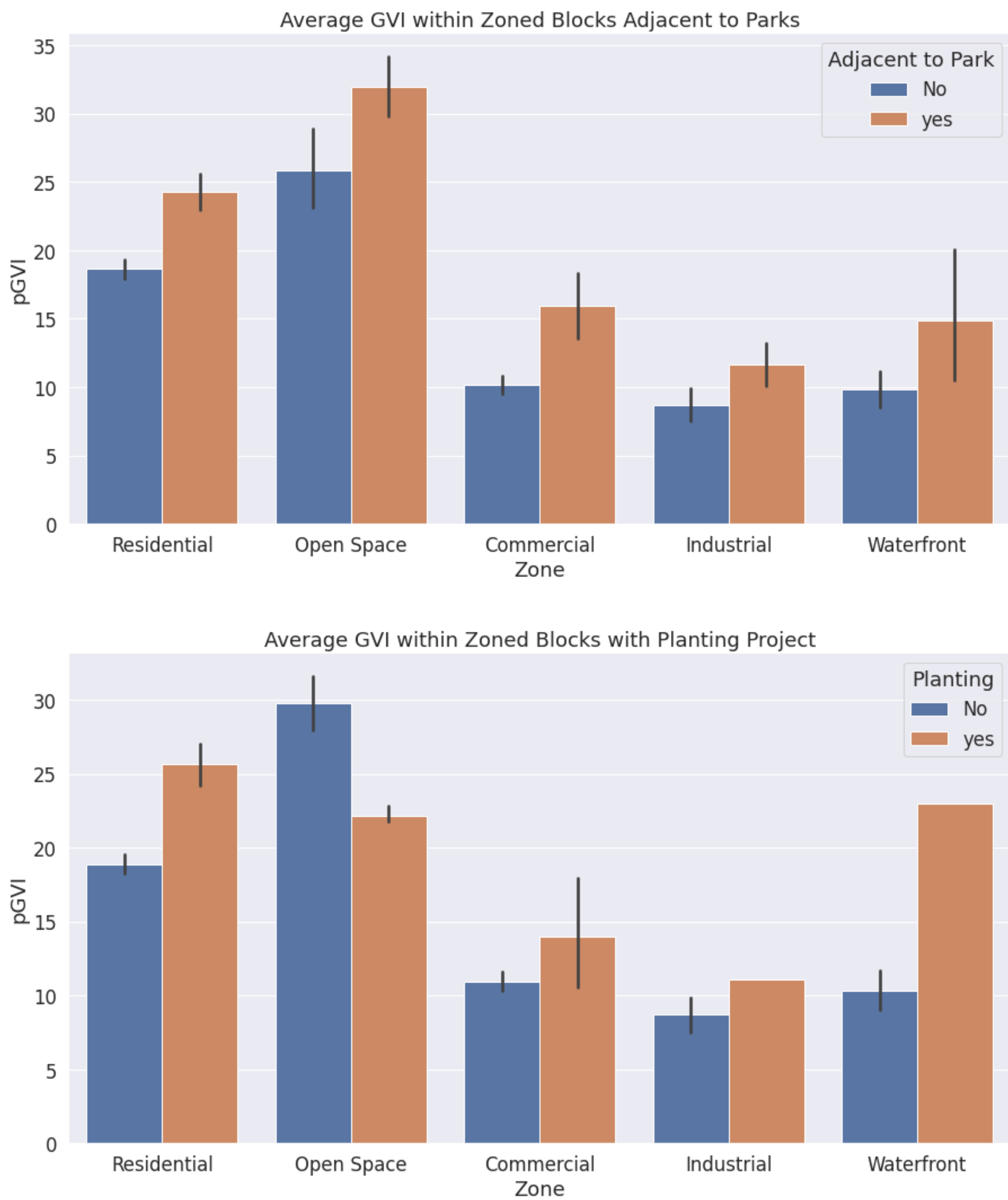
[92] Li, Xiaojiang, Carlo Ratti and Ian Seiferling. "Quantifying the shade provision of street trees in urban landscape: A case study in Boston, USA, using Google Street View." *Landscape and Urban Planning* 169 (2018): 81-91.
[93] Wachter, Susan. "The Determinants of Neighborhood Transformations in Philadelphia - Identification and Analysis : The New Kensington Pilot Study The Determinants of Neighborhood Transformations in Philadelphia Identification and Analysis : The New Kensington Pilot Study," no. February (2015).

analysis, I'll compare some additional variables within zoned scenarios and compare the weight of the different variables we've covered so far.

## Chapter 5

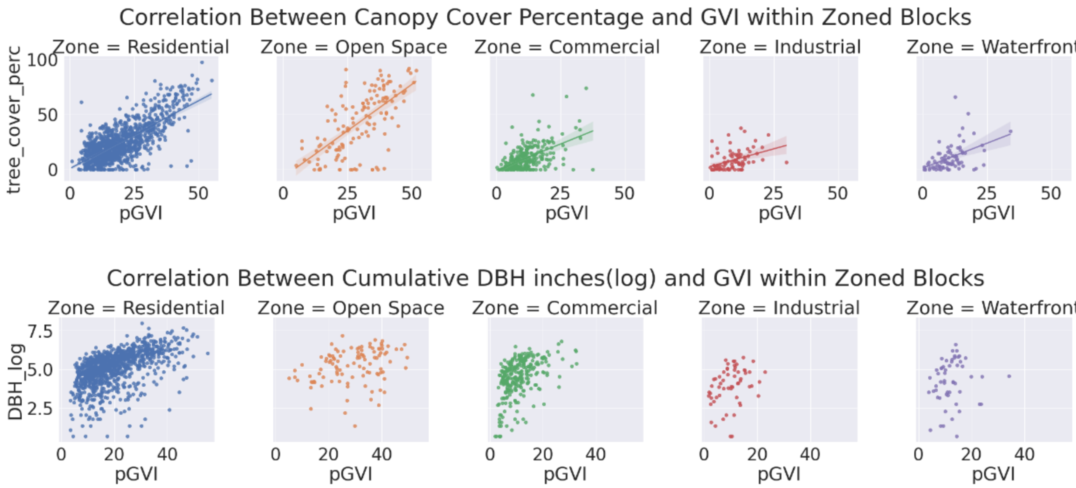
## ANALYSIS

*Figure 21*: GVI Distribution Parks and Planting



The location of parks and the presence of trees from a locally organized tree planting project are additional categorical data that illustrates the unique qualities of the GVI. Park trees were not included in this analysis, but GVI seems to capture tree canopy present on park property when blocks are directly adjacent to them. That said, in the lower graph, the only block category that doesn't seem to benefit from planting projects is open space. While this seems contradictory, what is likely happening is the effect of large parks with forested buffers outweighing the small parks that fit within other zoning districts. The planting projects involved street trees, and therefore park tree plantings are not accounted for here. This may have reduced the number of open space blocks that did actually receive a planting treatment. The limitations to this comparison stem from the inclusion of incomplete planting data. The number of blocks that received trees through DCH-coordinated projects, as determined through GIS and inventory data, is 147. This leaves many more that are without, but the permutations of the question of whether planting projects increase or maintain GVI, depending on where they occur, and how long those plantings have been in the ground should be further explored.

*Figure 22*: GVI/Canopy/DBH Within Zoned Blocks

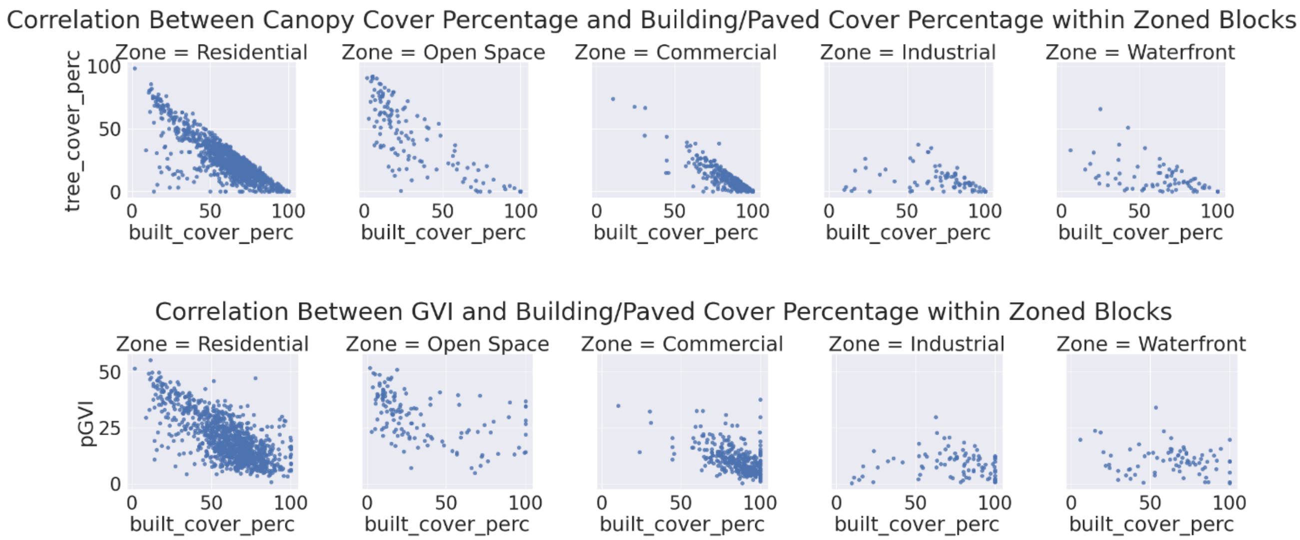



These plots further examine the relationship between GVI, tree canopy cover, and street tree inventory data. As the range of DBH data was very large in comparison to tree cover, I log transformed the DBH data for this set of plots. While there is a likelihood that private yard trees are being captured in the tree cover layer and contributing to GVI in a way that the DBH metric doesn't, there is a very strong positive correlation between DBH and GVI, topping out at around 20% GVI where it begins to flatten. Tree cover, on the other hand, has a more linear relationship that extends to higher GVI values. This may reflect the different rates of mortality between trees in front yards and in backyards, based on factors like soil conditions and space availability as it's affected by power lines and pavement versus backyard conditions. It's expected that trees growing in backyards may generally attain larger sizes, whereas trees growing in strips and tree pits in the ROW don't often survive that long.

As highlighted in the residential/commercial examples, the residential and commercial blocks do not typically share the same percentages of built coverage.

As this factor is negatively associated with both canopy cover and GVI, it's worth looking at how it differs in its influence across zoning district types.

*Figure 23*: GVI/Canopy Cover and Built Cover

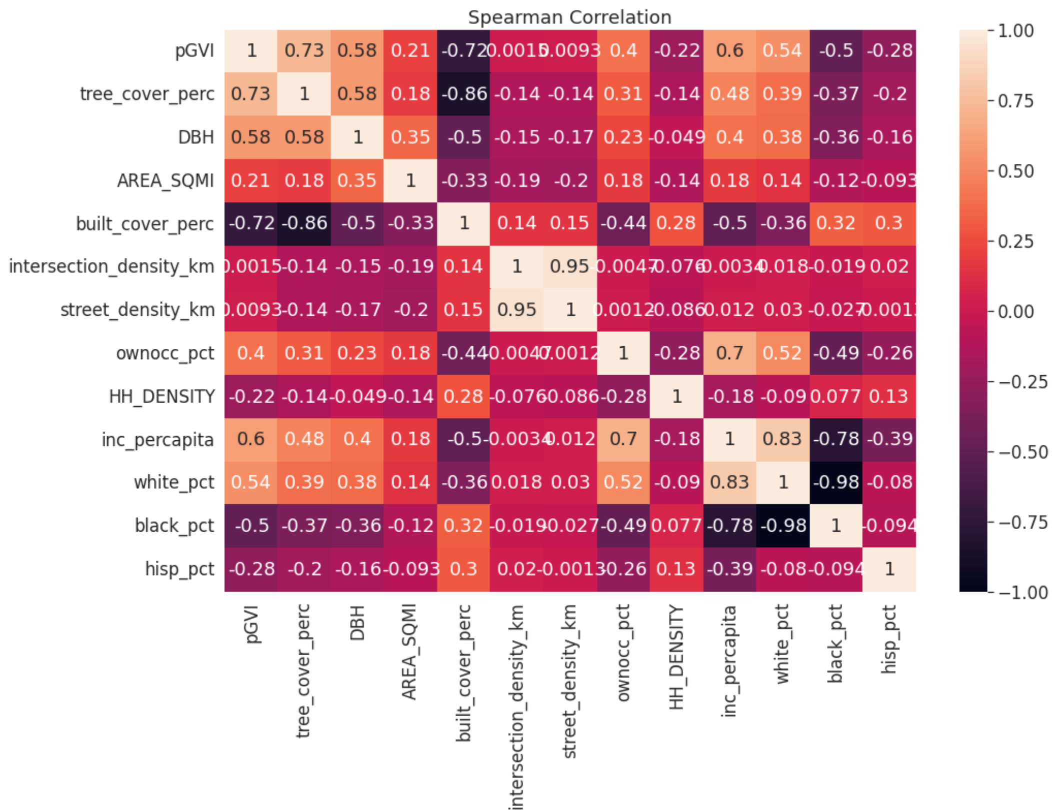



It appears that GVI is less influenced by built cover in the residential and commercial typologies. As tree cover and built cover come from the same data source a correlation is expected. The fact that GVI values that are high despite high built cover percentage is interesting. There also appear to be select blocks that retain GVI within nearly 100% built cover even where tree cover is close to zero. The occurrence of abandoned areas and the generation of woody species adjacent to these high built cover blocks may be more prevalent in commercial, industrial, and waterfront districts, but parks may account for those blocks in residential districts.

The in-between spaces, like these unmanaged spaces but also the forested buffers that elevate GVI for park and open space-adjacent blocks are a good example of how this measurement complements tree cover and tree inventories.

GVI quantifies what is often excluded by these other data sources, and at the same time connects them.

*Figure 24:* Residential Blocks Matrix



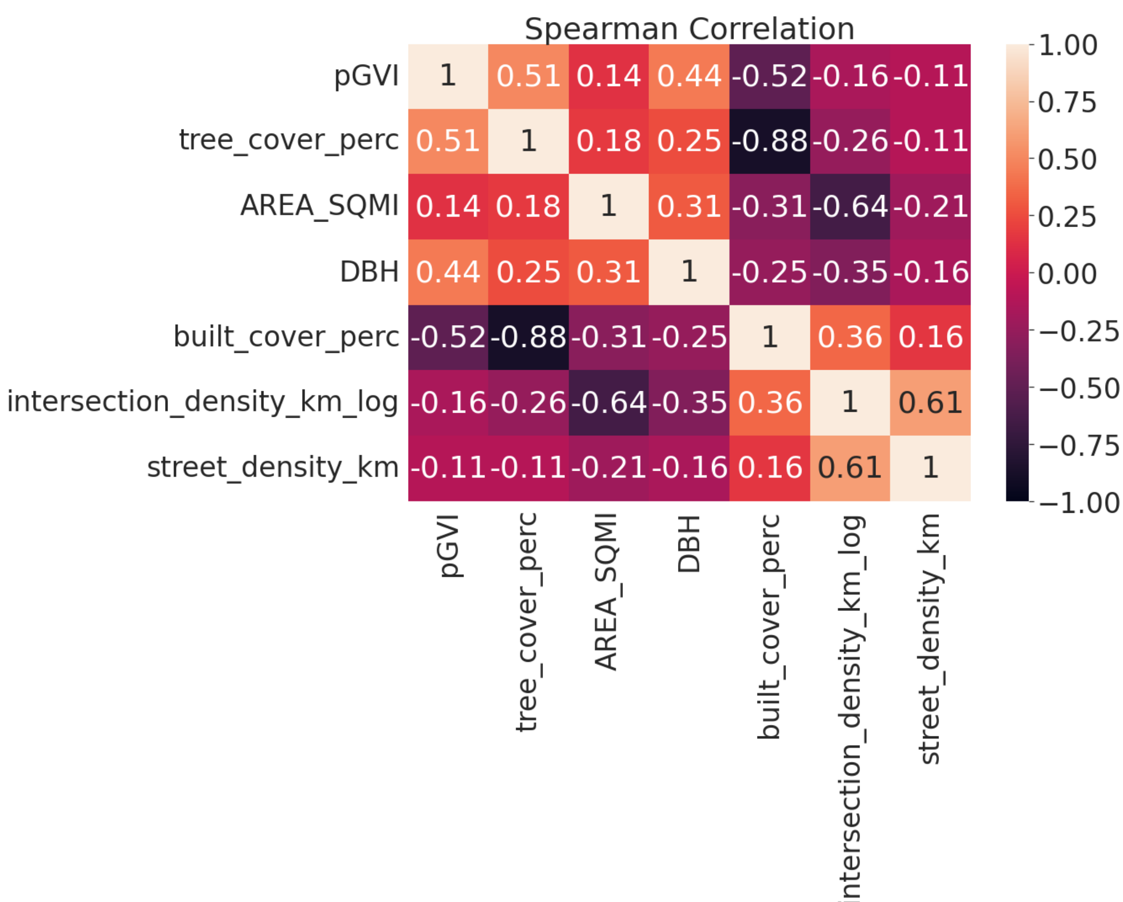

This matrix of Spearman correlation coefficients is measuring the monotonic association between all the non-nominal variables in our dataset for all residential blocks. While tree cover and DBH continue to be good predictors of GVI, and built cover an obstacle, a case can also be made for high-income, majority white blocks experiencing greater GVI than low-income, black majority blocks. Besides race and income, owner-occupied percentage also had a significant correlation with GVI, even moreso than with tree cover and DBH. While we typically gloss over the traditional aesthetic valuation of tree canopy, those values may be more represented in home-owners, invested in the property values, driving a likelihood of active tree stewardship. Cultivating a beautiful landscape that includes trees is still a popular pastime, and the connection between GVI and species should be an area of further study.

Another observation is the significance in other demographic factors as they correlate to GVI, tree cover, and DBH. Population density had a somewhat negative correlation with GVI, but still stronger than its effect on tree cover and DBH. Density and built cover were positively correlated, which may partially explain that damping effect on GVI, but by that logic, I would then expect a greater effect on tree cover. GVI and income per capita was the strongest correlation, positive or negative, and the high GVI values centered around high-income, detached single family home neighborhoods likely explains the strength of this association. White percentage and black percentage were nearly equally monotonic, except in different directions. As discussed above, there are many factors that determine residential distribution of white and black communities in Wilmington. Simply by looking at the tract map on Figure 13, we can see lower average GVI in the southeast and northeast, majority-black tracts, where factors like increased density and built cover contribute.

A hypothesis that could be explored is that GVI differentiates itself from tree cover and tree inventory values by being more responsive to demographic attributes and those variables related to racial distribution within Wilmington's housing. As I've seen in the highlighted differences between the three measures, GVI is the most strongly associated with the visible canopy and I could theorize that this dimension is more affected by change in investment and disinvestment.

The health and longevity of street trees or park trees depend on stewardship, which is highly dependent on the distribution of local resources. The successful maintenance of trees over time, through attention and accountability, is a difficult data point to capture, but GVI could provide a means to differentiate between positive and negative experiences in appearances over time. In addition, while intersection and street density did not measure very strong in any direction, further study could include pairing GVI points and the individual streets they were measured on to better understand the influence of street network structure.

Figure 25*: Commercial Blocks Matrix*




The incidence of trees in commercial districts is an understudied topic. While hedonistic pricing studies have been done on the cost of goods in treed commercial districts versus non-treed districts, the spatial characteristics of retail areas required a more detailed analysis than can be covered here. For this reason, I removed the census variables and ran the same analysis using only structural variables for commercial blocks. As seen in Figure 25, tree cover and DBH are also strong predictors of GVI. Built cover had less of an effect on GVI, which may point to less overall variability in GVI for this zone type. While this goes for residential blocks as well, further exploration into the configuration differences between the commercial zoning types could contribute to a stronger model for GVI in high usage, business districts. Intersection and street density did begin to show stronger association with GVI, tree cover, and DBH, but not by much. I thought that by removing the demographic variables, I could at least gain some understanding of what next steps might look like for understanding the different typologies of the commercial built environment.

For planners and business districts, issues like accessibility, walkability, parking, amenities, and green features are important in defining commercial areas and understanding how those factors influence GVI would complement this study. Based on this analysis, one key difference is that GVI is more strongly corelated with DBH than tree cover, which is not the case in residential districts. This makes sense, as commercial districts generally have a greater ratio of built cover, which lessens the effect of tree cover on GVI. In the following section, I'll discuss the potential applications of GVI to policy formulation and implementation.

# Chapter 6

## DISCUSSION

While the question of why certain blocks have a higher GVI than others is a much more complicated question than I was able to answer, I was able to establish this measurement as a useful complement to existing forms of canopy quantification. The availability of this data format hinges on monetization by private companies, but the ability to process and evaluate a large amount of data in a short amount of time makes GVI an accessible means of profiling trees through street view imagery. City managers are often working with limited resources, and the time and energies devoted to maintaining the tree inventory are a key input for urban forestry departments to operate properly. The collection and assessment of SVI could present an efficient way to complement certain kinds of assessments. For example, understanding the site history is an important component of a tree assessment. Typically, some institutional knowledge or surveys of homeowners of residents provide that history. With that said, the historical SVI able to be accessed through certain platforms, could compose a historical repository of tree images or GVI levels, used by the urban forester to understand current conditions better.

Being able to communicate urban forestry priorities and translate that into the effective use of resources for planting, hazard mitigation, and stewardship are ongoing challenges for the urban forest manager. Wilmington's creation of those resources have improved due to the efforts of the DCH and Wilmington's Urban Forest Administrator. Maintaining the tree inventory is key for responding to service requests and planning tree work, as is the interpretation of tree cover data for identifying changes in land use and tree canopy over the long term. Adding GVI analyses to these protocols could improve outreach efforts in terms of providing a visual context in conversations and planning processes that aim to create canopy goals for specific neighborhoods and communities. City agencies could utilize SVI to examine the built environment in a number of ways, and the incorporation of GVI as a pilot program for the Public Works Department could yield promising results. And in general, the accessibility to civic data is a related initiative that the city would need to embrace across the board. Allowing citizens to easily interact with data supports political engagement, but the development of tools that facilitate effective knowledge transfer and open data repositories can be challenging.[94]

One relevant planning tool is Complete Streets, utilized by over 120 municipalities to plan for and implement streets that are walkable, safe, and improve health and quality of life for users of all ages and abilities.[95] The

[94]Melissa Lee, Esteve Almirall, Jonathan Wareham. "Open Data and Civic Apps: First-Generation Failures, Second-Generation Improvements," 2016. https://dl.acm.org/doi/fullHtml/10.1145/2756542.
[95]Slotterback, C.S., Zerger, C., "Complete Streets from Policy to Project," 2013. http://www.dot.state.mn.us/research/TS/2013/201330.pdf.

associated concept of Woonerf streets or, “living yards”, includes the mixing of people, trees, cyclists, and cars in order to calm traffic and make them safer. As cities plan streets as green spaces for specific purposes and create urban forestry master plans, GVI could serve as a communicative metric between the two. The idea of “streets as parks” means that the qualities of tree canopy and accessibility take on unique characteristics, and GVI could be used to capture these unique street and tree specific interfaces.[96] Another example is the concept of “road diet”, whereby reducing lanes, widening sidewalks, adding bike lanes, and reducing speed limits, creates a more multimodal environment. In this context, augmenting these parameters with tree cover percentage or simply number of trees don’t seem sufficient in aligning tree canopy with these other goals. GVI, on the other hand, could provide very specific desired outcomes when it comes to the “complete” nature of tree canopy for a given project.

Tree ordinances are a policy sphere that often pertain to the health of single trees or the preservation of a ratio of forested land to developed land. By linking these policies to corresponding city-wide canopy goals, interests and values are aggregated over many different social and ecological boundaries. GVI provides an opportunity to disaggregate not just the geographical extent of tree canopy goals, but also perceptions and values. Cities could facilitate goal-setting conversations with residents and stakeholders using GVI as a means of reflecting where and how tree canopy might change for the better. Over the long-term,

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[96] Prager, By Todd. “Complete Streets for People...and Trees.” Arboricultural Consultant 53, no. 2 (2020): 17.

connecting policies like protection and canopy level ordinances to their actual outcomes needs to be better understood. A high-resolution, street level documentation of local trees could provide insights into the effects of policies and policy change over time.

Urban forestry master plans are multi-step processes that involved a sequence of understanding what exists, what is desirable, and what is needed to make those desires into reality. Once these measures are put into place, monitoring and evaluating results leads to corrective actions.[97] Both the inventory and evaluation stages benefit from up-to-date data and setting a baseline and updating SVI to evaluate changes to GVI could assist in defining this resource in a way that is understandable to the public. Soliciting public input can go in many directions, and one way to ensure requests can be accommodated by administrative capacity is to frame the question and answer in a way that is measurable. GVI allows the quantification of tree data in a novel but straightforward manner, in a way that might foster discussion and a shared language among planning participants.

My work presented here suggests the development of a GVI collection protocol that preserves the resolution and interpretability of the SVI data, so that long-term studies are feasible and repeatable. Furthermore, exploring the array of objects that can be segmented and therefore quantified within SVI, such as

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[97] Wisconsin Department of Natural Resources. "A Technical Guide to Developing Urban Forestry Strategic Plans Urban Forest Management Plans," 2011. https://dnr.wisconsin.gov/sites/default/files/topic/UrbanForests/UFPlanningGuide.pdf.

buildings, roads, sky-view, and other types of greenery, would provide additional insights that could be important for the decision-making processes of planners and policy makers. The ability to connect this resource to other administrative departments would support its usage, but also assist in developing the standards and methodologies that will improve the utility of SVI analysis on a practical level. This is not to say that this method can or should supplant the upkeep necessary for the tree inventory to function. The validity of tree inventory data will continue to support the development of GVI as an indicator of healthy urban canopy. The use of GVI in the planning and advocacy process is also an opportunity for further research. The potential to link GVI measured imagery to perceptions of the urban forest would be helpful in developing responsive plans for specific communities. I also hypothesize that integrating more structural variables related to road and sidewalk infrastructure would contribute to a fuller understanding of GVI.

Promoting street trees and their "ecological validity" or, their scientific legitimacy as contributors to sustainable urban landscapes, is the primary "struggle" of urban forest advocates.[98] The use of GVI to augment other forms of urban tree quantification provides a more comprehensive picture of how people experience and form their perceptions of trees. The non-economic and intangible value of trees matter and are often unincorporated at the operational level.[99]

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[98] Seamans, Georgia Norma Silvera. "The Ecological Street Tree: Mainstreaming the Production of Street Tree-Based Ecosystem Services in Northern California Cities, 1980-2008." University of California, Berkeley, 2010.
[99] Gómez-baggethun, Erik, and David N Barton. "Classifying and Valuing Ecosystem Services for Urban Planning."

Greening advocates risk overrepresenting tree benefits and ignoring “the trade-offs that are necessary to prioritise some benefits over others.”[100] Traditional modes of tree measurement would benefit in their ability to incorporate a more holistic view of the cultural values and corresponding ecosystem services that are identified in qualitative studies and surveys.

A volunteer tree steward I have worked with in the past was more bricklayer than tree planter. His greening efforts took place in a historic district, with sidewalks made of well-worn red bricks. Their lustre and charm were often broken up by large tree roots, rising towards the surface. I credit his success in getting permission from dozens of homeowners to plant trees, to his meticulous attention to relaying bricks once the planting was completed. People wanted trees, but they also wanted the entire scene to be set. Avoiding the issue would have been easier on his back, but I believe far fewer people would have agreed to help grow the city’s tree canopy. In this way, the effectiveness of tree advocates and city managers in protecting and distributing tree canopy relies on the public support of trees. The more our inquiries and justifications for the use of public resources come to include the lived experiences of people under the canopy, the more likely trees are also to be heard.

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[100] Moffat, Andy J. “Communicating the Benefits of Urban Trees: A Critical Review.” *Arboricultural Journal* 1375 (2016): 1–19. https://doi.org/10.1080/03071375.2016.1163111.