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Trees Take the Streets: Urban Tree Growth and Hazard Potential

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Abstract

Urban forestry is the science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society. As urbanization rapidly increases, so does urban forestry. Although increasing the number of trees in urban environments can be beneficial to human residents, trees in urban environments can also become hazardous if improperly trimmed, located, and cared for. For example, human-induced pruning via side trimming compromises tree branch structural integrity. This study investigates whether the phenomenon of side pruning can be brought about naturally by specific combinations of tree aspect relative to the tree's nearest building and nearest building height. Measuring trees in a predominantly commercial neighborhood in the Northern hemisphere, we found that trees on the south side of buildings (those which receive the most sunlight) have a greater proportion of branch diameter comprised of far branches and naturally mimic a possibly dangerous side-pruned shape. Nearest building height did not impact branch growth patterns. Therefore, trees planted on the south side of buildings have a higher potential to become hazardous, due to naturally induced asymmetrical branch growth, and thus should be monitored more closely for hazard potential.

Introduction

The world is urbanizing faster than ever before. It is projected that the amount of land converted to urban environments will double between 2010 and 2060 in the United States alone (Nowak 2018). As urbanization rapidly increases, urban forestry also continues to rise, making the relationship between industry, humans, and urban trees closer than ever. Moreover, humans benefit greatly from urban forestry, especially in terms of both physical and mental health (Ulmer et al. 2016). Studies to further the understanding of how urbanization affects trees are vital to adequate tree growth and survival, as well as to optimum human health and well-being. However, the rise in urban forestry can also pose serious threats to humans and urban structures in the form of hazardous trees (Pokorny 1992). For the purposes of this essay, a hazardous tree is defined as a tree whose lack of structural integrity poses risk to people and property. Hazardous trees can occur under various circumstances; for example, improper pruning of trees can lead to structurally unsound branch formations (Pokorny 1992). Trees that have been pruned in a side-trimmed formation particularly lack structural integrity (Figure 1) (Bartlett Tree Experts 2016). This stems from the fact that uneven branch distribution around the tree central axis, or the trunk, leads to uneven weight distribution. This creates stress and can cause potential trunk or branch breakage.

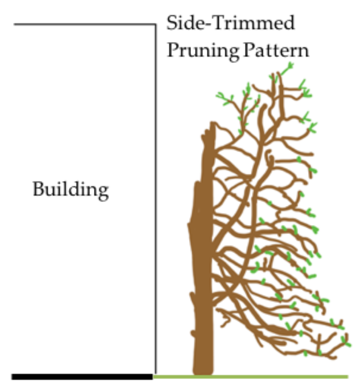

Figure 1 A schematic depicting the phenomenon of pruning a tree to be side-trimmed. Side-trimmed trees are more susceptible to decreased structural integrity leading to them being potentially hazardous.

Studies show that increasing urbanization poses challenges to tree growth and health. These studies have found that polluted soil, poor soil quality, heat stress, and numerous impervious surfaces are all urban factors that negatively affect trees (Jim 1998, Mullaney 2015). Studies also show that trees will change their whole body-shape in response to sunlight availability (Loehle 1986). Trees exhibit phototropism, a plant's affinity to grow towards sunlight. Less shade-tolerant trees exhibit higher levels of positive phototropism (Loehle 1986). Additionally, some trees in lower light conditions put more energy into branch growth than those with access to more light (King 1997). While it is known that trees will grow towards sunlight when they become shaded, few studies have analyzed the variation that urban pressures pose on tree branch growth. More explicitly, there has been little research analyzing the impact of tall buildings on sun availability for trees.

Planting trees that are properly suited for their surrounding urban environments is of increasing importance. Therefore, we hypothesize that this side-trimmed formation can occur not only as a result of intentional, improper pruning but also as a result of trees placed in incompatible urban environments that cause them to naturally grow into the side-trimmed shape. Ultimately, this research seeks to maximize the benefits of urban forestry by laying the groundwork for which environmental conditions may help avoid potential safety hazards that incompatible trees pose to urban residents.

In our preliminary observations, we found that trees located next to buildings in commercial neighborhoods had a lower percentage of their branches facing the nearest buildings than those in residential neighborhoods. These observations and results led researchers to test which building characteristics and tree placements are best suited for non-hazardous growth. Our study sought to a) determine the relationship between tree aspect (the compass direction a slope faces) relative to the building and the percentage of branch diameter comprised of far branches, and b) determine the relationship between the nearest building height and the percentage of branch diameter comprised of branches furthest from the trunk.

We hypothesized that a) trees to the north and east of their closest buildings will have a higher percentage of far branches that make up their diameters than trees to the west and south. We predicted that in urban environments, buildings behave similarly to hills. In the Northern hemisphere, trees with south and west aspects receive the most solar radiation during their growing season. Thus, a tree on the north side of a building is the equivalent of a tree on the north side of a slope and is therefore in shade for most of the day. If it is on the east side, the tree receives morning sun but is in the shade in the afternoon and evening. Therefore, our prediction stated that trees located north and east of buildings direct energy from their limited sunlight to grow longer branches away from the building in search of more sunlight, creating a natural side-trimmed shape (Loehle 1986).

We also hypothesized that b) trees near taller buildings will have a higher percentage of far branches that make up their diameter than trees near shorter buildings. This is because trees near taller buildings will be in the shade of the building for longer parts of the day and thus grow outwards away from the building seeking sunlight.

Methods

Study Area

Our study area was 52 blocks in Capitol Hill, a predominantly commercial urban neighborhood in Seattle, Washington (Figure 2). Seattle is a densely populated urban environment that has experienced rapid growth within the last decade (US Census Bureau 2019). Paralleling this increase in growth has been an increase in sustainability and urban forestry within this green city. The effects of compatible tree placement are tremendously pertinent to this area type. The Capitol Hill area is one of the longest-standing urban areas of the Seattle city center; therefore, if urban forestry patterns are present they will likely be exhibited in this neighborhood.

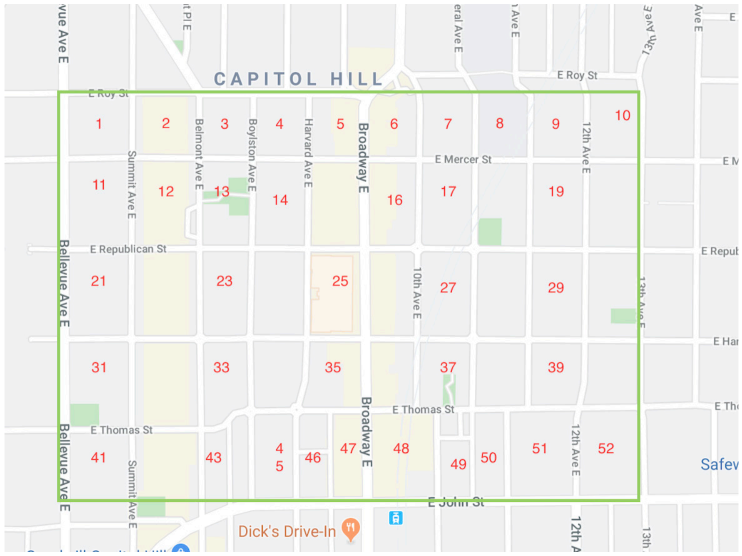

Figure 2 Our study area consisted of 52 blocks in the predominantly commercial urban neighborhood of Capitol Hill in Seattle, Washington. Capitol Hill is one of the oldest neighborhoods in Seattle with some of the oldest trees, and any tree growth patterns connected to urban development are likely to be exhibited there.

Field Methods

We collected data for our observational study in November, 2019 across multiple sampling days. We collected data each sampling session between the hours of 1:30 pm and 5:30 pm. We sampled 89 trees using random non-replacement sampling, having at least 20 trees sampled for each cardinal aspect direction. More specifically, we selected the cardinal direction, or the side of the block sampled, and used a random number generator to select which of the 52 blocks we would measure for that cardinal direction. If the same side of a particular block was selected twice, we would select again so as to not sample the same side of the same block twice. Sites like alleyways or garage ports which did not have any trees were considered unfit for sampling and were discarded. Then, when sampling trees on the selected block side, we used a random number generator to determine if we were sampling every other even or odd tree. Occasionally a tree would grow on private property or be over 5 m from the nearest building and thus could not be sampled. We included this tree when counting the trees on the block to maintain the randomness of the study, however we did not include this data for analysis. Moreover, if all the trees on the block were over 5 m from a building or grew on private property, a new block was randomly chosen to be sampled using the same process outlined above.

In order to measure the tree-to-buildings aspect, defined as the cardinal degree of the tree while facing its nearest building, we stood next to the trunk directly facing the closest building. Then, using a compass, we measured the aspect in degrees. We divided aspect into four quadrants: north buildings relative to the tree falling between 316°and 45°, east buildings relative to the tree falling between 46° and 135°, south buildings relative to the tree falling between 136° and 225° and west buildings relative to the tree falling between 226° and 316°. In order to measure building height, we counted the number of stories in the building. In order to measure whether a branch was near or far, we measured from the center of the trunk; near branches started on the half of the trunk closer to the building and far branches started on the half of the trunk closer to the street. In order to measure the radius of the near or far branches, we used a tape measure starting at the center of the trunk and measured outward, in meters, to the farthest tip of a branch. In some cases, an overhang or balcony protruded out of the building and ended between the building wall and the tree trunk. In these cases, we measured to the longest near branch despite it possibly being obstructed from view by the overhang.

In this study, we have controlled for season and neighborhood by sampling predominantly commercial trees during the same month of fall. Although we did not control for tree species, our large sample size should have negated this possible confounding variable. A potential limitation to our methods was our inability to access potential data related to construction in the vicinity of our samples. Possible construction could have impacted branch growth patterns.

Data Analysis

We conducted an ANOVA to compare the mean percentage of the branch diameter composed of far branches. We also conducted a linear regression to determine the relationship between the number of stories in the nearest building and the percentage of the branch diameter composed of far branches (R Core Team 2019).

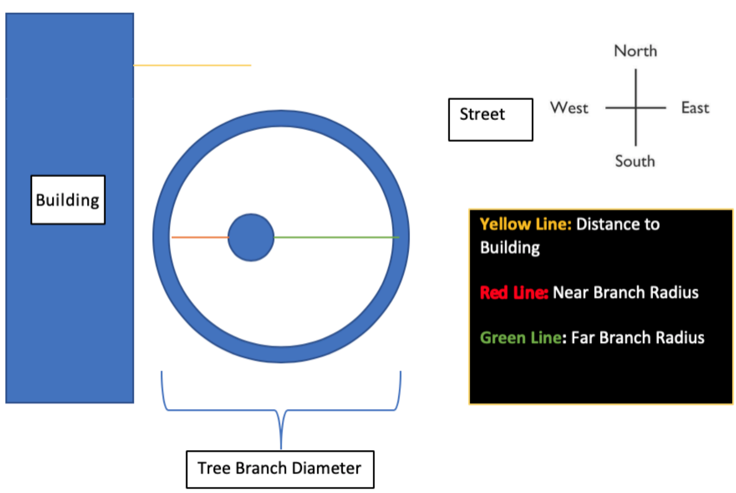

Figure 3 This figure is a visual presentation of the common definitions used throughout this report.

Results

We measured 89 trees covering all four tree aspect directions relative to their closest building: north, east, south, and west. The tree's aspect relative to the building has a significant effect on the percentage of far branches comprising the tree's diameter (Figure 4). However, there is only a significant difference in the mean far branch percentage between trees with south and north aspects relative to their buildings. Mean, denoted by μ, describes an average, in this case the average percentage of branches that comprise the trees' diameters on north blocks versus south blocks. P-value, denoted as *P*=, describes the likelihood an observation occurred by random chance; a low p-value, usually less than *P*=0.05, describes a low likelihood of results occurring by random chance and thus a high probability that the results describe a nonrandom pattern in nature. Thus, after comparing all experimental conditions and calculating the respective P-values, the relationship between average percentage of far branch radii for trees with south aspects and the average percentage of far branch radii for trees with north aspects is likely nonrandom. Therefore, these results present a possible trend in the natural growth of trees with slopes facing north versus south. (south μ= 76.27%, north μ=64.86%, *P*=.03, F_3=3.06)(Figure 4*)* Other relationships were not significant (Table 1).

Our results correlating the far branch percentage and near building story height were significant, although the overall relationship was positive and weak. While this trend in the data is supported by a low P-value, there is no correlation between nearest building story height and percentage of far branches comprising the branch diameter, as measured by the R^2 value. (*P*= 2^{-16*}, R^2= .03, F_{87}=13.78). An R^2 measures the proportion in variation in the dependent variable that can be explained by pressures inflicted by the independent variable—a low R^2 value can be interpreted as a low likelihood that the changes in the independent variable effect the changes in the dependent variable. In this case, the low R^2 value can be interpreted as the nearest building story height having low likelihood of relating to the percentage of far branches comprising the branch diameter (Figure 5).

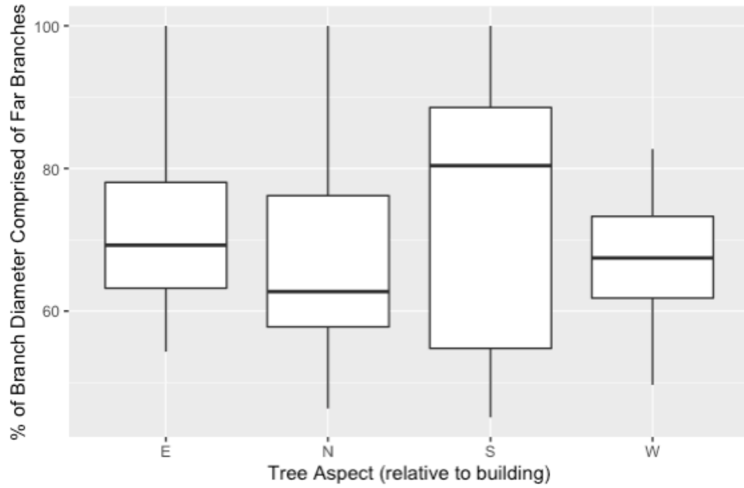

Figure 4 The relationship between the percentage of branch diameter comprised of far branches and tree aspect relative to its nearest building for trees in Capitol Hill, Seattle, WA. Our measurements were collected in November, 2019. Results are statistically significant (*P*=.03*, F_3=3.06).

Possible Tree Orientation Combinations	P value
N-E	0.34
S-E	0.66
W-E	0.72
S-N	0.03*
W-N	0.93
W-S	0.14

Table 1 The statistical significance of each tree aspect combination. It includes the results for a Tukey's multivariate test, from which p-values were determined. Results are that *P*<.05 are statistically significant.

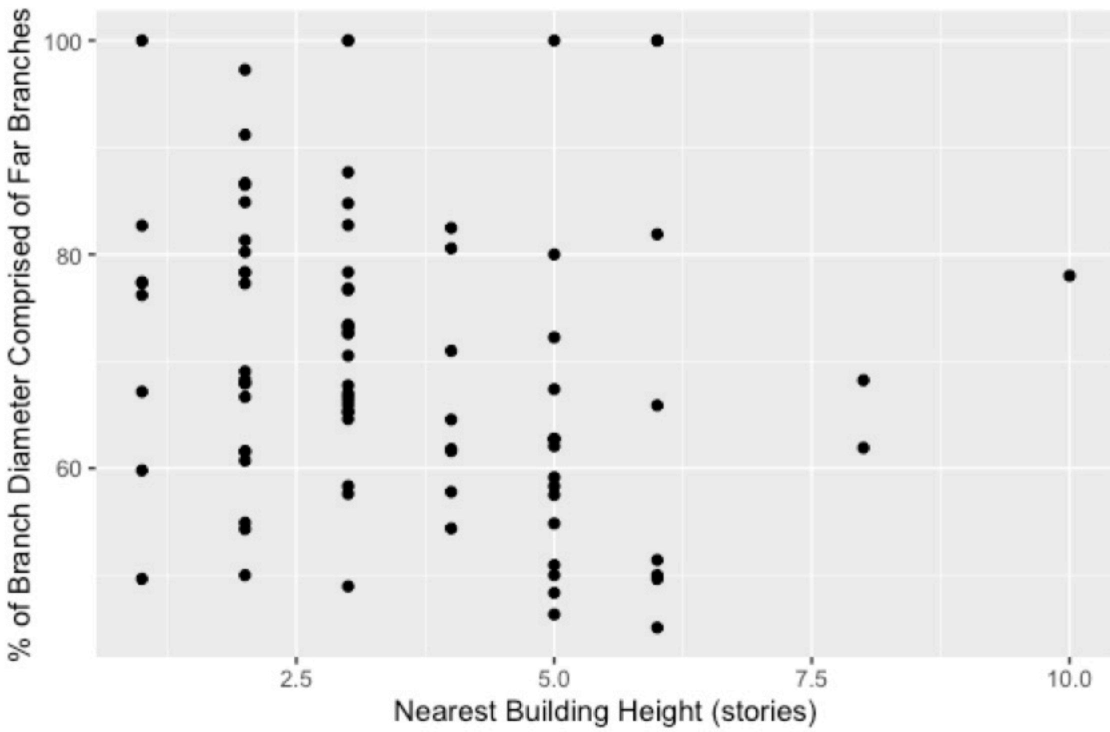

Figure 5 The relationship between the percentage of branch diameter comprised of far branches and the height of the tree's nearest building for trees in Capitol Hill, Seattle, WA. Our measurements were collected in November, 2019. There is a significant weak positive relationship between the two variables ($P = 2^{-16*}$, $R^2 = .03$, $F_{87} = 13.78$).

Discussion

Ultimately, we found that there is only statistically significant evidence for the relationship between trees with south aspects versus trees with north aspects and percentage of branch diameter comprised of far branches (Figure 4). Thus, the hypothesis that a) trees to the north and east of their closest building will have a higher percentage of far branches that make up their diameter than trees to the west and south of their buildings, was incorrect. Our data claims nothing statistically significant regarding relationships between any other direction combination.

Similarly, we found that there is no correlation between far branch percentage and the height of the nearest building. Thus our hypothesis that b) trees nearest taller buildings will have a higher percentage of far branches that make up their diameter than trees nearest shorter buildings, was incorrect. Given that both hypotheses were opposite to our results, our assumptions as to how urban buildings affect tree branch growth were likely incorrect. However, it is possible that components of the mechanisms by which we made these assumptions, like sun and shade, are still impacting tree branch growth.

Initially, both of our hypotheses predicted that branches would be pressured to grow towards sunlight. We believed that because our samples were collected from trees in the Northern Hemisphere, the west- and south-facing trees receive the most solar radiation during their growing season, and north- and east-facing trees are mostly in the shade, causing them to grow their far branches in search of sunlight. This could still be true. However, since near branch radius was more or less controlled (<5m), the far branches were the only ones experiencing high variability. Thus, trees with south aspects that received sunlight grew their branches out, away from the building, as they captured the increased energy to do so. The trees with north aspects that were more shaded and received less sunlight did not have as much energy to put into branch growth (Rincon and Huante 1993). This could explain the reduction in far branch percentage we saw in trees with north aspects.

Furthermore, our data did not reflect our predictions about far branch percentage and the height of the nearest building to the tree. Specifically, trees nearest buildings under two stories still retained very high far branch percentages (Figure 5). Moreover, no trees nearest buildings over seven stories had over 80% of their tree branch diameter comprised of far branches. This leads us to believe that the length of the building's shadow is less significant than the tree's aspect relative to the building. Trees may spend little time in large shadows without impacted growth patterns. Instead, the amount of time the tree spends in the sun due to the aspect of the tree to its closest building most likely has a greater impact on tree branch growth patterns, regardless of how large it is (King 1997).

The trends exhibited still pose urban health hazards. First, longer branch growth into streets continues to impact urban environments, though simply on trees with a south aspect rather than north. The further the branch grows away from its attachment site, the greater the stress exhibited on that attachment site, increasing the potential for breakage, especially in extreme weather conditions (Bartlett Tree Experts 2016). Furthermore, the longer the far branch, the higher percentage of the branch that is likely to cover people, property, and traffic. Additionally, the greater the far branch percentage that makes up the tree's branch diameter, the less efficient the counter balance is on the other side, heightening the chance for branch abnormalities that undermine structural integrity (Bartlett Tree Experts 2016).

There are also ways that trees can be considered hazardous but not of immediate physical threat; for example, the rise of trees in urban areas is an early symptom of gentrification (Bataglia et al. 2014). While there are no studies to show urban-tree planting can cause gentrification, large scale tree planting goals are often associated with broad, green infrastructure projects that increase the cost of owning and renting property in the surrounding area. For example, a study in Portland, Oregon, a city of comparable size and age to Seattle with similar seasonal sunlight patterns, found that tree planting is associated with neighborhood-level gentrification, although the magnitude of the association was small, and increased with tree age (Donavan et al. 2021).

Thus, accounting for tree growth patterns may also impact the cost of tree upkeep and make trees more accessible in low-income neighborhoods of urban environments. Our study predicts that trees with south aspects will grow further into street traffic and problematize urban development, thus requiring greater upkeep. In order to make urban infrastructure and trees accessible to low-income neighborhoods in the Northern Hemisphere, we advise planting trees with north aspects, as they will likely require less upkeep and are less likely to cause potential hazards. Trees with south aspects relative to buildings should be planted an appropriate distance from the building to accommodate symmetrical branch growth and account for these trends.

Future research may focus on urban trees with variant levels of shade tolerance and responses to urban pressures. Additional work could also focus on obtaining records of hazardous trees in urban environments to analyze their respective aspects. This would broaden sample size and also bridge the link between the potential for trees to become hazardous and actual hazardous trees. Another area of study regarding the hazard potential of trees would be to test for the structural integrity of a branch by assessing the strength of its attachment point. These research approaches will continue the conversation started in this study and continue to maximize the benefits of urban forestry by understanding the environmental conditions that may help urban planners avoid potential safety hazards that incompatible trees pose to urban residents. Hopefully, trees with less hazard potential will require less upkeep and in turn provide equitable access to trees in all urban areas.

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