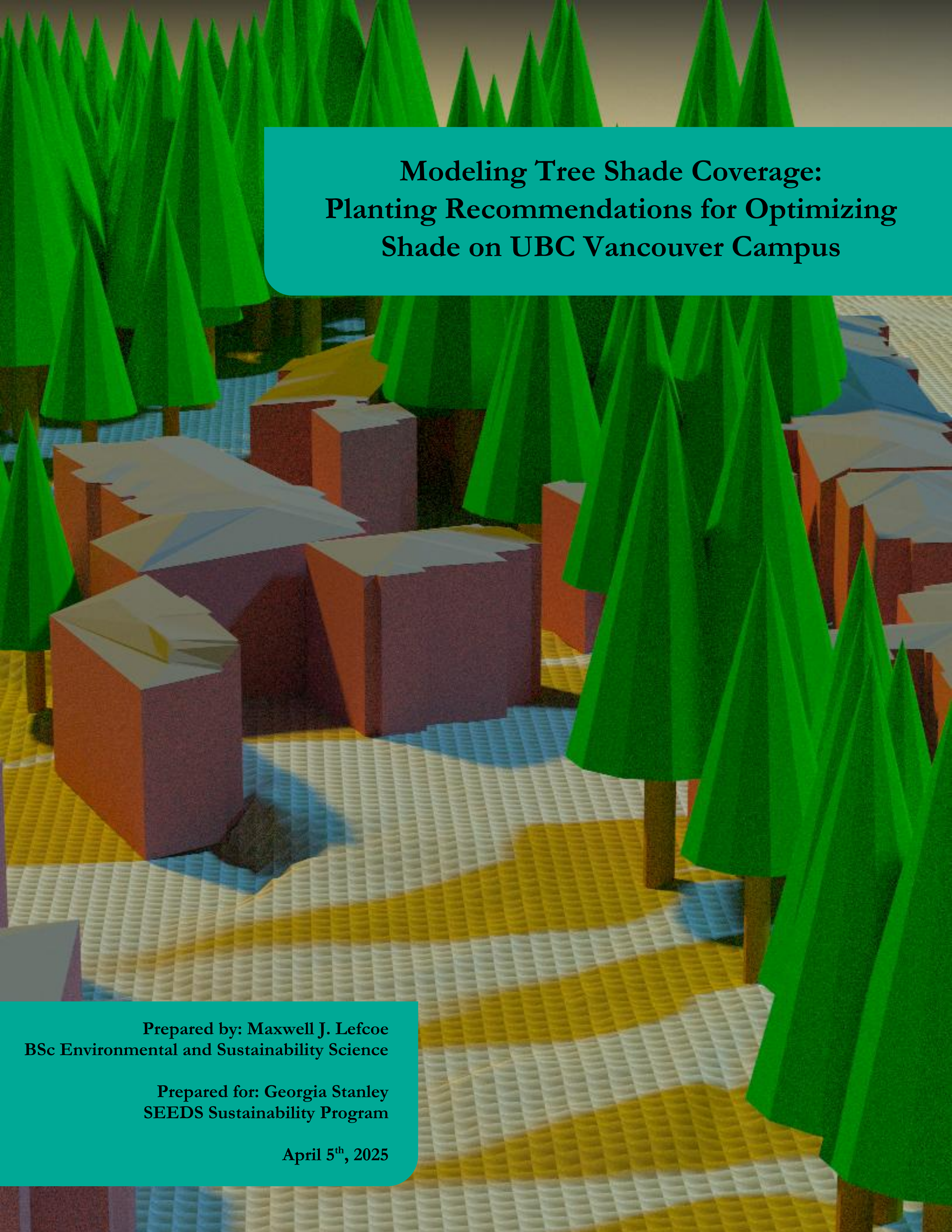

Modeling Tree Shade Coverage: Planting Recommendations for Optimizing Shade on UBC Vancouver Campus

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April 5th, 2025

This study takes place on the University of British Columbia's Vancouver Campus, located in the ancestral unceded territory of the xʷməθkʷəy̓əm (Musqueam) People. We acknowledge the traditions and culture of the Musqueam and all other Indigenous Peoples who have long been the stewards of this land. We are grateful for the opportunity to conduct research in the Forest Sciences Centre in Vancouver.

Executive Summary

Tree shade in urban environments serves to improve human thermal comfort and building energy use during the summer months. Under future climates, tree shade becomes an even more important ecosystem service that promotes climate change resilience. Tree shade was modelled in order to optimize shade coverage on UBC Vancouver campus by providing recommendations for tree planting based on species and planting configuration. Using LiDAR point clouds of 463 individual trees from species considered resilient to climate change, median normalized shade area per species was modelled over the course of one day. Furthermore, the total tree shade for each neighbourhood on campus was modelled using the same LiDAR dataset in order to determine which planting configurations most effectively shaded buildings. The planting configurations of neighbourhoods with a higher percentage of total tree shade falling on buildings were examined in order to provide recommendations for future planting efforts. Deodar cedar and black pine were observed to provide the highest normalized median shaded area, and are recommended for planting in order to promote climate change resilience and shade cover on UBC campus. University Boulevard and Chancellor Place were found to be the neighbourhoods with the most efficient planting configurations for the purpose of shading buildings. This was due to trees planted in thin belts along the south-west and south-east faces of buildings, maximizing individual shade contributions from each tree along the sun-facing side of each building. This tree planting configuration is recommended for the optimal shading of important targets on UBC campus, especially when resources are limited and must be properly allocated.

Keywords: LiDAR, Shade, Trees, Sustainability, Urban Forestry, Planning, 3D Modeling

Table of Contents

1. Introduction

In the face of rising temperatures due to climate change, tree shade can be used as a method to maintain comfortable temperatures for humans living in urban environments. Street trees can lower surrounding air temperatures by up to 7ºC (Armson et al., 2013), simply due to consistent shade and evapotranspiration. These lowered temperatures have a direct effect on the quality of life in urban neighborhoods, and can lower the energy consumption of nearby shaded buildings by reducing their use of air conditioning (Pandit & Laband, 2010). In order to combat climate change and its adverse effects, the University of British Columbia (UBC) is implementing the Neighbourhood Climate Action Plan (NCAP). The NCAP outlines a plan to reach net zero emissions in UBC neighbourhoods by 2050, while fostering climate change resilience and ecosystem services (Campus & Community Planning, 2024). The planting of trees around UBC Vancouver campus is included in this plan as a nature-based solution to climate change. Climate resilient plantings that can promote shade coverage and mitigate the Urban Heat Island effect are prioritized in the NCAP. The goal is to maximize shade coverage, while examining the potential cooling benefits such as human thermal comfort and reduced building energy use. This study provides recommendations for optimal tree planting on UBC Vancouver campus that maximize shade area and efficiency.

Despite the well documented benefits of tree shade in urban environments and methods of determining potential shade coverage, specific recommendations for tree planting based on shade are not readily available. Previous studies and projects include shade frequency maps outlining which areas in UBC residential neighborhoods are unshaded and in need of street trees (Wang, 2024), and an analysis on tree stand composition's effect on urban cooling (Xu, 2023). These resources provide methods of quantifying tree shade and a general guide as to where on UBC campus tree shade is most needed. Now, building upon previous research, this study aims to determine which tree species and planting configurations can maximize shade coverage by modeling shade at the individual tree and neighbourhood levels.

Compared to shade frequency mapping and general shade coverage estimations, shade mapping using detailed three-dimensional models allows for more specific recommendations on tree planting that optimize the cooling benefits of trees. Three-dimensional models were created from LiDAR data in order to isolate the amount of tree shade cast by individual trees of unique species. Tree species selection was based not only on shade coverage offered but also resilience to the effects of climate change. Using a similar method, tree planting configuration was compared between neighbourhoods by assessing how efficiently trees can shade important targets such as buildings. Tree species are determined to be climate resilient if they can "tolerate a broad range of sites under future climate" (metrovancouver, n.d.). Species such as black pine, pacific madrone, and gingko biloba fall into this category.

2. Data and Study Site Summary

2.1 Study area

The study will target the residential neighbourhoods on the University of British Columbia Vancouver campus (Fig. 1). These lands are designated for non-institutional uses and have been providing housing, amenities, and services for UBC and the broader community. UBC Vancouver campus is located within the Coastal Western Hemlock zone, a biogeoclimatic zone along the coast of BC (Government of British Columbia, 2024). The climate has one of the highest precipitation rates in all of Canada and is the wettest zone in all of BC with a mean annual precipitation 2200 mm (Centre for Forest Conservation Genetics, n.d.). It is characterized by its highly productive forests and mild climate, with a mean annual temperature of 5.5ºC. The most dominant species is of course western hemlock, followed by western redcedar and douglas-fir. Other common species on UBC campus include northern red oak and Norway maple.

Average summer temperatures in the metro Vancouver area are expected to rise by 3.7 ºC by 2050 due to climate change, potentially resulting in the loss of the temperate climate expected in the CWH biogeoclimatic zone (University of British Columbia, 2023). This means hotter temperatures and dryer summers impacting ecosystem services and human thermal comfort throughout the entire region.

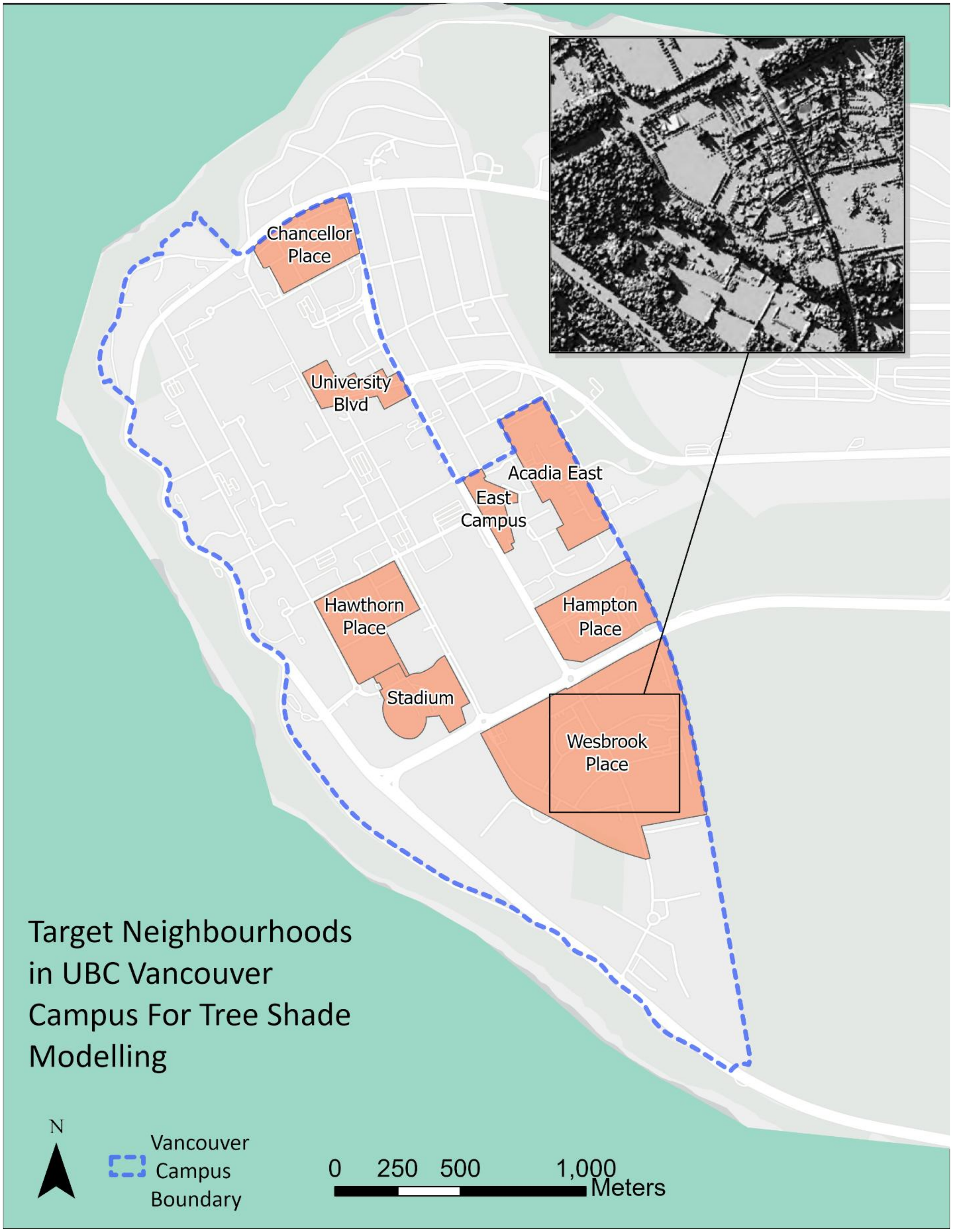

Figure 1: The study area, neighbourhoods present within UBC Vancouver campus, derived from the UBC Vancouver geospatial online database (University of British Columbia, 2024). An inset map provides an example of tree shade present within Wesbrook Place neighbourhood.

2.2 Data Summary

2.2.1 LiDAR

LiDAR (Light Detection and Ranging) is a remote sensing tool that in essence consists of a transmitter and a receiver. The transmitter is a laser that emits several light pulses in rapid succession, which are then reflected back to the receiver. By analyzing the intensity of the signal and the time elapsed between transmission and reception, the elevation of the feature hit by a light pulse can be determined (Wandinger, 2005). The receiver can also select for specific wavelengths or polarization states in order to classify surface types. The LiDAR system is often flown on an aircraft, although ground-based LiDAR also exists. LiDAR has a wide variety of applications including forestry, urban planning, ecology and archaeology. The LiDAR data used in this study is taken from the city of Vancouver's 2022 LiDAR dataset (City of Vancouver, 2022), which covers both Vancouver and the UBC Endowment Lands with a total area of 134 kilometers squared. The LiDAR was flown on September 7th and 9th, 2022, and has an average density of 49 points per square meter with a vertical accuracy of 0.081 meters. All point data was classified into 8 separate surfaces: (1) Unclassified, (2) Bare earth and low grass, (3) Vegetation shorter than 2 meters, (4) Vegetation taller than 2 meters, (5) Water, (6) Buildings, (7) Other and (8) Noise. 14 of the 181 available tiles can be used to cover the study area containing all of UBC Vancouver campus.

LiDAR is often used in forestry for its ability to provide high-quality data on three-dimensional properties like elevation (Akay et al., 2009). Often this is represented in the form of Digital Elevation Model, from which hillshade, slope, and aspect can be derived. LiDAR has been particularly useful in urban settings to detect and isolate individual trees (Münzinger et al., 2022), allowing for three-dimensional representations of tree structure such as crown shape. This capacity for structural analysis of individual trees makes LiDAR ideal for evaluating shade in an urban setting.

2.2.2 Sun Position Data

Data on the position of the sun is necessary for shade simulation. Sun position data is available from SunCalc, an independent, open-source package for R (Thieurmel, 2025). The times and positions are mathematically modelled, approximating the rising and setting of the sun to within 1 or 2 minutes of the actual values. For our purposes, this dataset describes the sun's position over Vancouver, BC in a sequence of time steps over a given time interval by providing:

1. The solar altitude: The vertical angle representing the height of the sun above the horizon
2. The solar azimuth: The horizontal angle representing the direction of the sun's rays

With this information, the length and orientation of a shadow cast by a given tree can be calculated for a given time.

3. Methods

In order to assess which tree species and planting configurations can be used by planners to optimize shade cover on UBC Vancouver campus, LiDAR point clouds and sun position data were used to model tree shade over time (Fig. 2).

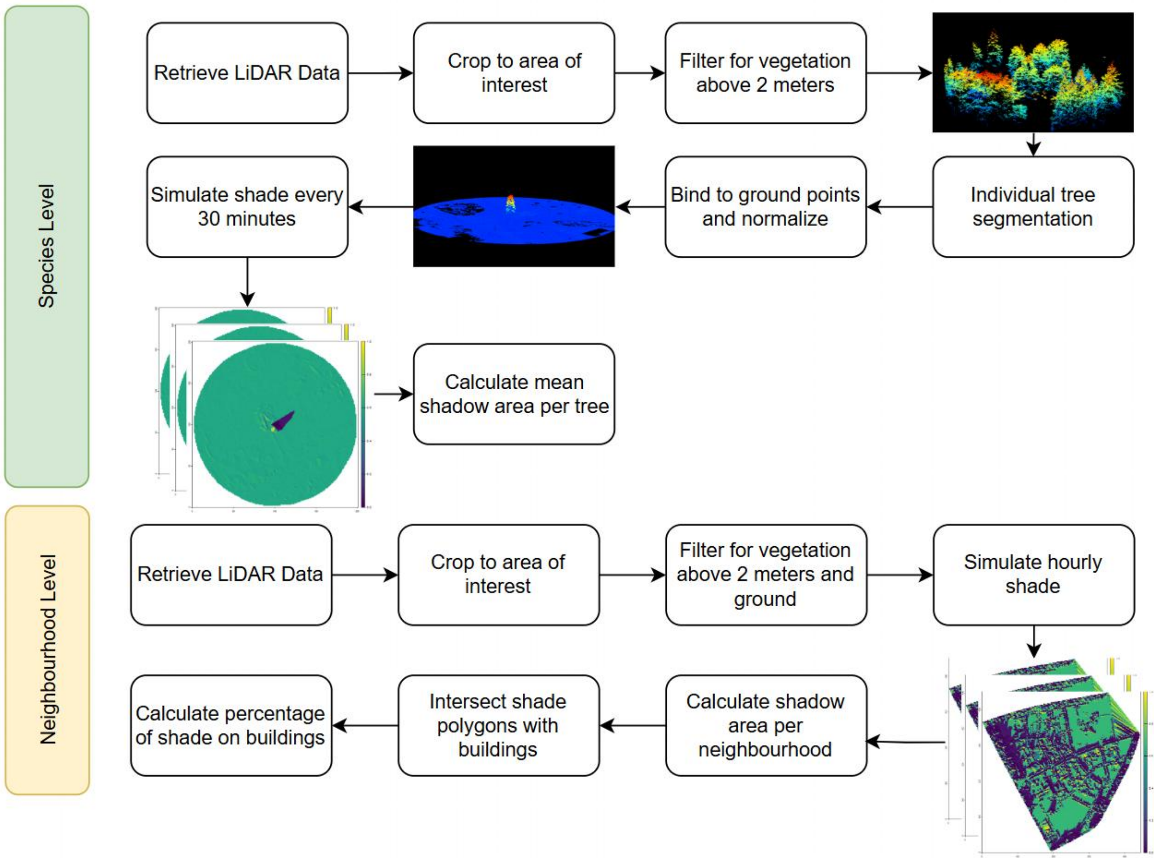

Figure 2: Generalized methods used to analyze species and neighbourhood level tree shade on UBC Vancouver campus.

3.1 Modeling species level tree shade

Previous studies mapping the shade coverage across UBC Vancouver campus (Wang, 2024) made use of a Digital Surface Model (DSM) at a 1-meter resolution in order to calculate hillshade at a campus-wide scale. This allowed for the identification of areas in need of better shade coverage. This study aims to inform planners on what tree species to plant, and how to plant them in order to maximize efficient shade coverage in those areas. Airborne LiDAR was used to generate DSMs for regions of interest at a 0.5-meter resolution. This finer resolution was required in order to represent shade dynamics at an individual tree scale. While ground-based LiDAR would allow for more accurate three-dimensional representations of trees (Rosskopf et al., 2017), it would render the results of the analysis difficult to reproduce due to cost and accessibility. Ground-based LiDAR would not be as easily applicable across large areas, and the added detail of exact leaf shape and canopy structure would not affect the results of this study which only takes into account overall canopy shape.

First, LiDAR data covering the whole of UBC campus was clipped to 764 areas of interest containing climate resilient tree species, and further filtered to contain only trees of interest. Trees with crown area smaller than the 25th percentile or larger than the 90th percentile for a given species were filtered out in order to account for either juvenile trees and/or failed segmentations of the point cloud. The data was further filtered to remove tree species with less observations than the 65th percentile of total observations, resulting in a final total of 463 trees analyzed. The 65th percentile was chosen due to the high number of species with only a single observation. A shade simulation was run in 30-minute intervals over the hottest day on record from the previous year, July 17th 2024 (Environment and Climate Change Canada, 2024). This involved calculating sun positions using the R package SunCalc (Thieurmel, 2025), providing solar altitude and azimuth every 30 minutes. The 463 point clouds of individual trees were interpolated using a pit-free algorithm to create Canopy Height Models (CHM) at a 0.5-meter resolution that served as elevation matrices, which were then modelled for shade using the solar position data to provide light direction. The resulting raster files were reclassified in order to extract the area of the shadow cast by each tree at each time interval, which allowed for the mean daily shade provided by individual trees to be calculated. Daily means were normalized by tree height in order to account for the relation between height and shade cover, leaving only the effect of canopy shape to be analyzed.

Once tree shade had been modeled, tree shade hotspots on UBC Vancouver campus were found by interpolating tree height and mean shade area per tree over the entire study area. This was done in order to compare example areas with trees that either provide very good shade coverage or very poor shade coverage. The two resulting layers, along with a raster of the density of climate change resilient trees on campus, were normalized between 0 and 100 (Equation 1), then weighted and combined (Equation 2). The resulting index ranged between 5.5 and 58.4, with higher values indicating the presence of more climate change resilient tree shade. In order to compare a sample shade hotspot with a low shade area, three-dimensional models were created using LiDAR derived canopy metrics indicating tree height and crown width.

3.2 Modeling neighbourhood level tree shade

For the purposes of this study, optimal tree planting configuration is described as how much unique shade each individual tree contributes to shading important targets, which in this case were the buildings in residential neighbourhoods. In order to optimize tree planting configuration in neighbourhoods across UBC Vancouver campus, LiDAR data covering the entire study area was clipped to each neighbourhood. The point cloud for each neighbourhood was filtered to contain only trees and ground returns, then used to create a CHM at a 0.5-meter resolution using a pit-free algorithm to serve as an elevation matrix for shade simulation. Shade was simulated every hour, again using the solar positions from July 17th, 2024. The resulting raster files were reclassified in order to extract the total area of shade provided by trees in each neighbourhood for each time interval. The extracted tree shade rasters were converted to polygons and intersected with building footprint polygons in order to calculate the area of shade falling on buildings for each time interval. The percentage of total tree shade area per neighbourhood that fell on buildings was calculated for each time interval, which allowed for a daily mean percentage to be calculated.

$$y = \frac{x - \min(x)}{\max(x) - \min(x)} * 100$$

Equation 1

$$Tree\ Shade = (Tree\ Height * 0.4) + (Mean\ Shade\ Area\ Per\ Species * 0.4) + (Tree\ Density * 0.2)$$

Equation 2

4. Results

4.1 Species level tree shade

Using LiDAR to model shade from trees, the extent of shade cover provided by an individual tree was calculated. This study aims to verify whether tree species has a significant correlation with the extent of shade cover provided, and if so, to provide tree planting recommendation that optimize shade coverage on UBC Vancouver campus.

Ponderosa pine had the highest median normalized shade cover area at 27.36 m^2, closely followed by deodar cedar at 26.30 m^2 and black pine at 25.34 m^2 (Fig. 3). The tree species with the lowest median normalized shade cover area was callery pear at 7.50 m^2. Despite only having the 6^{th} highest median normalized shade cover area, honey locust had the highest mean normalized shade cover area at 37.81 m^2 due a number of outliers with extremely high normalized daily shade areas.

Climate change resilient tree shade hotspots were mostly located far outside or surrounding UBC neighbourhoods (Fig. 4). Tree shade hotspots contained larger, wider trees and a higher density of climate change resilient species.

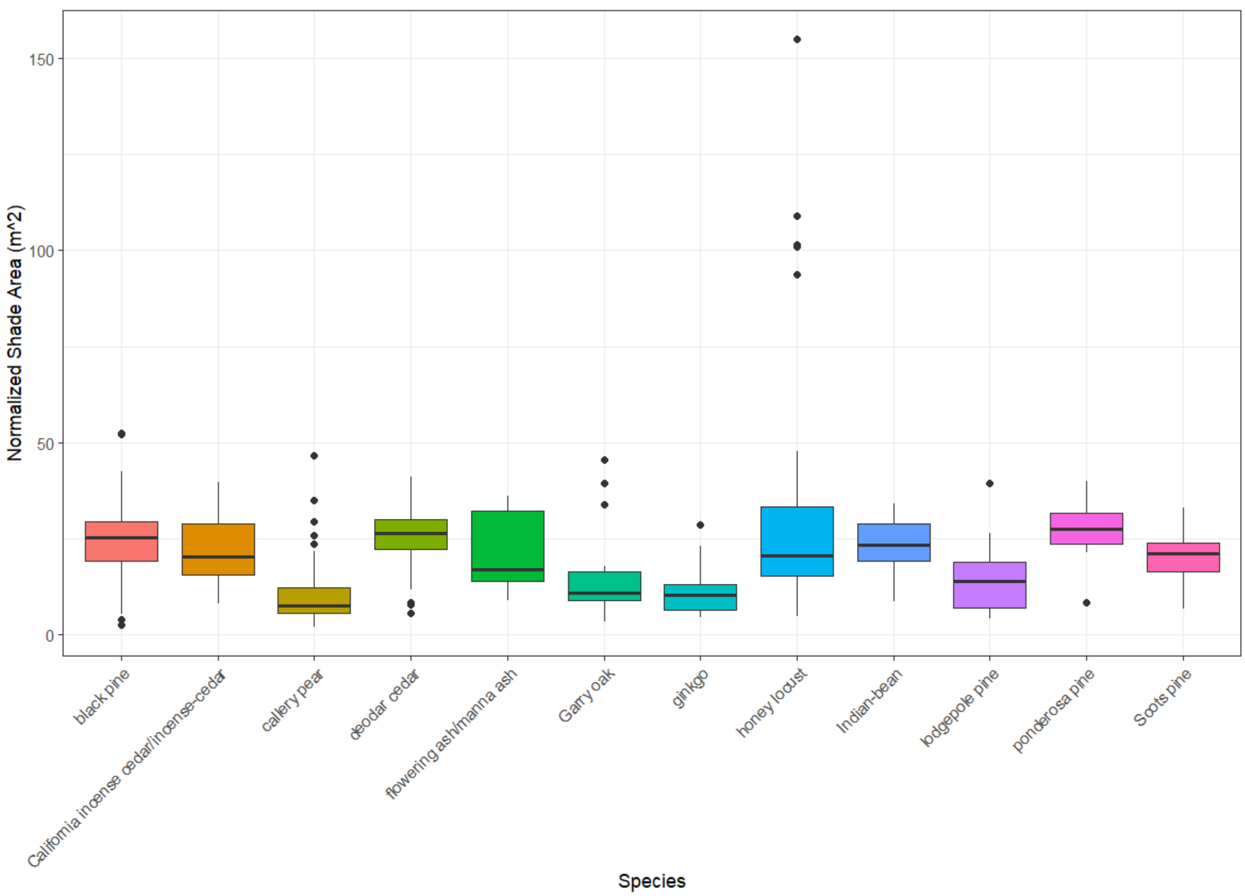

Figure 3: The shade area offered by the 12 most common species of climate change resilient trees on UBC Vancouver campus. Ponderosa pine, deodar cedar, and black pine offer the highest median shade cover. It can be seen that the individual trees that offer the most shade cover on campus are all honey locusts.

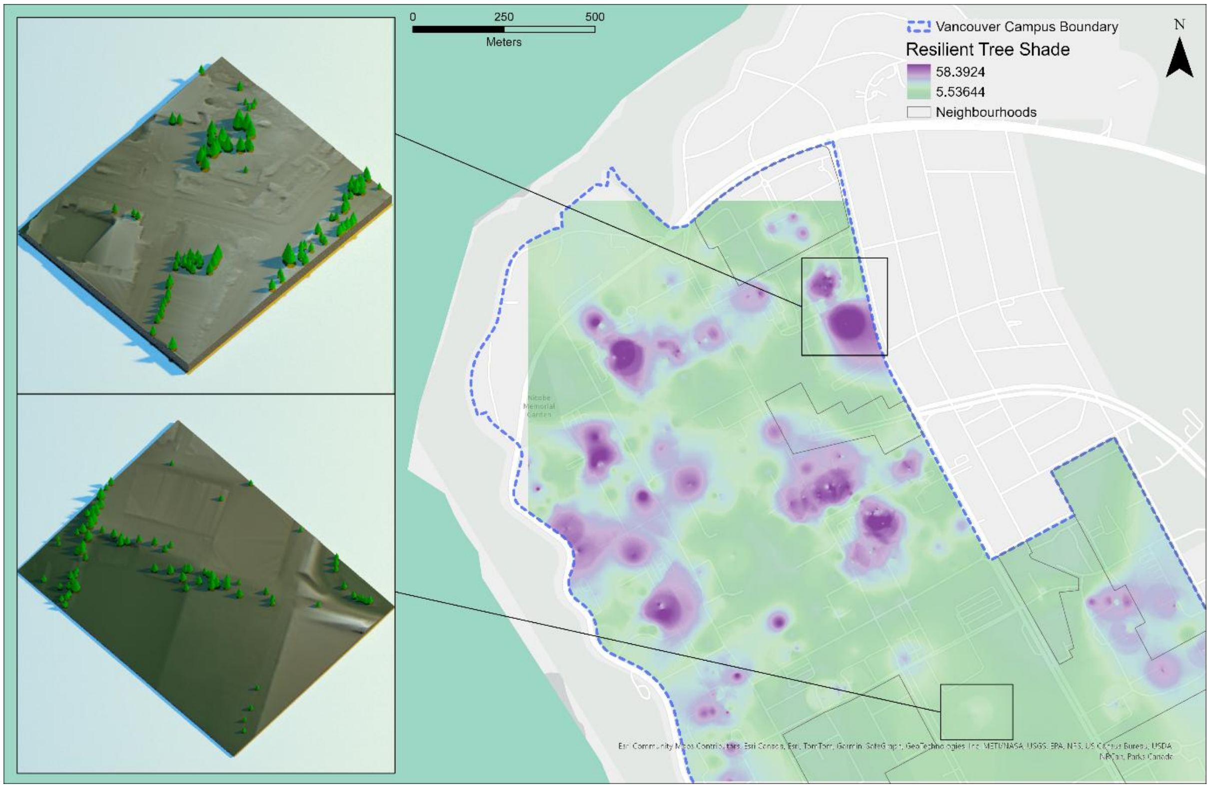

Figure 4: Hotspots of shade cast by climate change resilient tree species, along with three-dimensional comparisons of high and low shade areas. The trees and shadows found in the example hotspot are much larger than those in the example low-shade area. Overall, the presence of climate resilient tree species that provide large amounts of shade is sparse within residential neighbourhoods.

4.2 Configuration of neighbourhood tree shade

University Boulevard was the neighbourhood with the highest mean percentage of tree shade falling on buildings at 31.37%, closely followed by Chancellor Place at 30.92 %. The neighbourhood with the lowest mean percentage of tree shade falling on buildings was stadium with only 2.84% (Table 1). Chancellor place, while having a slightly lower mean percentage, had much less variance with respect to time of day than University Boulevard (Fig. 5).

Time	Acadia East (%)	Chancellor Place (%)	East Campus (%)	Hampton Place (%)	Hawthorn Place (%)	Stadium (%)	University Blvd (%)	Wesbrook Place (%)
6:00:00	22.021	35.264	21.495	31.182	24.719	4.983	47.374	20.040
7:00:00	22.455	35.662	21.965	32.423	24.487	5.246	43.613	20.221
8:00:00	18.448	27.665	13.662	26.569	25.338	1.476	25.917	14.632
9:00:00	19.605	30.403	17.145	28.389	26.627	2.206	25.254	16.669
10:00:00	20.532	33.771	18.280	30.427	27.521	3.987	21.842	18.401
11:00:00	21.298	35.712	19.719	31.328	27.999	5.338	22.647	19.616
12:00:00	21.422	36.025	20.299	31.189	26.853	5.110	35.654	20.169
13:00:00	21.254	35.830	20.629	30.736	25.699	4.852	45.486	19.730
14:00:00	22.765	33.731	21.914	32.695	23.458	1.969	42.031	18.685
15:00:00	23.154	33.265	21.122	31.320	21.632	1.664	38.101	17.050
16:00:00	22.378	31.450	19.219	29.648	18.216	0.986	32.111	14.352
17:00:00	20.941	28.670	15.311	26.882	15.078	1.115	22.988	12.002
18:00:00	19.159	26.516	12.890	24.634	13.518	1.478	22.694	10.453
19:00:00	18.726	23.066	11.083	23.841	14.715	1.940	24.809	8.907
20:00:00	18.932	22.815	10.325	23.828	17.935	1.771	25.564	9.124
21:00:00	18.397	24.901	10.560	24.649	22.222	1.260	25.879	12.054
mean	20.71789112	30.922	17.226	28.73367623	22.25110897	2.836	31.373	15.757

Table 1: Percentage of tree shade that falls on buildings for each neighbourhood on UBC Vancouver campus, with the position of the sun taken hourly on the 17th of July, 2024. Mean values highlighted in green represent relatively high percentages, while those highlighted in red represent relatively low percentages.

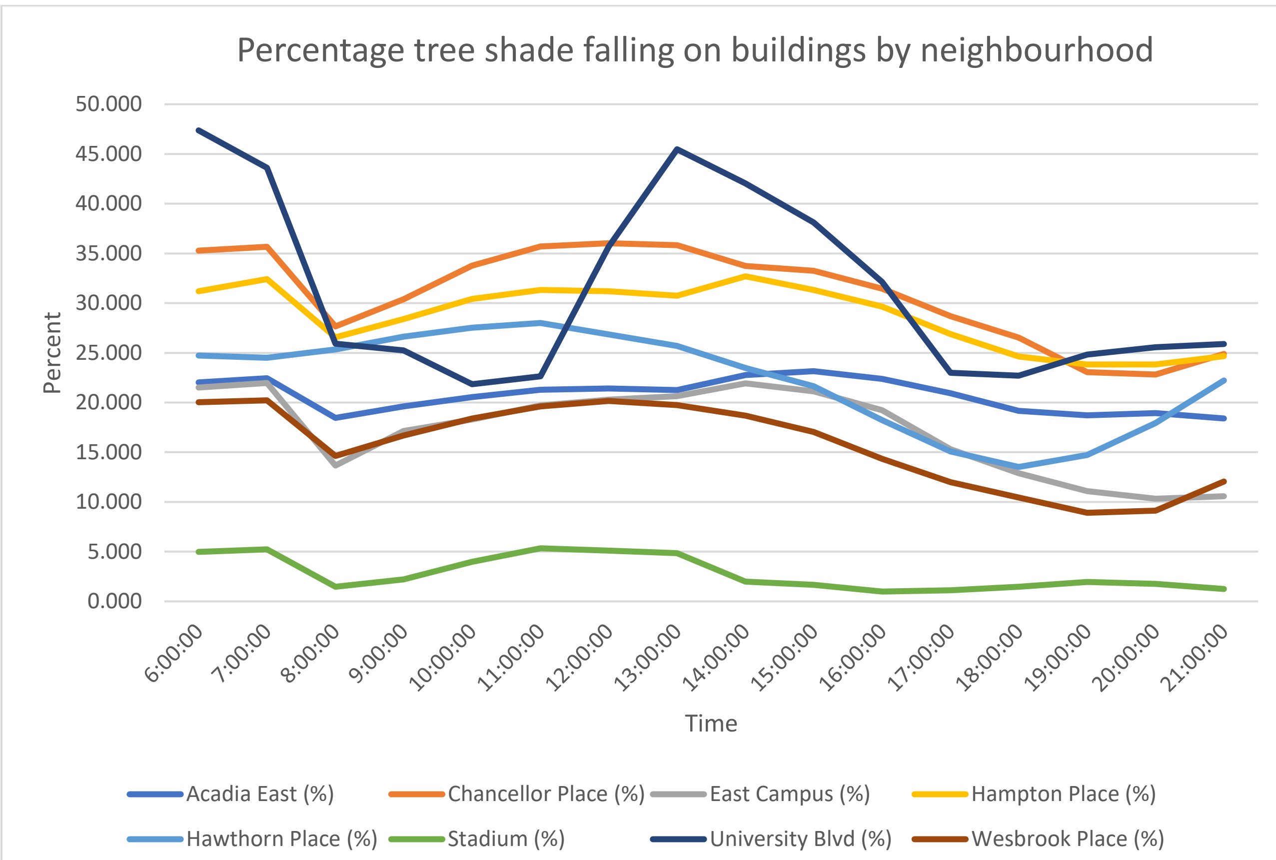

Figure 5: The percentage of total tree shade that falls on buildings for each neighbourhood on UBC Vancouver campus throughout one day. University Boulevard has the highest maximums, while Chancellor Place maintained consistently high percentages.

5. Discussion

Recommendations for strategic tree planting are required in key areas across UBC Vancouver campus that have been identified as having low shade coverage, such as pedestrian walkways or residential neighbourhoods (Wang, 2024). The results of this observational study are used to determine how to allocate resources in order to best improve shade coverage, which in turn will improve human thermal comfort and building energy savings during the summer months. Further research building upon the results of this study could provide insights into the effects of shade, tree species, and planting configuration on energy consumption in buildings during the summer months.

5.1 Species Planting Recommendations

Deodar cedar and black pine are recommended for planting in order to improve shade coverage on campus due to their observed higher median normalized shade cover. In the case where more species diversity is desired, southern catalpa, California incense cedar, scots pine, and honey locust should be prioritized. These species are all considered very suitable under possible future climate scenarios, meaning they can tolerate a broad range of sites including the driest possible sites (metrovancouver, n.d.). Notably, these climate change resilient tree species often fall outside of residential neighbourhoods on UBC campus. In order to expand ecosystem services such as shade in accordance with the goals of UBC's Neighbourhood Climate Action Plan (Campus and Community Planning, 2024), it is recommended that more species considered "very suitable" under future climates be planted within residential neighbourhoods.

5.2 Planting Configuration Recommendations

An optimal tree planting configuration is one that can provide the most shade cover to important targets such as buildings with the least amount of allocated resources. This means maximizing the shade contributions of individual trees, rather than planting the largest number of trees. The percentage of shade falling on buildings in each neighbourhood on campus can be compared to mapped tree locations (Fig. 6) in order to better understand the effect of planting configuration on shading efficiency. Neighbourhoods with trees planted in thin belts in close proximity to buildings have a high shade efficiency. It is important to remember that this analysis emphasizes the position of trees planted, not the number. While University Boulevard is one of the neighbourhoods most in need of additional tree planting efforts (Wang, 2024), the positions of the trees currently planted are ideal for shading buildings. Comparatively, Acadia East is a neighbourhood with a large number of trees that are clustered together throughout it, lowering the individual contributions of each tree to shading buildings. While planting large amounts of trees in blankets across an urban landscape can provide numerous ecosystem services (Escobedo et al., 2011), it is a less efficient method of shading important targets in dense urban cores. Additionally, south-west and south-east faces of buildings in the northern hemisphere receive the most sun throughout the course of a day (Zhao, 2017). This further explains University Boulevard's high shading efficiency, given that the majority of trees in the neighbourhood are planted by the south-east face of the nearest building. In order to optimize the efficiency of tree shade on campus, it is recommended that trees be planted in thin belts to the south-west or south-east and in close proximity to important targets such as buildings or pedestrian areas.

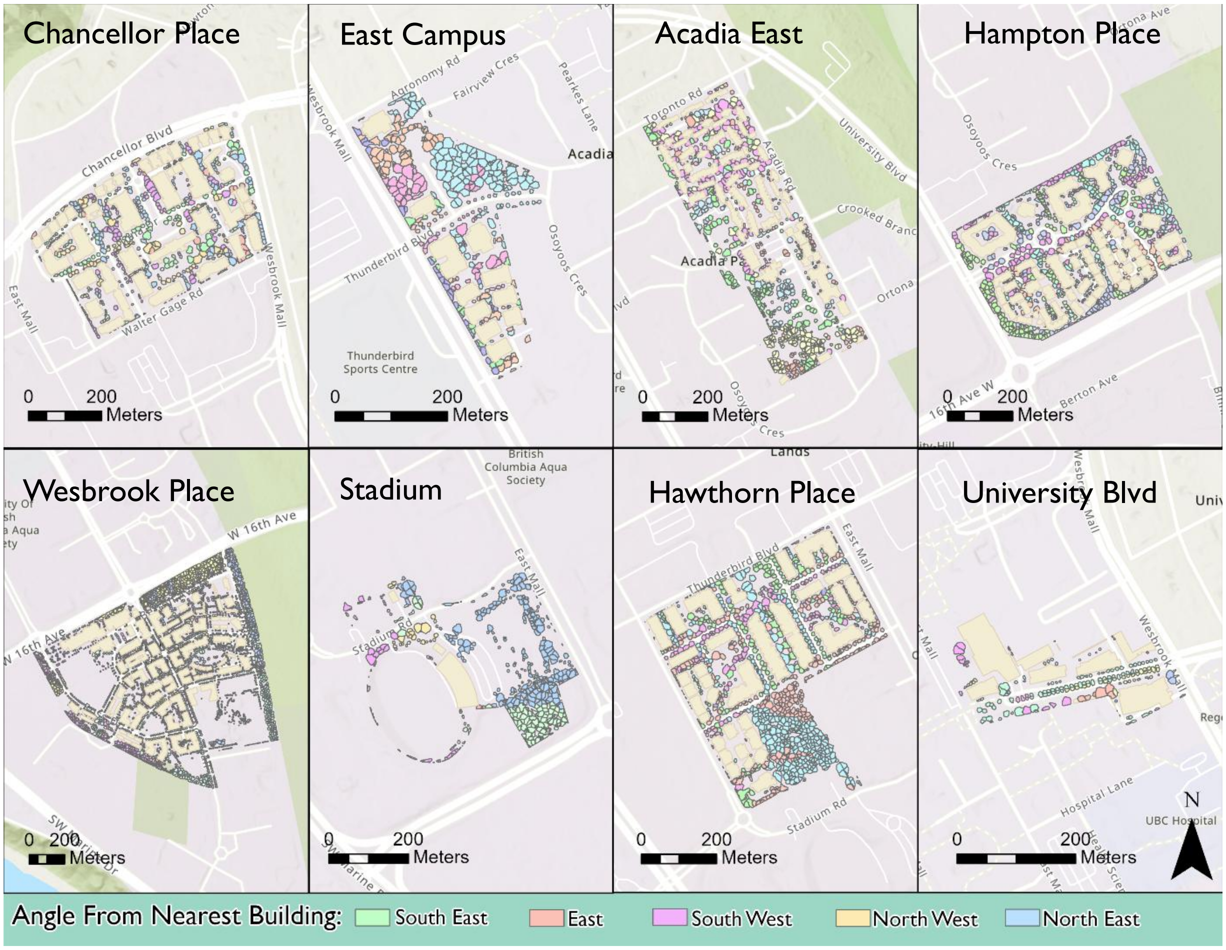

Figure 6: In order to compare tree planting configuration between neighbourhoods, each tree was assigned a colour representing its angle relative to the nearest building. Trees in University Blvd are planted in a thin strip to the south of and in close proximity to most buildings.

5.3 Limitations

The sample size of this study was limited in part due to the number of trees excluded from the analysis due to erroneous segmentation of the point cloud. This likely introduced bias with regards to which species are most easily segmented by the chosen algorithm. In the case of this study, while honey locusts did not provide a high median normalized shade area, they were the species with the highest mean. A larger sample size of honey locusts could have greatly influenced the results of this study. It is recommended that further studies on species level contributions to tree shade include a larger sample size for each species. Additionally, while the methods used effectively captured canopy shape and size, all shade models considered trees to be completely opaque. Since no consideration was given to canopy structure, trees with large, sparse canopies that allow light to pass through them were observed to provide a high normalized median shade cover. Ponderosa pine is one such example, and was left out of planting recommendations for this reason.

Another limitation of this study is that the only tree planting configurations observed were those already existing within the study area. In order to more accurately examine the effects of planting configuration on shading efficiency, it is recommended that all or nearly all possible tree positions be modeled with regards to buildings in order to comprehensively determine the best possible planting locations at a smaller scale. Due to the urban nature of UBC Vancouver campus, recommendations for planting locations should be supplemented with further research into soil volume and other environmental variables in order to assess the viability of planting recommended species at a given location.

5.4 Future Directions

The major strengths of this study are its use of LiDAR at small scales and fine resolutions in order to accurately assess the effect of canopy shape, size, and position on shade cover. Despite its limitations, this study sets a very strong baseline, both for recommendations and methods, that can easily be built upon in order to achieve a robust set of planting instructions that can be applied over the entire study area.

The most promising directions for future research involve the use of voxelization of the point cloud in order to assess how much light is capable of passing through the canopy of a given species. A major limitation of this analysis is the fact that modeled trees were opaque. An index for canopy or leaf density could be assigned to individual voxels, allowing for a more complete shade cover analysis that takes into account canopy structure and leaf area. A larger sample size of trees for each species is also recommended in order to eliminate outliers and refine shade estimations. Beyond improving upon these recommendations, climate and soil variables should be assessed and included in order to locate areas on campus where planting in accordance with these recommendations is actually feasible.

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