Shade Mapping for Neighbourhood Climate Adaptation and Community Wellbeing

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Cover Photo: Picture taken by Chenyao Wang on July 9th, 2024.

Executive Summary

Shades are important to urban environments as they provide comfort, reduce heat-related stress, and enhance overall wellbeing. This report presents a comprehensive study on shade mapping for Neighbourhood climate adaptation and community wellbeing within the University of British Columbia (UBC) Point Grey campus. The primary objectives are to develop methodologies for shade mapping, identify areas with insufficient shade coverage, and provide actionable recommendations for improving shade distribution. Using high-resolution LiDAR data and sun position data, a Digital Surface Model (DSM) was created to represent campus elevation, and hillshade analysis was employed to simulate shade coverage at 15-minute intervals. Findings reveal that pedestrian areas have the highest mean shade coverage (0.69507), while concrete areas have the lowest (0.434512). Significant variations exist across Neighbourhoods, with East Campus and Hampton Place showing high, consistent shade, while Stadium and UBlvd require improvement. Bus stations also exhibit variability in shade, with UBC Exchange Bay 8 having the lowest coverage (0.160035). Recommendations include enhancing shade consistency in pedestrian areas, providing shelters in open concrete spaces, and increasing shade in Neighbourhoods like Wesbrook Place and UBlvd. Limitations of the study include the hillshade method's inability to account for shaded areas underneath trees or structures and the need for ground-truth validation. Future work should explore 3D multipatch analysis, incorporate detailed tree inventory data, and integrate shade analysis into broader urban planning efforts. This methodology-driven research aims to inspire further enhancements to the campus environment, ensuring optimized shade coverage and contributing to a more comfortable and sustainable urban landscape.

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1. Introduction

The recent heat dome that enveloped the Pacific Northwest in June 2021 was an unprecedented event, shattering temperature records by several degrees Celsius and resulting in numerous heat-related deaths and hospitalizations (Philip et al., 2022). This extraordinary heat wave underscored the severe impacts of climate change, which has been increasingly linked to the frequency and intensity of such extreme weather events. According to the rapid attribution analysis, the probability of this heat wave occurring without human-induced climate change is virtually zero, emphasizing the significant role of global warming (Philip et al., 2022). Urban areas are particularly vulnerable to extreme weather due to the Urban Heat Island (UHI) effect, which exacerbates the heat intensity in densely built environments (Oke, 1982). The UHI effect increases energy demand for cooling, elevates air pollution levels, and exacerbates heat-related health problems, becoming more severe due to rapid urbanization and the reduction of natural vegetation in cities (Li & Bou-Zeid, 2013; L. Zhao et al., 2014). Current adaptation strategies include increasing green spaces, installing cool roofs and pavements, and improving building insulation to reduce heat absorption (Akbari et al., 2001; Santamouris, 2014). Among these strategies, planting trees to create shade is a particularly sustainable and straightforward solution, effectively mitigating the UHI effect and enhancing urban resilience against heat waves (Vailshery et al., 2013).

This study focuses on the adaptation strategy of planting trees and creating more shades due to their multifaceted benefits in urban environments, which are more natural and cost-effective with less human intervention compared to other strategies. Tree shades play a critical role in urban settings by providing cooling, enhancing aesthetics, and offering numerous ecological benefits (Dwyer & Miller, 1999). Recent studies have demonstrated that the cooling effect of tree shades directly helps reduce the Urban Heat Island (UHI) effect by lowering surface and air temperatures, significantly improving outdoor comfort, and reducing energy consumption for air conditioning (Akbari et al., 2001; Vailshery et al., 2013). For instance, shaded areas can be up to 2-9°C cooler than unshaded areas, highlighting the significant thermal regulation provided by tree canopies (Vailshery et al., 2013). Moreover, the equitable distribution and accessibility of shade are crucial for ensuring that all community members, especially vulnerable groups, can benefit from cooler environments (Q. Zhao et al., 2017). Beyond the direct cooling effects, tree shades also influence human decision-making indirectly by affecting choices about outdoor activities, commuting routes, and waiting areas for public transportation (Shuying et al., 2009). Understanding these indirect impacts can inform better urban planning and community design to enhance comfort and well-being of all residents during hot seasons, providing them with same level of equity and accessibility to shades.

The primary purpose and objective of this study is to develop a baseline map to comprehensively understand the shade coverage within the UBC Point Grey Campus, particularly in high-traffic areas and regions where people tend to spend prolonged periods such as residential Neighbourhood, hard landscapes and various public infrastructures, and its implications for climate adaptation and community wellbeing. The objectives of this study include: (1) designing appropriate tools and methodologies to support shade mapping assessments for the UBC Campus and Residential Neighbourhood, (2) identifying areas that lack sufficient shade in daytime with high temperature and are more vulnerable to potential heat dome, with a focus on high-traffic and long-stay areas, (3) applying these tools to simulate shade coverage in campus level, residential Neighbourhood level, public infrastructure level, and (4) providing actionable recommendations to address identified gaps in shade coverage and setting shade coverage targets for future urban planning. By achieving these objectives, this study will contribute to more effective urban planning and enhance community resilience for the UBC Point Grey Campus against extreme heat events.

2. Study Area and Data Description

2.1 Study Area

The study area (Figure 1) encompasses the University of British Columbia (UBC) Point Grey campus lands, which include a diverse mix of land uses and ecological zones. The primary land uses within the plan are:

- Academic: This includes areas dedicated to teaching, research, and other academic activities, as well as student housing.
- Green Academic: Open areas that support land-based teaching, research, and related activities.
- Neighbourhood Housing Areas: Zones providing a range of rental and long-term lease housing options.

The Neighbourhood Housing Areas are further divided into several Neighbourhoods, each with its unique characteristics and planned developments. These Neighbourhoods include Hampton Place, Hawthorn Place, Wesbrook Place, Chancellor Place, East Campus, and the future Stadium and Acadia Neighbourhoods.

In terms of ecological context, the UBC Point Grey campus is situated along the southern Coastal Western Hemlock zone, characterized by a mesothermal climate with a mean annual temperature of 8°C. This zone receives the highest average rainfall in the province, with a mean annual precipitation of 2228 mm, and less than 15% of the precipitation falls as snow. Key ecological features of this zone include:

- Dominant Tree Species: Western hemlock (Tsuga heterophylla), Western redcedar (Thuja plicata), Douglas-fir (Pseudotsuga menziesii), Western white pine (Pinus monticola), and Bigleaf maple (Acer macrophyllum).
- Additional Species: Norway maple (Acer platanoides) and Freeman maple (Acer × freemanii) are also abundant on campus.
- Land Use Heterogeneity: The area includes forests, gardens, buildings, roads, and other infrastructure, with developed land being the predominant class.

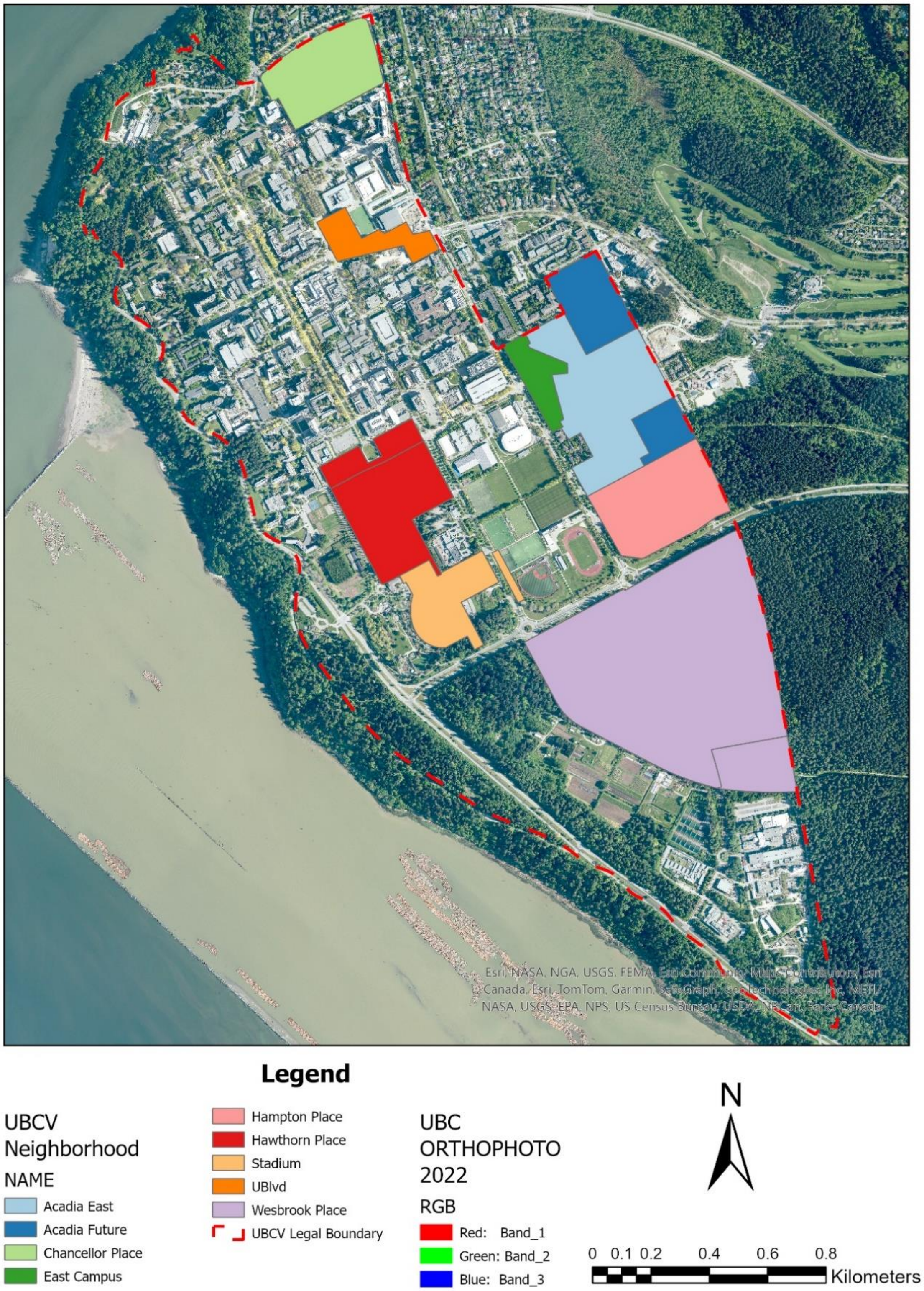


Figure 1. UBC Point Grey Campus Boundary and Neighbourhoods. The map displays the UBC Point Grey campus boundary and its Neighbourhoods, including Hampton Place, Hawthorn Place, Wesbrook Place, Chancellor Place, East Campus, and the future Stadium and Acadia Neighbourhoods.

2.2 LiDAR Data

LiDAR (Light Detection and Ranging) is a remote sensing technology that employs laser pulses to measure distances to the Earth's surface, producing precise, three-dimensional data about the Earth's topography and surface characteristics. The system functions by emitting laser pulses from an aircraft, which then reflect off various objects and return to the sensor. The time taken for these pulses to return is used to calculate distances, enabling the creation of detailed topographic maps (Wehr & Lohr, 1999). LiDAR data is widely used in numerous fields, such as geography, forestry, and urban planning, due to its high accuracy and detail.

The LiDAR data for this project was sourced from the City of Vancouver's 2022 LiDAR dataset, which covers 134 square kilometers with 181 tiles (*LiDAR 2022*, 2023). This dataset includes classifications such as bare earth, vegetation, buildings, water, and noise, collected in September 2022. It has a high density of approximately 49 points per square meter and a vertical accuracy of 0.081 meters.

For this study, 11 LiDAR tiles covering the UBC Point Grey campus were specifically used. These tiles provided comprehensive coverage and allowed for the creation of various digital models essential for the shade mapping project. The high-resolution data facilitated the development of accurate Digital Surface Models (DSMs), which are critical for precise shade simulation and analysis.

2.3 Sun Position Data

Sun position data is crucial for accurately simulating shadows and understanding the shading patterns on the UBC Point Grey campus. This data provides information on the direction and length of the shadow cast by the Sun at given times of the day.

The data for this project was sourced from the Sun Position and Sun Direction tables provided by the National Research Council of Canada (NRC). These tables list the solar azimuth and altitude for the 21st day of each month, a time when the Sun reaches its most extreme positions (NRC, 2023). This dataset is specifically designed to be used for various applications including urban planning, building design, and driving safety, as it helps to understand the impact of sunlight at different times of the day and year.

Table 1 provides an example of the Sun Position and Sun Direction table for June 21st, 2024. It includes time intervals at 15-minute increments from 13:00 to 14:15, showing the hour angle, solar altitude, solar azimuth, and shadow length factor. The hour angle represents the time difference from solar noon, where each hour corresponds to 15 degrees. Solar altitude indicates the height of the sun above the horizon, while solar azimuth shows the compass direction from which the sunlight is coming. The shadow length factor is a multiplier used to determine the length of a shadow based on the height of the object casting it.

Table 1. Sun Position and Direction for June 21st, 2024. This table shows an example of the hour angle, solar altitude, solar azimuth, and shadow length factor for each 15-minute interval from 13:00 to 14:15.

Time	Hour Angle	Solar Altitude	Solar Azimuth	Shadow Length Factor
13:00	0.77	62.6	203.4	0.52
13:15	1.02	61.5	210.4	0.54
13:30	1.27	60.2	216.9	0.57
13:45	1.52	58.6	222.9	0.61
14:00	1.77	56.9	228.4	0.65
14:15	2.02	55.0	233.6	0.70

The accuracy of the solar angles listed in these tables is approximately 0.5 degrees, equivalent to the Sun's diameter. However, when the Sun is at the horizon, the accuracy slightly decreases due to atmospheric refraction, which is not accounted for in these calculations. This high level of accuracy ensures that the data can be reliably used for precise shadow simulations.

The shadow direction is measured from the north through east, and the length of a shadow cast by any object is calculated by multiplying the height of the object by the shadow length factor provided in the tables. This information is vital for understanding how buildings and other structures cast shadows throughout the day, which is essential for assessing shade coverage and planning for climate adaptation and community wellbeing.

3. Methods

This study aims to develop a baseline shade map and use it to measure the effective shade coverage across UBC Point Grey Campus and at a Neighbourhood and public facility level. Shades and shadows on campus are formed when sunlight is blocked by objects such as buildings or trees. To simulate these shades accurately, it is essential to 1) know the elevation of objects on campus, 2) know the sun position (azimuth and altitude) and its movement in corresponding period.

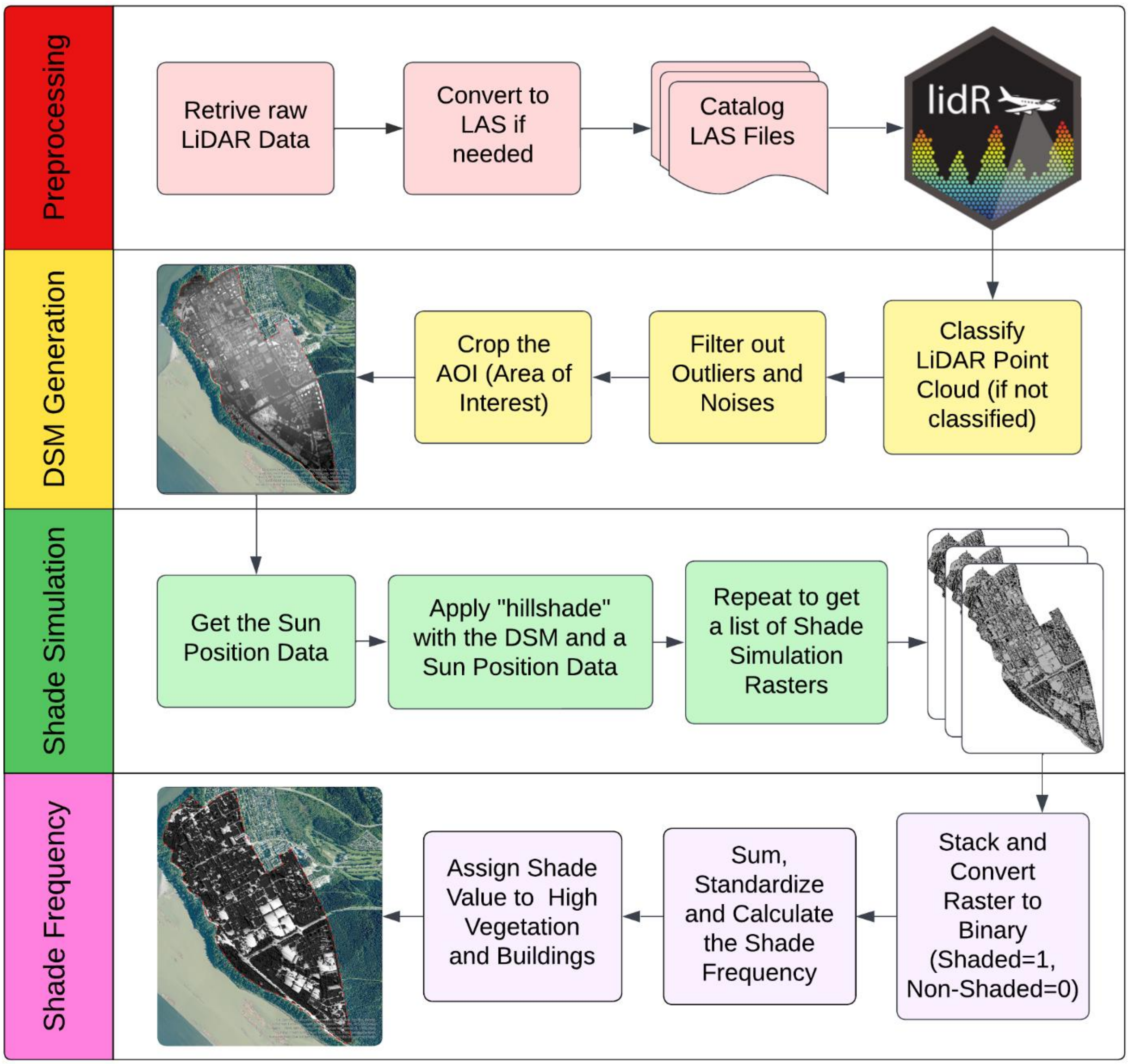


Figure 2 Visualized methods workflow, including reprocessing, DSM (digital surface model) generation, shade simulation, and shade frequency. Methods were consistent for Vancouver LiDAR data 2022.

3.1 Measure the Elevation of Objects

LiDAR data provides elevation information, which is critical for simulating shades. For accurate shade simulation, a Digital Surface Model (DSM) will be created from the LiDAR point cloud after filtering out unclassified and noisy points.

3.1.1 Unclassified and Outlier Points Filter

The LiDAR data contains various classifications, including unclassified points and potential outliers such as temporary tower cranes (Figure 2, Left) or birds (Figure 2, Right). These points need to be filtered out to avoid misleading results in the analysis. Filtering ensures that temporary or anomalous structures do not distort the shade simulation, which relies on an accurate representation of the permanent features of the campus.

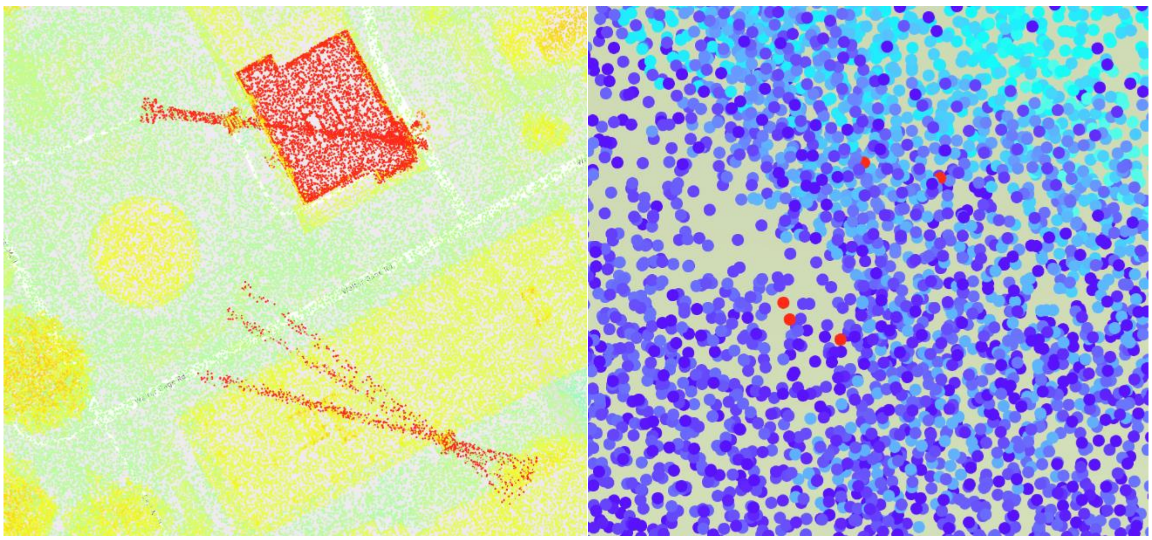


Figure 3. **Left:** Example of temporary structures such as tower cranes identified in the LiDAR data. **Right:** Anomalous points such as birds detected in the LiDAR data. These outliers need to be filtered out to ensure accurate representation of the permanent features on campus for precise shade simulation.

3.1.2 Digital Surface Model (DSM)

Digital Surface Model (DSM) is a raster image interpolated from the LiDAR points that represent the uppermost positions of all objects on campus the elevation variations across the campus. In this research, it was generated at a 1-meter spatial resolution, deploying a pit-free algorithm at thresholds of 0, 2, 5, 10, and 15 meters, and used a subcircle radius of 0.2 meters. This method ensures detailed and accurate representation of the surface, accounting for various object heights.

Figure 3 shows the DSM of the UBC Point Grey Campus. The shaded areas with value from 44.604 to 154.67, indicate variations in elevations of objects, with darker shades (lower value) representing lower elevations and lighter shades (higher value) representing higher elevations. The DSM is crucial for simulating how different objects cast shadows at a time of the day, since objects with higher elevations produce larger and longer shadows, while lower elevations produce smaller and shorter ones. By developing and utilizing these methods, the study ensures that the shade simulation accurately reflects the true height of objects, allowing for precise analysis and application in urban planning and climate adaptation strategies.

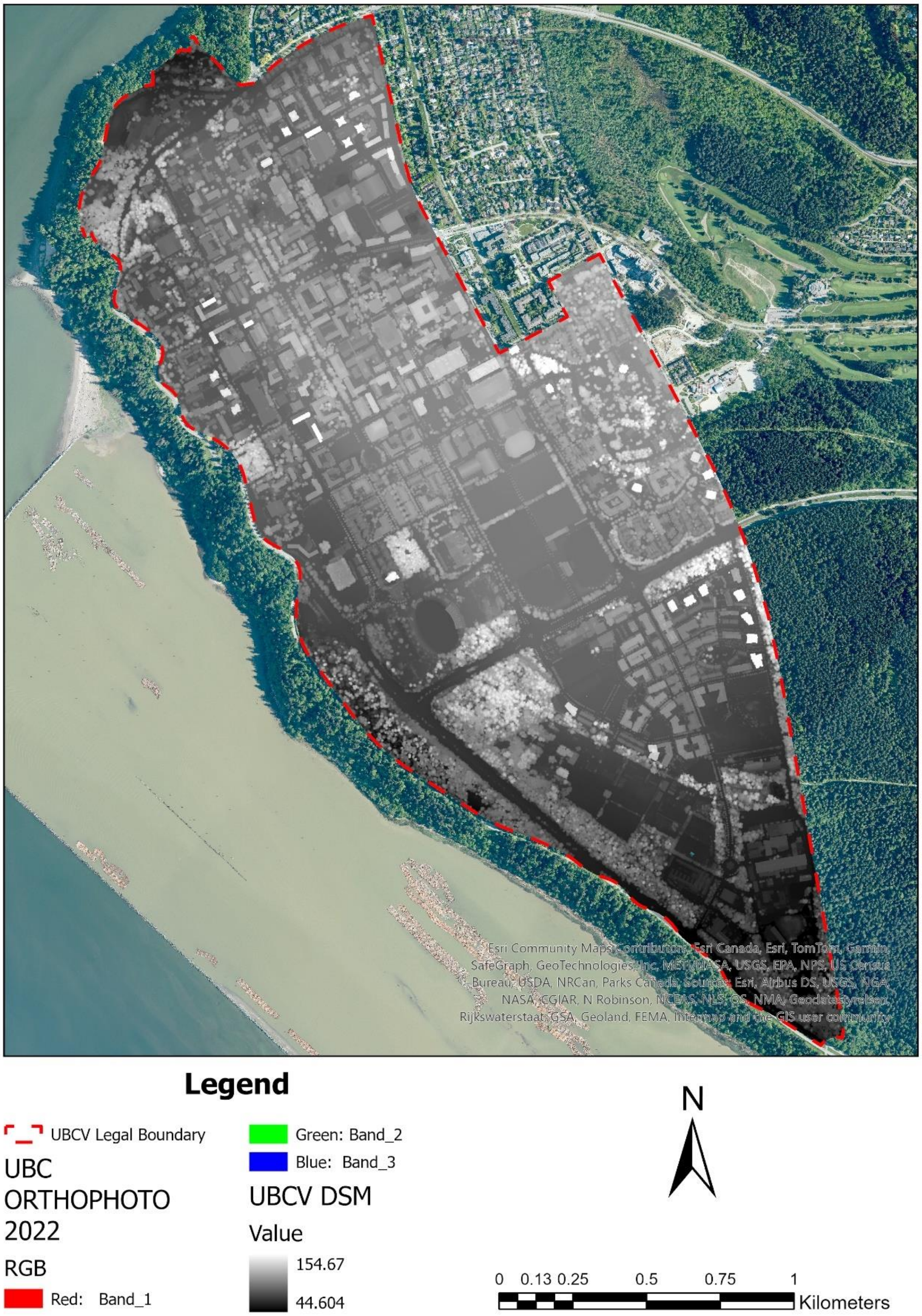


Figure 4. Digital Surface Model (DSM) of the UBC Point Grey Campus. The shaded areas with values from 44.604 to 154.67 indicate variations in elevations of objects, with darker shades (lower value) representing lower elevations and lighter shades (higher value) representing higher elevations.

3.2 Sample the Time Period and Calculate Sun Movement

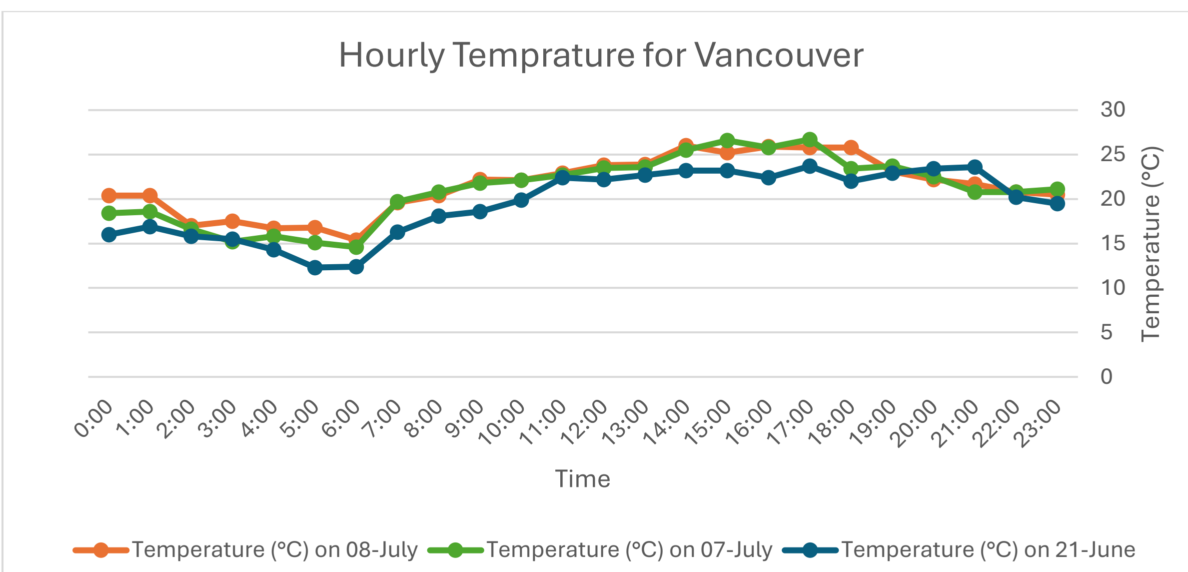
After generating the DSM to represent the elevation of objects across the UBCV campus, the next step to accurately simulate shade coverage is to determine the sun's position and movement for the chosen time period. The sun position data, including azimuth and altitude, for these intervals can be obtained from the NRC sun position tables as stated in Section 2.3. By connecting these 15-minute interval data points, the entire sun movement for the selected period can be charted.

There are various approaches to sampling the time period, such as selecting the day with the longest daylight, the same day each month throughout the year, or specific days in June, July, August, and September, which are typically the hottest months. Although more samples can enhance accuracy, computational power and other factors necessitate a balanced approach. Therefore, sampling should align with the research objectives and be guided by historical data.

For instance, in this study, the objective is to identify gaps in shade coverage during potential heat dome events, particularly in high-traffic areas and regions where people spend extended periods. Based on historical data, June 21st, 2024, was chosen for analysis as it is one of the hottest days and has the longest daylight. The specific time period selected for analysis is from 13:00 to 20:00, corresponding to the hours with the highest daytime temperatures, which is also based on historical data for date with high temperature (Table 2). July 7 and July 8 were included in the analysis because they are two of the hottest days of the year, providing additional validation for the chosen time period.

This strategic approach ensures that the shade simulation is both accurate and relevant, providing valuable insights for urban planning and climate adaptation strategies.

Table 2. Hourly Temperature for Vancouver on 21-June, 07-July, and 08-July 2024. This graph illustrates the hourly temperature variations, showing that the hottest time period for a typical day is from 13:00 to 20:00. This data is used to select the appropriate time period for shade simulation analysis during potential heat dome events.



3.3 Shade Simulation using Hillshade

Hillshade is a widely used tool in GIS for simulating the effect of sunlight on the landscape by creating a shaded relief map from a digital elevation model (DEM). It works by calculating the illumination of each cell in a DEM based on the angle of the sun above the horizon (solar altitude) and the sun's position (solar azimuth). The tool creates an output raster where each pixel value represents the intensity of illumination:

- **Input:** The input for the Hillshade tool includes the DEM or DSM, solar azimuth, and solar altitude.
- **Output:** The output is a shaded relief map with pixel values ranging from 0 to 254. A value of 0 represents shadowed areas, while 254 represents fully illuminated areas.

When the "model shadow" option is enabled, it adds an additional layer of realism by accounting for shadows cast by terrain features. This can help in identifying areas that remain shaded throughout the day, which is critical for applications such as urban planning and climate adaptation strategies.

In this study, the hillshade tool is applied to the DSM created in Section 3.1, using specific sun azimuth and altitude values derived from the NRC sun position tables as discussed in Section 3.2. By applying the hillshade tool at 15-minute intervals, a series of shade simulation maps are generated, each representing a different time of the day. These maps provide detailed insights into how shade coverage varies across the UBC Point Grey campus throughout the day. Each pixel in these maps has a value ranging from 0 to 254, with 0 representing shaded areas.

The position of the sun changes throughout the day, affecting the size and shape of shadows cast by objects. Figure 4 shows the shadow simulation from the hillshade tool for 3:30 PM when the hour angle is 3.27, sun altitude is 44.0, sun azimuth is 254.1, and shadow length factor is 1.04.

Since 0 represents the shaded area, it is straightforward to extract all shaded areas by converting the raster to a binary raster, where 0 means "shaded" and 1 to 254 means "not shaded." By stacking all binary shade rasters in 15-minute intervals for the chosen time period and dividing by the total number of rasters, a shade frequency map can be generated. This map provides a proportion from 0 to 1 that indicates how often each pixel is shaded throughout the chosen time period. However, one disadvantage of using the hillshade tool is that the shade calculation is based on the DSM and only considers shadows on the surface of objects. This approach can lead to significant omissions in shadow coverage, particularly in urban forest and built-up areas.

In urban forest areas, the hillshade tool only displays shadows on the tree canopy surface, thereby missing the shade underneath the trees. For forested areas, it can be assumed that all areas underneath the tree canopy are shaded. Conversely, for street trees, the shadow coverage underneath them varies with the sun's position and is not completely shaded throughout the day.

When the sun is at its highest point, the shadow cast by street trees is at its largest. In built-up areas, the hillshade tool only simulates shadows on the tops of buildings or structures, neglecting the shaded areas underneath and within these buildings. While areas inside buildings are absolutely shaded, there are structures like shade canopies at transit exchanges, where the area underneath may not be completely shaded. Similar to the street trees, the shadow coverage in these partially shaded areas changes throughout the day depending on the sun's position.

To address the limitations of the hillshade tool and to make the shadow statistics more reflective of reality, this research assumes that areas inside buildings, shade structures and high vegetation (like tree canopies) are shaded 80% of the time. Therefore, these areas are assigned a value of 0.8 to better approximate the actual shade coverage. Figure 5 shows the comprehensive shade frequency map after considering areas underneath trees and buildings.

3.4 Statistics for Shade Coverage

Having calculated the shade frequency values for the UBCV campus, further analysis can be conducted at any level. Since our primary concern for this research is the shade coverage of human-built surfaces where people frequently access, such as paths and bikeways, we will use the UBCV hard landscape polygon, which has been classified into Concrete, Driveway, Parking, Pedestrian, Road, to mask out non-human-built surface areas. Figure 6 shows the shade frequency on hard landscapes across the UBC Point Grey campus. The shaded areas highlight the distribution of shade coverage on human-built surfaces. The values range from 0 to 1, where 0 represents areas that are never shaded and 1 represents areas that are always shaded. By using the UBCV hard landscape polygon to mask out non-human-built surfaces, this visualization focuses on paths, bikeways, and other areas where people spend time and require shade. It ensures that the analysis is relevant to areas where people spend time and need shade and provides a clear overview of how well-shaded the campus is, helping urban planners identify regions that may need additional shading to enhance community wellbeing and climate adaptation strategies.

In this research, three levels of such shade coverage on hard landscape will be emphasized: the entire campus, individual Neighbourhoods, and specific locations including pedestrians and bus stops.

Entire Campus Level

The shade frequency for the entire campus will be calculated to provide an overview of how well-shaded the UBCV campus is. This will help in understanding the general distribution of shade across all human-built surfaces on the campus.

Neighbourhood Level

To understand shade coverage within specific Neighbourhoods, zonal statistics will be applied to individual Neighbourhood polygons. This analysis will reveal variations in shade coverage between different Neighbourhoods, helping to identify areas that might need more shade provision.

Specific Locations (Pedestrians and Bus Stops)

For point locations such as bus stops, a buffer zone was created around each point before performing zonal statistics. This will help in assessing the shade coverage at these specific locations, which are crucial for pedestrian comfort and usability.

The Zonal Statistic Table will include:

- **COUNT:** Number of pixels within the zone.
- **AREA:** Area of the zone in square meters.
- **MIN/MAX/RANGE:** Minimum, maximum, and range of shade frequency values within the zone.
- **MEAN:** Average shade frequency value within the zone.
- **STD:** Standard deviation of shade frequency values within the zone.
- **SUM:** Total sum of shade frequency values within the zone.
- **MEDIAN:** Median shade frequency value within the zone.
- **PCT90:** 90th percentile of shade frequency values within the zone.

In this study, the focus will be on the mean and standard deviation of the shade frequency:

- The **mean shade frequency** provides an overall average of how often areas within the zone are shaded throughout the day. A higher mean indicates better shade coverage, while a lower mean indicates areas that are less frequently shaded.
- The **standard deviation** indicates the consistency of shade coverage within the zone. A higher standard deviation means that shade is more concentrated, such as in forested areas, leading to pockets of high and low shade. A lower standard deviation suggests a more uniform distribution of shade across the zone, which is typically desirable in areas where even shade coverage is important for public comfort and health.

This analysis offers detailed insights into shade coverage across different zones, enabling urban planners to make informed decisions to enhance community wellbeing and support climate adaptation strategies.

Figure 5. Shadow simulation for the UBC Point Grey Campus at 15:30 on June 21st. The hillshade tool is applied to the DSM using specific sun azimuth and altitude values. Each pixel value ranges from 0 to 254, with 0 representing shaded areas. This figure illustrates how the position of the sun at 15:30.

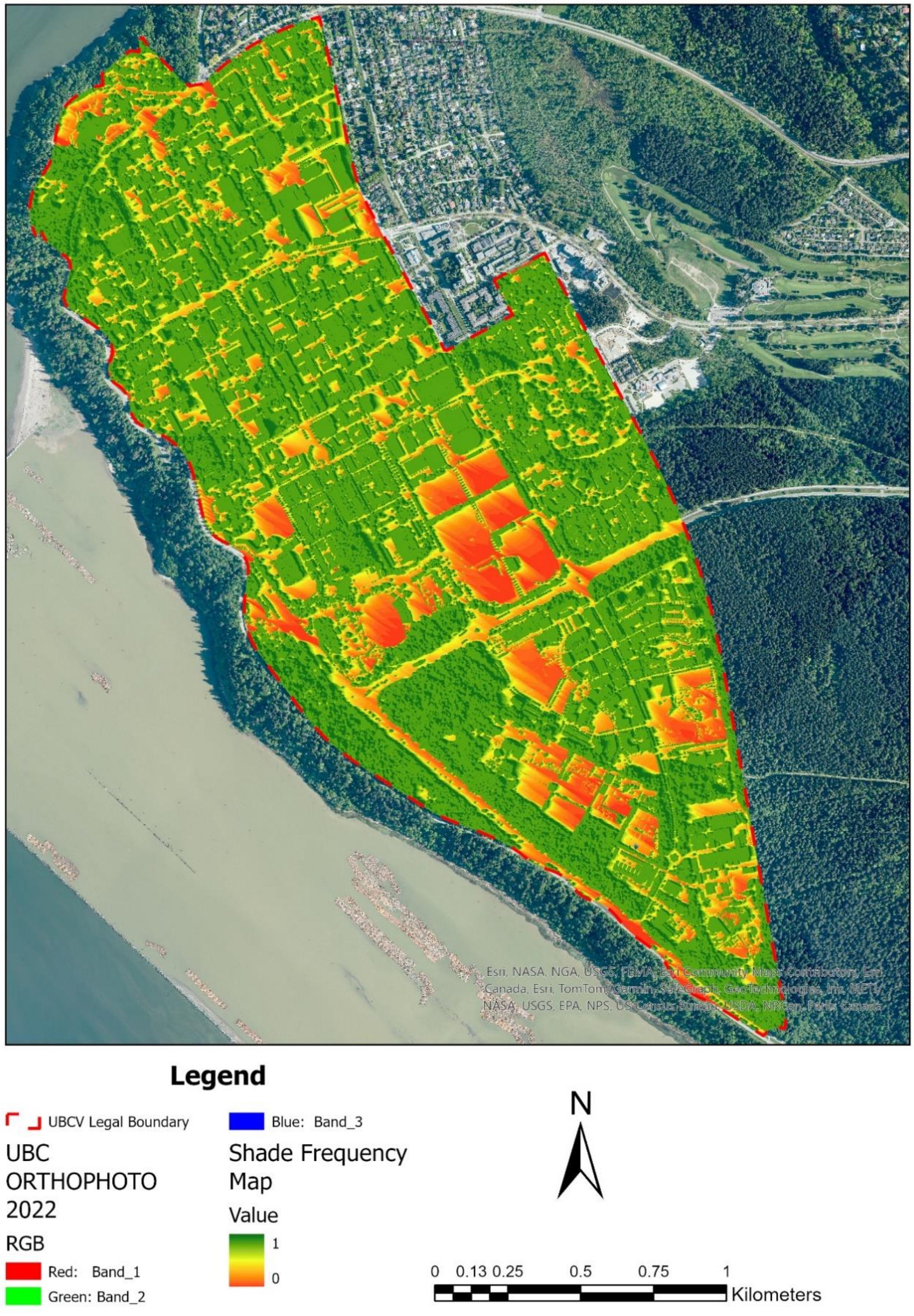


Figure 6. Comprehensive shade frequency map for the UBC Point Grey Campus. This map represents the proportion of time each pixel is shaded during the chosen time period (0 to 1). It includes adjustments for the limitations of the hillshade tool by assuming that areas underneath buildings and high vegetation are shaded 80% of the time.

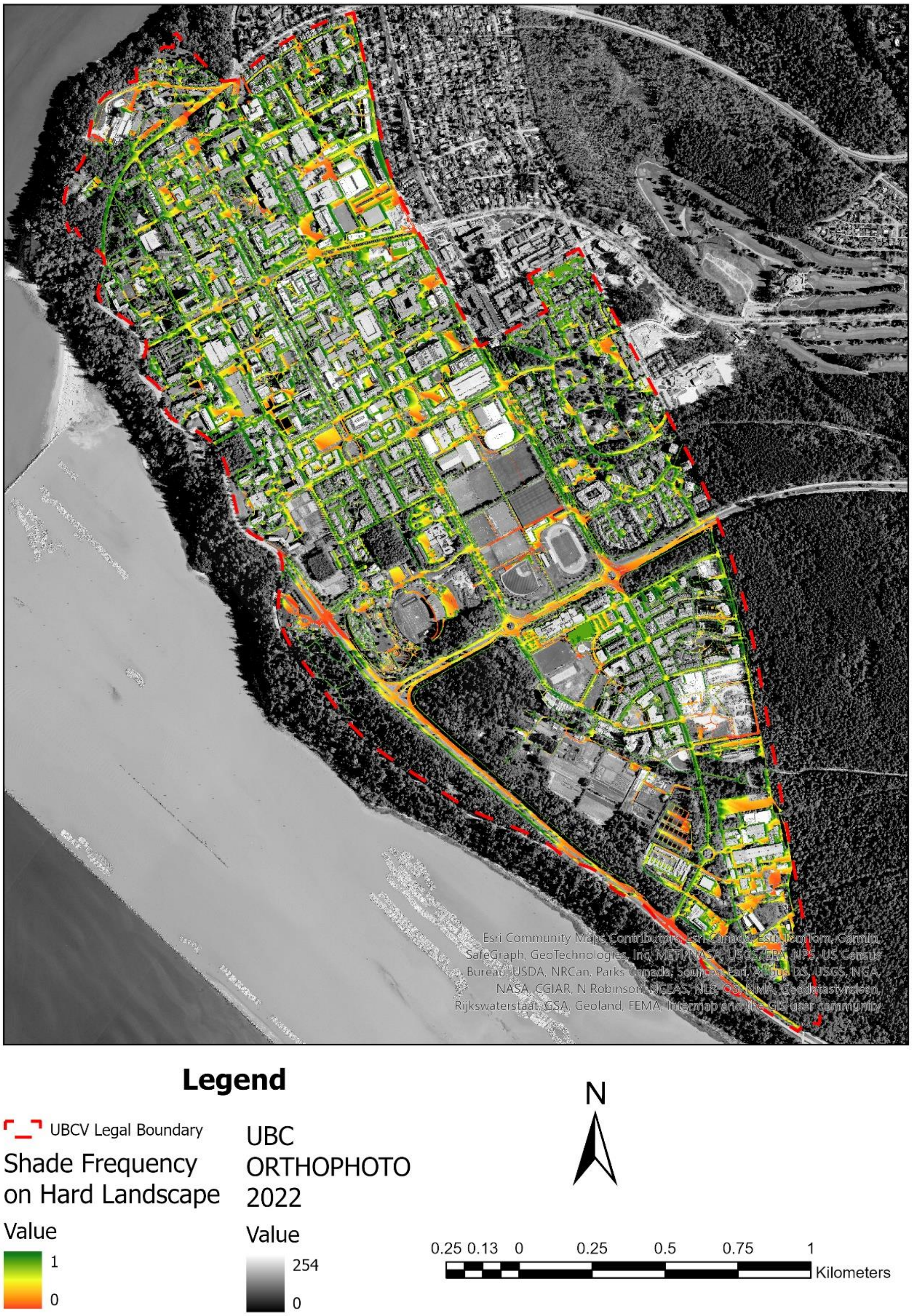


Figure 7. This figure shows the shade frequency on hard landscape surfaces like paths and bikeways on the UBC Point Grey campus. The values range from 0 (never shaded) to 1 (always shaded), helping to identify areas needing more shade for improved community wellbeing and climate adaptation.

4. Result

4.1 Shade Frequency for UBCV Campus

In terms of shade coverage for hard landscape across the UBCV campus, the mean coverage is 0.65, which means that during hot hours (from 1 pm to 8 pm), approximately 65% of the hard landscape including Concrete, Driveway, Parking, Pedestrian, and Road are covered by shades. This overall shade coverage is significant for ensuring that large areas of the campus provide some degree of protection from direct sunlight, contributing to the comfort and wellbeing of the campus community.

Among all types of hard landscape, pedestrian areas have the highest mean shade coverage at 0.69507 with the lowest standard deviation of 0.2473. This high mean coverage and low variability indicate that pedestrian areas consistently benefit from substantial shade. This is particularly important as it ensures a more comfortable walking experience for students, faculty, and visitors during the hottest parts of the day, reducing exposure to direct sunlight and potentially lowering the risk of heat-related discomfort or illnesses.

Conversely, concrete areas exhibit the lowest mean shade coverage at 0.434512 and the highest standard deviation of 0.309464. This suggests that concrete areas are less consistently shaded, with greater variability in shade coverage. The lower shade coverage in concrete areas can be attributed to the fact that many of these areas include large, open spaces such as playgrounds, sports fields, or parking lots, which lack overhead structures or trees that could provide shade.

Parking areas also show relatively low mean shade coverage at 0.562997 with a standard deviation of 0.257945. Similar to concrete areas, parking lots often consist of wide-open spaces without significant overhead cover, leading to less consistent shade coverage. This lower shade availability can contribute to higher temperatures in parked vehicles and increased discomfort for individuals accessing these areas during peak sun hours.

Driveways and roads have mean shade coverages of 0.62685 and 0.60014 respectively, with standard deviations of 0.255912 and 0.27556. These values indicate moderate shade coverage with some variability. The shade coverage in these areas can be influenced by the presence of roadside trees, buildings, and other structures that intermittently block direct sunlight.

The detailed breakdown of the shade frequency for different types of hard landscape is presented in the table below:

Table 3. Breakdown of the shade frequency for different types of hard landscape across the UBCV campus, showing the area (in square meters), mean shade coverage, and standard deviation for driveways, parking areas, roads, pedestrian areas, and concrete surfaces.

Landscape Type	Aera ($m^{2)}$	Mean	Standard Deviation
Driveway	145744	0.62685	0.255912
Parking	118789	0.562997	0.257945
Road	294176	0.60014	0.27556
Pedestrian	524494	0.695079	0.2473
Concrete	32202	0.434512	0.309464

4.2 Shade Frequency for UBC Neighbourhoods

The analysis of shade frequency across different Neighbourhoods within the UBC campus reveals variations in shade coverage due to differing land uses and stages of development. The mean shade coverage for each Neighbourhood is detailed in the table below:

Table 4. Detailed shade frequency for each Neighbourhood within the UBCV campus, showing the area (in square meters), mean shade coverage, and standard deviation. The table highlights variations in shade coverage across Neighbourhoods due to different land uses and stages of development.

Neighbourhood Name	Aera (m^2)	Mean	Standard Deviation
Hampton Place	113130	0.801659	0.123072
East Campus	31931	0.80882	0.139268
Chancellor Place	92716	0.763196	0.177126
Wesbrook Place	503286	0.686587	0.262094
Hawthorn Place	137206	0.788978	0.136777
UBlvd	36745	0.682389	0.235796
Stadium	69477	0.45889	0.300001
Acadia East	151934	0.752432	0.1919
Acadia Future	85595	0.77333	0.164427

Stadium has a significantly lower mean shade coverage (0.45889) compared to other Neighbourhoods. This is due to the predominant land use for sports activities, with hard landscapes primarily consisting of driveways and parking lots, which generally have less shade coverage.

Wesbrook Place, with a mean shade coverage of 0.686587, is another area with relatively lower shade coverage. This can be attributed to the large southeast region that is still under construction and lacks substantial shade, reducing the overall mean shade coverage for this Neighbourhood.

UBvlvd also exhibits a lower mean shade coverage (0.682389). This is particularly noticeable on pedestrian paths within the Neighbourhood, which lack sufficient shading, thereby affecting the overall mean shade coverage.

In contrast, East Campus has the highest mean shade coverage at 0.80882, indicating well-distributed and consistent shade across its hard landscape. This is followed closely by Hampton Place (0.801659) and Hawthorn Place (0.788978), both of which also show high levels of shade coverage with relatively low standard deviations, reflecting consistent and effective shading in these Neighbourhoods.

The remaining Neighbourhoods, such as Chancellor Place, Acadia East, and Acadia Future, also demonstrate substantial shade coverage, with mean values ranging from 0.752432 to 0.77333, indicating a well-shaded environment which contributes to the comfort and wellbeing of residents and visitors during hot hours.2w

4.3 Shade Frequency for UBCV Bus Stop

The shade coverage analysis extended to 42 bus stations within the UBCV campus, using a 5-meter buffer around each station. The analysis identified three poorly shaded bus stations and three well-shaded bus stations, as shown in Tables 5 and 6.

4.3.1 Poorly Shaded Bus Stations

1. **UBC Exchange Bay 8**: This station has the lowest mean shade coverage (0.160035) and a standard deviation of 0.022069. Its poor shading is attributed to its location next to a construction site with no shade-providing objects.
2. **EB W 16 Ave FS Wesbrook Mall**: With a mean shade coverage of 0.213528 and a standard deviation of 0.080408, this station has large trees on its southeast that do not provide shade when sunlight comes from the northwest during summer.
3. **WB W 16 Ave NS Wesbrook Mall**: This station has a mean shade coverage of 0.353121 and a standard deviation of 0.023416. Similar to EB W 16 Ave FS, the northwest positioning of trees results in insufficient shade during summer afternoons.

Figure 7 displays three bus stations that are identified as poorly shaded. Due to data mismatches between LiDAR-generated data and aerial photographs, EB W 16 Ave FS Wesbrook Mall and WB W 16 Ave NS Wesbrook Mall appear to have full shade coverage in the aerial photos. However, this does not accurately reflect the conditions during peak sunlight hours. These images were captured earlier in the day, when the sun's position does not cast direct light on these locations. As a result, the shading depicted in these photos does not represent the actual shade conditions during the hottest parts of the day, when shade is most critical. This discrepancy is further discussed in Section 5.3, where the limitations associated with mismatches between LiDAR data and aerial photographs are examined. Aerial images can sometimes capture conditions that are not representative of peak heat times, leading to potential misinterpretations of shade coverage in the analysis.

Common Factors for Poorly Shaded Bus Stations:

- Proximity to construction sites or areas with few or no shade-providing objects.
- Large trees situated in positions that do not block sunlight effectively during peak sunlight hours (e.g., trees on the southeast side when sunlight is coming from the northwest).

Table 5. 3 Poorly Shaded Bus Stations with the Least Shade Coverage.

Bus Station Name	Zone Code	Mean	Standard Deviation
UBC EXCHANGE BAY 8	33	0.160035	0.022069
EB W 16 AVE FS WESBROOK MALL	13	0.213528	0.080408
WB W 16 AVE NS WESBROOK MALL	14	0.353121	0.023416

Figure 8. Aerial images of the three poorly shaded bus stations: UBC Exchange Bay 8, EB W 16 Ave FS Wesbrook Mall, and WB W 16 Ave NS Wesbrook Mall. These stations show minimal shade coverage during peak sunlight hours, highlighting areas for potential improvement in shading solutions.

4.3.2 Well-Shaded Bus Stations

1. **SB Wesbrook Mall at TRIUMF Centre**: This station boasts a high mean shade coverage (0.886774) and a standard deviation of 0.086261, benefiting from nearby buildings and tall trees providing ample shade.
2. **SB East Mall FS Eagles Dr**: With a mean shade coverage of 0.890716 and a standard deviation of 0.089233, this station is well-shaded due to its proximity to large trees and buildings.
3. **SB Wesbrook Mall NS Birney Ave**: This station has the highest mean shade coverage (0.908773) and a standard deviation of 0.088475, primarily due to the large trees and building structures nearby.

Figure 8 shows three well-shaded bus stations: SB Wesbrook Mall at TRIUMF Centre, SB East Mall FS Eagles Dr, and SB Wesbrook Mall NS Birney Ave. These bus stations benefit from nearby buildings and tall trees, which provide significant shade coverage during peak sunlight hours.

Common Factors for Well-Shaded Bus Stations:

- Presence of large trees and buildings nearby that effectively block sunlight.
- Strategic placement under or near structures that provide consistent shade throughout the day.

Table 6. 3 Well Shaded Bus Stations with the Most Shade Coverage.

Bus Station Name	Zone Code	Mean	Standard Deviation
SB WESBROOK MALL AT TRIUMF CENTRE	19	0.886774	0.086261
SB EAST MALL FS EAGLES DR	26	0.890716	0.089233
SB WESBROOK MALL NS BIRNEY AVE	20	0.908773	0.088475

Figure 9. Aerial images of the three well-shaded bus stations: SB Wesbrook Mall at TRIUMF Centre, SB East Mall FS Eagles Dr, and SB Wesbrook Mall NS Birney Ave. These stations benefit from nearby buildings and tall trees, providing significant shade coverage during peak sunlight hours.

4.4 Shaded Frequency for Parks and Usable Neighbourhood Open Space

The shade frequency analysis extended to various parks and usable Neighbourhood open spaces within the UBC campus, highlighting areas with both high and low mean shade coverage. The analysis identified three poorly shaded parks and three well-shaded parks, as shown in the provided data and figures.

4.4.1 Poorly Shaded Parks

1. **Brockhouse Park**: This park has the lowest mean shade coverage (0.414759) with a standard deviation of 0.282231. The low shade coverage can be attributed to the open, unshaded areas primarily used as a playfield, which do not provide adequate shade during peak sunlight hours. The absence of large trees or shaded structures contributes to the park's exposure to direct sunlight, making it less comfortable during hot periods.
2. **Theology Mall - Round**: This area, with a mean shade coverage of 0.425757 and a low standard deviation of 0.069159, is poorly shaded due to the absence of large trees and the

presence of small shrubs that are insufficient to provide substantial shade. The limited vegetation cover results in minimal shading, particularly during the hottest parts of the day.

3. **Theology Mall**: Similarly, Theology Mall exhibits a low mean shade coverage of 0.440892 and a standard deviation of 0.245946. The lack of significant shade-providing structures or large trees contributes to the overall low shade coverage, making the area more prone to heat exposure.

Figure 9 shows the aerial images of these poorly shaded parks. The open spaces and lack of substantial vegetation are evident, which results in lower shade coverage during critical hours of the day. These areas would benefit from targeted interventions, such as planting additional trees or installing shade structures to enhance comfort and usability.

Table 7 3 Poorly Shaded Parks with the Most Shade Coverage.

Name	Zone Code	Area (m^2)	Mean	Standard Deviation
Theology Mall	15	552	0.440892	0.245946
Theology Mall - Round	16	49	0.425757	0.069159
Brockhouse Park	18	24587	0.414759	0.282231

Figure 10 Aerial images of Brockhouse Park and Theology Mall at UBC. Brockhouse Park's low shade coverage is primarily due to its large open playfield area, which lacks overhead shade. The Theology Mall area, including Theology Mall - Chancellor, Theology Mall - Folio, and Theology Mall - Round, exhibits lower shade coverage due to the absence of large trees, with only small shrubs that do not provide sufficient shade.

Common Factors for Poorly Shaded Parks:

- Large, open spaces with minimal vegetation.
- Absence of large trees or shade-providing structures.
- Predominantly used as playfields or other open activities that do not require immediate shade.

4.4.2 Well-Shaded Parks

1. **Wesbrook Buffer**: This urban forest area surrounding the Wesbrook residential Neighbourhood boasts the highest mean shade coverage (0.852248) with a low standard deviation of 0.093809. The area consists of medium to high vegetation, providing consistent and effective shade coverage throughout the day.
2. **Lot 2**: This area has a mean shade coverage of 0.859352 and a standard deviation of 0.099885. The high vegetation density within Lot 2 offers substantial shade, making it one of the most comfortable outdoor spaces during peak heat times.
3. **Eagles Nest**: With a mean shade coverage of 0.858275 and a standard deviation of 0.115524, Eagles Nest benefits from the combination of surrounding buildings and tall trees that provide extensive shade. This results in a well-shaded environment that remains cool and comfortable even during the hottest parts of the day.

Figure 10 illustrates the well-shaded parks, showcasing the dense vegetation and strategic placement of trees and buildings that contribute to the high shade coverage. These parks provide ideal environments for recreation and relaxation, especially during periods of intense sunlight.

Common Factors for Well-Shaded Parks:

- High density of medium to tall vegetation.
- Presence of buildings or other structures that enhance shade coverage.
- Strategic location of trees and foliage to maximize shade throughout the day.

Table 8 3 Well Shaded Parks with the Most Shade Coverage.

Name	Zone Code	Area (m^2)	Mean	Standard Deviation
Lot 2	13	11450	0.859352	0.099885
Wesbrook Buffer	21	43476	0.852248	0.093809
Eagles nest	26	1676	0.858275	0.115524

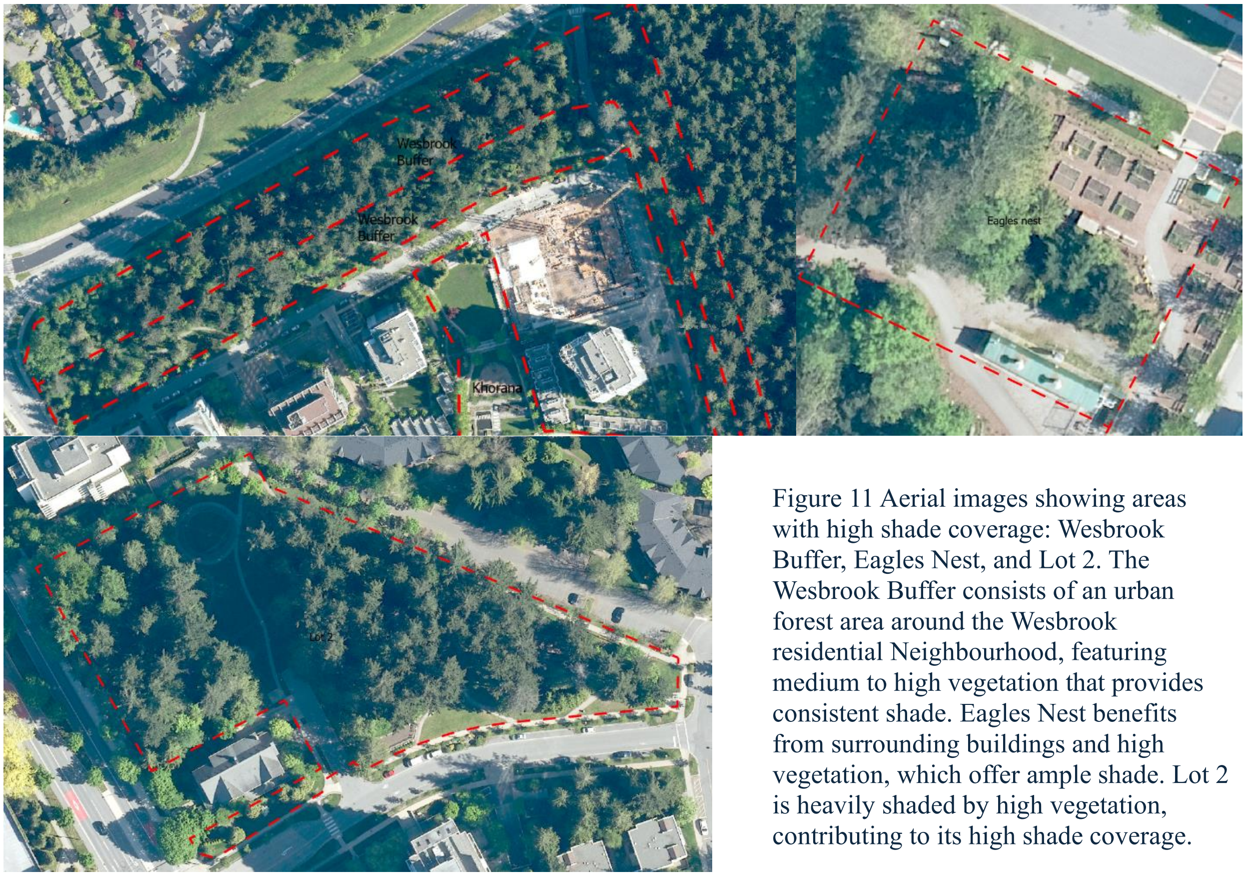


Figure 11 Aerial images showing areas with high shade coverage: Wesbrook Buffer, Eagles Nest, and Lot 2. The Wesbrook Buffer consists of an urban forest area around the Wesbrook residential Neighbourhood, featuring medium to high vegetation that provides consistent shade. Eagles Nest benefits from surrounding buildings and high vegetation, which offer ample shade. Lot 2 is heavily shaded by high vegetation, contributing to its high shade coverage.

5. Recommendations, Limitations and Future Works

As a methodology-driven research project, the objective was to develop a robust approach to analyzing shade coverage across the UBCV campus and demonstrate its application through detailed statistics and information. The results presented in this report highlight one specific way the developed methodology can be applied to inform urban planning and enhance shade coverage for the wellbeing of the campus community.

All results stated in Section 4 are based on statistics. While statistics can reveal patterns and tendencies, they may not be sufficient for planners to make precise decisions. Visualization tools, like Figures 4 and 5, provide planners with opportunities to zoom into specific areas, identifying where shade is lacking and where additional trees or shade structures are needed. These visual aids complement statistical analysis by offering a clearer, more detailed understanding of shade distribution across the campus, which is the most valuable part of the research.

Moreover, the results shown are just one possibility. This methodology can be expanded and adapted to various other fields impacted by shade, such as energy efficiency, ecological conservation, and public health. The insights gained from this research should inspire further enhancements to the campus environment, ensuring that shade coverage is optimized and contributes to a more comfortable and sustainable urban landscape.

5.1 Recommendations for Future Planning

5.1.1 For the Whole Campus:

The importance of shade coverage on the UBCV campus cannot be overstated, particularly for pedestrian areas where people spend significant amounts of time walking, commuting, and engaging in outdoor activities. Effective and consistent shade coverage is essential for providing comfort, reducing heat-related stress, and promoting overall wellbeing among students, faculty, and visitors.

While the analysis shows that pedestrian areas generally have good shade coverage, with a mean coverage of 0.69507, there are still zones that remain under-covered. This inconsistency indicated by the standard deviation of 0.2473 can result in uncomfortable walking experiences during the hottest parts of the day, increasing the risk of heat-related discomfort or illnesses. To address these gaps, it is crucial to enhance the consistency of shade in pedestrian areas. Installing additional shade structures, such as canopies or pergolas, can provide immediate relief in areas with frequent human activities. Additionally, strategically planting more trees with broad canopies can offer long-term shade solutions that grow over time and adapt to the campus landscape.

For areas classified as concrete, such as fields or playgrounds, which currently lack sufficient shade, placing shelters or shaded rest areas can provide necessary respite for individuals engaging in outdoor activities. These shelters can be designed to blend with the campus aesthetics while offering functional benefits. For example, incorporating green roofs or vinecovered pergolas can enhance both the visual appeal and environmental benefits of these structures.

In summary, by focusing on enhancing shade coverage for pedestrian areas and installing shelters in open concrete spaces, the UBCV campus can ensure a more comfortable and safer environment for its community, particularly during peak sunlight hours. This proactive approach will not only improve the quality of life on campus but also demonstrate a commitment to sustainable and people-centered urban planning.

5.1.2 For UBC Neighbourhoods:

Targeted interventions are necessary to increase shade coverage in Neighbourhoods like Wesbrook Place and UBlvd, where shade is currently insufficient. Enhancing shade coverage in these areas can significantly improve the microclimate, making it more comfortable for residents and visitors alike.

For Wesbrook Place, which has a mean shade coverage of 0.686587, the lower shade availability can be attributed to large areas still under construction and lacking substantial shade. To address this, planting trees in these under-developed regions is a crucial step. Trees with broad canopies should be selected to ensure that as they grow, they provide extensive and consistent shade. In the interim, temporary shelters or shade structures can be installed to offer immediate relief until the newly planted trees mature.

UBlvd is different from regular Neighbourhoods in that it has more walking areas where pedestrians frequently access. Its current mean shade coverage of 0.682389 indicates a need for improvement. Given the high pedestrian traffic, increasing the number of trees along walkways is essential. Trees should be strategically planted to create shaded corridors that enhance the walking experience. In addition to tree planting, the installation of shade structures such as awnings or covered walkways can provide immediate benefits. These structures not only offer shade but also protect pedestrians from inclement weather, adding to their overall utility.

In summary, for Neighbourhoods like Wesbrook Place and UBlvd, a combination of long-term and short-term strategies is recommended. Planting trees and installing temporary shade structures in currently under-shaded areas will create a more comfortable and inviting environments for all users, enhancing the overall quality of life in these Neighbourhoods.

5.1.3 For Bus Stations:

Bus stations, especially those in high-traffic areas, require more shade to improve the waiting experience for commuters. Providing adequate shade at bus stops is crucial for enhancing commuter comfort, reducing heat exposure, and improving overall user experience. There are several strategies to achieve this:

Installing Shade Structures: Permanent shade structures such as canopies or awnings can be installed at bus stops. These structures should be designed to provide maximum coverage throughout the day, considering the sun's position and movement. Materials used should be durable and capable of withstanding weather conditions while providing ample shade.

Planting Trees: Strategically planting trees around bus stops can create natural shade. Trees with broader canopies should be chosen to ensure they provide effective cover. It is important to consider the placement of these trees to maximize their shading potential throughout the day, especially during peak sunlight hours. Trees should be positioned to cast shadows over waiting areas without obstructing pathways or visibility.

Addressing Specific Bus Stations: Some bus stations already benefit from natural shade provided by existing trees or shelters. For example, stations such as SB Wesbrook Mall at TRIUMF Centre, SB East Mall FS Eagles Dr, and SB Wesbrook Mall NS Birney Ave have high mean shade coverage due to their strategic placement. These examples highlight the importance of thoughtful planning and design in creating well-shaded bus stops.

Considering Sun Position and Direction: When planning new tree plantings or installing shade structures, it's essential to account for the sun's position and direction during the hot season. This ensures that the shade provided is effective throughout the day. Trees should be placed on the side where they will block the most sunlight, depending on the specific location and sun path.

Temporary Solutions: While waiting for newly planted trees to mature, temporary solutions such as installing temporary shelters or shade sails can provide immediate relief. These can be removed or replaced once the permanent shade solutions are effective.

By implementing these strategies, the shading at bus stops can be significantly improved, providing commuters with a more comfortable and cooler waiting environment. The combined approach of installing both natural and artificial shade structures will ensure that bus stops are well-protected from the sun throughout the day.

5.1.4 For Parks and Usable Neighbourhood Open Spaces:

Parks and open spaces serve various purposes and are designed to meet the needs of different activities. Therefore, recommendations for enhancing shade coverage must be tailored to each park's intended use rather than applying a one-size-fits-all approach.

For example, Brockhouse Park is primarily dedicated as a playfield with open spaces that naturally have little shade. In such areas, rather than introducing extensive tree coverage that could interfere with recreational activities, it is more appropriate to focus on providing sufficient shade around the perimeter of the playfield. This could include installing shaded rest areas with benches or planting trees around the edges of the field to offer temporary respite for people who are resting between activities.

On the other hand, spaces like Theology Mall - Round are designed more for landscape aesthetics and as visual elements within the campus, rather than for prolonged human occupation. The low shade coverage in these areas is unlikely to cause significant discomfort since people do not typically spend extended periods there. Thus, enhancing shade in such locations may not be necessary or could even detract from the intended visual impact of the space.

By recognizing the distinct purposes of different parks and open spaces, urban planners can make informed decisions that balance the need for shade with the functional and aesthetic goals of each area. For parks where shade is essential for comfort, targeted interventions like planting trees in key locations or adding shade structures should be prioritized. Conversely, for parks that serve more as visual landscapes, maintaining low shade coverage may be appropriate to preserve their intended design and use.

5.2 Potential Uses of the Baseline Shade Coverage Mapping

5.2.1 Identify Low Shade Coverage Areas:

The baseline shade map is a valuable tool for urban planners and landscape architects, providing a clear visual representation of areas with insufficient shade. By pinpointing these low shade coverage zones, planners can prioritize interventions to improve the microclimate and enhance the comfort of these areas. Ground-truth validation through on-site investigations is crucial to ensure the accuracy of the baseline shade map and to validate the findings from hillshade analysis.

Using the baseline shade map, planners can:

Prioritize Planting Sites: Identify specific locations where tree planting or the installation of shade structures is most needed. This targeted approach ensures resources are allocated efficiently, maximizing the impact of shade enhancement efforts.

Design Effective Shade Solutions: Develop strategic plans for planting trees with broad canopies or installing shade structures in areas identified as having low shade coverage. Consideration of the sun's path and seasonal variations will help ensure these solutions provide effective shade throughout the day and year.

Enhance Public Spaces: Improve the usability and comfort of public spaces such as parks, playgrounds, and pedestrian pathways by increasing shade coverage. This is particularly important in areas where people gather or spend extended periods.

Support Heat Mitigation Strategies: Contribute to broader urban heat island mitigation strategies by increasing vegetative cover and shade in critical areas, thereby reducing ambient temperatures and improving urban resilience to heatwaves.

By guiding future planning with data-driven insights, the baseline shade map plays a crucial role in creating a more comfortable and sustainable urban environment.

5.2.2 Solar PV System Analysis:

The baseline shade map is also instrumental in identifying areas that are frequently exposed to solar radiation, which is essential for promoting the installation of solar photovoltaic (PV) systems. Analyzing rooftop solar PV potential in urban areas involves assessing the available rooftop area that receives adequate sunlight, a factor that varies significantly due to building shadows.

In contrast to identifying shaded areas, the baseline shade map helps planners to:

Maximize Solar Energy Utilization: Determine which rooftops receive sufficient sunlight throughout the day and are suitable for installing solar PV systems. This ensures that solar panels are placed in locations where they can generate maximum energy.

Optimize Rooftop Space: Accurately estimate the available rooftop area for solar PV installations by analyzing building shadows. This includes considering factors such as shadow length, direction, and duration to ensure the panels are not obstructed by nearby structures.

Plan for Solar Infrastructure: Guide the development of solar infrastructure in urban areas by identifying ideal locations for solar panel installations. This can be integrated into building designs and urban planning to enhance renewable energy adoption.

Balance Shade and Solar Needs: Achieve a balance between providing shade for pedestrian comfort and maximizing solar energy capture. For instance, strategically planting trees or installing shade structures in a way that does not significantly interfere with rooftop solar potential.

Using the baseline shade map, urban planners can make informed decisions that support both shade enhancement and solar energy initiatives, contributing to a more sustainable and resilient urban environment.

5.3 Limitations

Hillshade Limitations: The hillshade method used in this research has inherent limitations. It primarily simulates shadows on the surface of objects based on their height and the sun's position but does not account for shaded areas underneath trees or structures like bus shelters. This limitation means that the analysis might underestimate the actual shade provided by large trees with extensive canopies or by architectural features designed to offer shade. Additionally, hillshade analysis is limited to horizontal surfaces and cannot accurately model the shade on vertical surfaces such as the sides of buildings. This restriction is significant in urban environments where the vertical surfaces of buildings can play a crucial role in shading streets and pedestrian walkways.

Data Timeliness: The analysis in this study relies heavily on LiDAR data, which captures the 3D structure of the environment. However, LiDAR data can become outdated, especially in rapidly developing urban areas where new buildings, roads, and other structures are continually being constructed or modified. Using outdated LiDAR data can lead to inaccuracies in the shade coverage analysis, as it may not reflect the current state of the urban landscape. Therefore, it is crucial to ensure that the LiDAR data used is as recent as possible to maintain the accuracy and relevance of the analysis.

Data Mismatch: There is a potential for mismatches between the LiDAR data and aerial photographs used in the study. These mismatches can occur due to differences in the timing of data acquisition, variations in data resolution, and changes in the landscape over time. Such discrepancies can affect the accuracy of the shade analysis and lead to incorrect conclusions about shade coverage. Ground-truth data, obtained through on-site investigations, is essential for validating the findings from the hillshade analysis and ensuring that the data accurately represents the actual conditions on the ground.

Spatial and Temporal Resolution: The spatial and temporal resolution of the data used in the hillshade analysis can also present limitations. High spatial resolution is necessary to capture detailed features of the urban environment, but it requires significant computational resources and data storage. Similarly, fine temporal resolution, such as the 15-minute intervals used in this study, enhances the accuracy of the shade simulation but increases the computational load. Balancing the need for high resolution with the available computational capacity is a critical challenge in conducting large-scale urban shade analysis.

Assumptions in Shade Coverage: The study made certain assumptions, such as assigning a shade value of 0.8 to areas underneath buildings and high vegetation. While these assumptions help to approximate real-world conditions, they introduce a level of uncertainty into the analysis. The actual shade provided can vary based on numerous factors, including the density of foliage, the height and orientation of buildings, and seasonal changes in vegetation.

Computational Power and Resources: Conducting detailed shade analysis, especially over large urban areas, requires substantial computational power and resources. The limitations in available computational resources can constrain the scope of the analysis, affecting the ability to process high-resolution data or perform long-term simulations that account for seasonal variations in shade.

5.4 Future Work

3D Multipatch Analysis: To address the limitations of the hillshade method, future research should explore 3D multipatch analysis. This approach can simulate shadows on both horizontal and vertical surfaces, providing a more comprehensive understanding of shade distribution in urban environments. While this method requires significantly more computational power, it can overcome the limitations of 2D hillshade analysis and offer a more accurate representation of shade.

Tree Inventory Data: Incorporating detailed tree inventory data can enhance the accuracy of shade analysis by identifying the specific species and characteristics of trees that contribute to shade coverage. Understanding the correlation between tree species, their canopy size, and the shade they provide can guide more effective tree planting strategies. This data can help urban planners select the most suitable tree species for different urban areas to maximize shade coverage and improve the urban microclimate.

Enhanced Computational Techniques: Advancing computational techniques and software can enable more detailed and efficient shade analysis. Leveraging high-performance computing resources and developing algorithms optimized for large-scale urban shade mapping can improve the accuracy and efficiency of the analysis. This advancement will allow researchers to handle larger datasets and perform more complex simulations, enhancing the quality of shade coverage assessments.

Integration with Urban Planning: Integrating shade analysis into broader urban planning efforts is essential for creating sustainable and comfortable urban environments. Shade coverage should be considered in the design and development of new buildings, roads, and public spaces. By incorporating shade analysis into urban planning, cities can ensure that new developments contribute positively to the urban microclimate, providing adequate shade for pedestrians and reducing the urban heat island effect. This integration can also support the implementation of green infrastructure and other sustainable urban design practices.

By addressing these recommendations and limitations, and exploring future research directions, we can enhance the effectiveness of shade coverage analysis and contribute to more comfortable and sustainable urban environments.

Appendix

Shade Frequency Statistics for Bus Stations

Name	Zone Code	Mean	Standard Deviation
SB WESBROOK MALL NS AGRONOMY RD-	1	0.800368	0.003164
SB WESBROOK MALL AT HAMPTON PL	2	0.874814	0.092645
NB WESBROOK MALL FS THUNDERBIRD BLVD	3	0.74244	0.116133
NB WESBROOK MALL AT TRIUMF CENTRE	4	0.690109	0.104276
WB W 16 AVE FS WESBROOK MALL	5	0.812732	0.083376
WB STADIUM RD FS WEST MALL	6	0.824007	0.058979
WB THUNDERBIRD BLVD FS LARKIN DR	7	0.723961	0.099843
SB WEST MALL FS HAWTHORN LANE	8	0.490354	0.308931
EB NW MARINE DR NS EAST MALL	9	0.478621	0.234005
SB WESBROOK MALL FS IONA DR	10	0.734348	0.22222
EB NW MARINE DR FS WEST MALL	11	0.54023	0.158508
NB WESBROOK MALL AT 2900 BLOCK	12	0.732272	0.134174
EB W 16 AVE FS WESBROOK MALL	13	0.213528	0.080408
WB W 16 AVE NS WESBROOK MALL	14	0.353121	0.023416
EB W 16 AVE NS WESBROOK MALL	15	0.49821	0.249843
NB WESBROOK MALL NS W 16 AVE	16	0.654277	0.275816
WB NW MARINE DR FS CECIL GREEN PARK RD	17	0.461008	0.223103
SB WESBROOK MALL FS THUNDERBIRD BLVD	18	0.664251	0.211369
SB WESBROOK MALL AT TRIUMF CENTRE	19	0.886774	0.086261
SB WESBROOK MALL NS BIRNEY AVE	20	0.908773	0.088475
NB WESBROOK MALL FS BIRNEY AVE	21	0.780445	0.069785
UBC EXCHANGE BAY 10	22	0.597187	0.23347
UBC EXCHANGE BAY 11	23	0.434919	0.192517
EB AGRONOMY RD NS WEST MALL	24	0.816379	0.049123
EB THUNDERBIRD BLVD NS EAGLES DR	25	0.613528	0.26358
SB EAST MALL FS EAGLES DR	26	0.890716	0.089233
EB ROSS DR FS BIRNEY AVE	27	0.875172	0.049391

SB WEST MALL FS NW MARINE DR	28	0.677726	0.110626
SB LOWER MALL FS UNIVERSITY BLVD	29	0.654288	0.123835
WB ROSS DR NS BIRNEY AVE	30	0.486687	0.154698
NB EAST MALL FS EAGLES DR	31	0.632602	0.264165
UBC EXCHANGE BAY 7	32	0.465997	0.261753
UBC EXCHANGE BAY 8	33	0.160035	0.022069
NB LOWER MALL NS UNIVERSITY BLVD	34	0.532257	0.134433
UBC EXCHANGE BAY 1	35	0.731121	0.12049
UBC EXCHANGE BAY 2	36	0.72575	0.119539
UBC EXCHANGE BAY 4	37	0.533362	0.250635
UBC EXCHANGE BAY 6	38	0.473592	0.305526
UBC EXCHANGE UNLOAD ONLY--	39	0.53182	0.25593
SB WESBROOK MALL NS AGRONOMY RD	40	0.800354	0.003103
NB WESBROOK MALL NS AGRONOMY RD	41	0.556852	0.245108

Shade Frequency Statistics for Parks and Usable Neighbourhood Open Spaces

Name	**Zone Code**	**Area (m^2)**	**Mean**	**Standard Deviation**
Nobel	1	11581	0.585691	0.276053
Theology Mall - Chancellor	2	300	0.726483	0.218874
Folio-St Marks	3	429	0.787847	0.123393
Future	4	9494	0.663219	0.251596
Eagles Park	5	2551	0.745298	0.177443
Theology Mall - Folio	6	305	0.527123	0.316671
Hawthorn Park	7	323	0.829038	0.099434
Iona - Playground	8	4960	0.743783	0.226387
Smith	9	11506	0.690088	0.208311
St Marks Duplex	10	177	0.836197	0.108135
Epiphany Chapel	11	2107	0.712472	0.204613
St Andrews	12	1722	0.831583	0.148477
Lot 2	13	11450	0.859352	0.099885
Iona	14	1114	0.681681	0.248489
Hawthorn Park	15	3371	0.740748	0.171477
Theology Mall	16	552	0.440892	0.245946
Theology Mall - Round	17	49	0.425757	0.069159

Khorana	18	9763	0.759354	0.170351
Brockhouse Park	19	24587	0.414759	0.282231
Village Green	20	2014	0.755796	0.185001
Jim Taylor Park	21	2642	0.742442	0.171437
Wesbrook Buffer	22	19287	0.85159	0.105011
Sumac - Cascara	23	753	0.813344	0.148569
Others	24	14856	0.848488	0.081874
Wesbrook Buffer	25	24284	0.85279	0.083829
Carey Hall	26	484	0.794899	0.121496
Main Mall Greenway - Eagles Dr	27	592	0.692276	0.180193
Eagles nest	28	1676	0.858275	0.115524
Norman Mackenzie Square	29	820	0.715013	0.189937
St Marks	30	495	0.832337	0.11596
Future	31	10488	0.483126	0.267058
Others	32	6390	0.8545	0.105226
Main Mall Greenway - Larkin Dr	33	596	0.792016	0.140164
Wesbrook Greenway	34	24526	0.839713	0.139987
Jim Taylor Park - Old Barn	35	2765	0.779333	0.129394
Webber Lane	36	1364	0.655501	0.22898

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