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Student Research Report

Assessment of Green Roof Suitability by Active Remote Sensing of University of British Columbia Buildings

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THE UNIVERSITY OF BRITISH COLUMBIA

Assessment of Green Roof Suitability by Active Remote Sensing of University of British Columbia Buildings

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Abstract

Green roofs are a promising mitigation tool against environmental concerns caused by increased urbanization. This study aims to address which of the University of British Columbia's buildings are most suitable for a retrofitted green roof using active remote sensing. Through the assessment of the six characteristics of buildings, a suitability score was given to all the buildings within the area of interest on campus. The six suitability criteria are roof slope, rooftop area, building usage, building ownership, structural materials, and light intensity. The six suitability characteristics where selected based off literature on existing green roof retrofitting analyzing their structure, types and performance. This study is part of the Social Ecological Economic Development Studies (SEEDS) Sustainability Program to address sustainability policies and practices on UBC's campus. The building suitability analysis resulted in the detection of five buildings with the greatest suitability score and their total rooftop area being 31,940.80 m^2. Each of the five buildings then was further investigated in terms of the vegetation health and density surrounding the buildings to isolate potential concerns of planting in the area. The mean NDVI of the existing greenery surrounding the top five suitable buildings is 0.67, indicative of moderate to high density vegetation. Implementing green roof retrofitting on the suitable UBC buildings requires an additional accessibility analysis to maximize the positive social impacts of increasing campus greenery and make decisions on the green roof structure.

Keywords:

Green roof; Retrofit; Sustainability; Remote sensing; Urbanization; University of British Columbia; Suitability; Vegetation; Lidar

Introduction

The Effect of Urbanization on Green Space

Urban areas face challenges in resiliency to climate change. The result of urbanization has led to 56% of the world population residing in urban areas, causing a need for sustainable solutions to the problems of urbanization (Alim et al., 2022). As the development of urban areas continues, the literature shows a decrease in green spaces and permeable surfaces along with increases in air pollution, the heat island effect, and energy consumption (Alim et al., 2022). The heat island effect occurs when an area has a higher average temperature then its surrounding area (Taha, 2004). In order to develop roads and buildings, it is often green spaces that are lost, leading to a significant decrease in ground permeability. In urban areas, about 40- 50% of impermeable surfaces are roof tops (Stovin, 2010). The permeability of the roofs can be improved with the installation of green roofs. A benefit of green roofs, is that it does not require additional land consumption, only that of the existing building. Making green roofs an impactful strategy for addressing common problems of urbanization. The criteria for a roof to be well suited for a green roof is the slope, usable area, building ownership and use, structural integrity, and light intensity. The purpose of this paper is to evaluate buildings on the University of British Columbia (UBC) Vancouver campus to create a list of suitable building roofs for the retrofit of green roofs.

As urbanization continues, energy demands of the dense urban centers increases. The energy consumption for air conditioning and central heating poses challenges in developing cities (Wang et al., 2022). Buildings often account for a majority of energy consumption for entire nations, most of which goes to maintaining building temperature (Castleton et al., 2010). Green roofs can act as a buffer protecting the rooftop from heat loss while improving solar reflectivity (Castleton et al., 2010). Retrofitting rooftops here at UBC may assist in the goals set by the Climate Action Plan 2030, to have campus buildings be 80% more energy efficient by 2032 (*UBCV CAP2030 FINAL.Pdf*, n.d.) Previous records have even suggested that most buildings retrofitted with a green roof do not require additional structural support due to the increased weight (Castleton et al., 2010). Though the age and original structural materials must be accounted for. The green roof structure also plays a role in the thermal buffering potential, as thicker layers of the substrate can reduce heat loss or gain from the building, though adding more weight. Substrate thickness correlates with the 4 categories of green roof structure: single-course extensive, multi-course extensive, semi-intensive and intensive (Shafique et al., 2018). The complexity and thickness increase, respectively. In order for green roofs to be an efficient solution for building energy consumption, multiple factors must be weighed out to provide a maximum benefit at the least cost.

Green Roof Solutions

Green roofs can be broadly classified as extensive or intensive. Each further subdivides to create the 4 types mentioned above. Extensive green roofs consist of a thin layer of substrate (<15 cm) which carpets areas of rooftops but can only facilitate the growth of shallow rooting plants such as grasses and sedums (Stovin, 2010; Vijayaraghavan, 2016). They are quite common since they require less maintenance, irrigation, cost, and weight load (Cascone, 2019). These traits allow extensive green roof installation on roofs with less accessibly and with a larger slope. Since cost plays a large role in installation and maintenance, extensive green roofs provide a great option. The purpose of intensive green roofs is often to provide garden space, community gardens, and increase benefits such as water retention, carbon sequestration, and thermal performance (Vijayaraghavan, 2016). Intensive green roofs require a substrate depth of greater than 15-20 cm and can facilitate the growth of a large range of plant types. This comes with a higher cost of maintenance, greater weight load, requirement of a low degree of slope, and functional accessibility (Cascone, 2019). Components required for both types are generally the same consisting of the following layers: vegetation, growth substrate, filter fabric, drainage element, protective layer, root barrier, insulating layer, waterproof membrane, and the roof deck. Successful green roofs are determined by the health of vegetation along with their structural integrity. Careful choices must be made in regard to materials and vegetation in order to create optimal green roof conditions.

Retrofitting UBC Buildings for Green Infrastructure

The University of British Columbia (UBC) has implemented the Climate Action Plan 2030 (CAP 2030) and the UBC Green Building Action Plan, both aiming to reduce carbon emissions and continue toward the goal of net zero operations by 2035 (*UBCV_CAP2030_FINAL.Pdf*, n.d.). A strategy put forth in increase carbon capture on campus is retrofitting existing buildings with energy saving infrastructure such as green roofs. Retrofitting existing UBC buildings may pose challenges due to structural limitations. The structure and materials of the UBC campus buildings must be considered in our suitability analysis. Previous experiments assessing roof materials found that between concrete, steel frame, and timber, that reinforced concrete had the greatest sparing weight capacity and could facilitate the installation of semi-intensive and intensive green roof types. Steel and wood are feasible options for retrofitting but may require additional structural support even to accommodate the weight of an extensive green roof (Stovin, 2010).

The objective of this study is to create a list of suitable UBC buildings for the installation and maintenance of green roofs. To do so, an analysis of building suitability must be determined. The suitability will be quantified as a factor of the structure of the roof, rooftop slope, rooftop area, building use, building management, and light intensity. The building usage, ownership and materials information is accessible from UBC records. The rooftop slope, light intensity, and area will be determined using LiDAR and Planet Scope imagery.

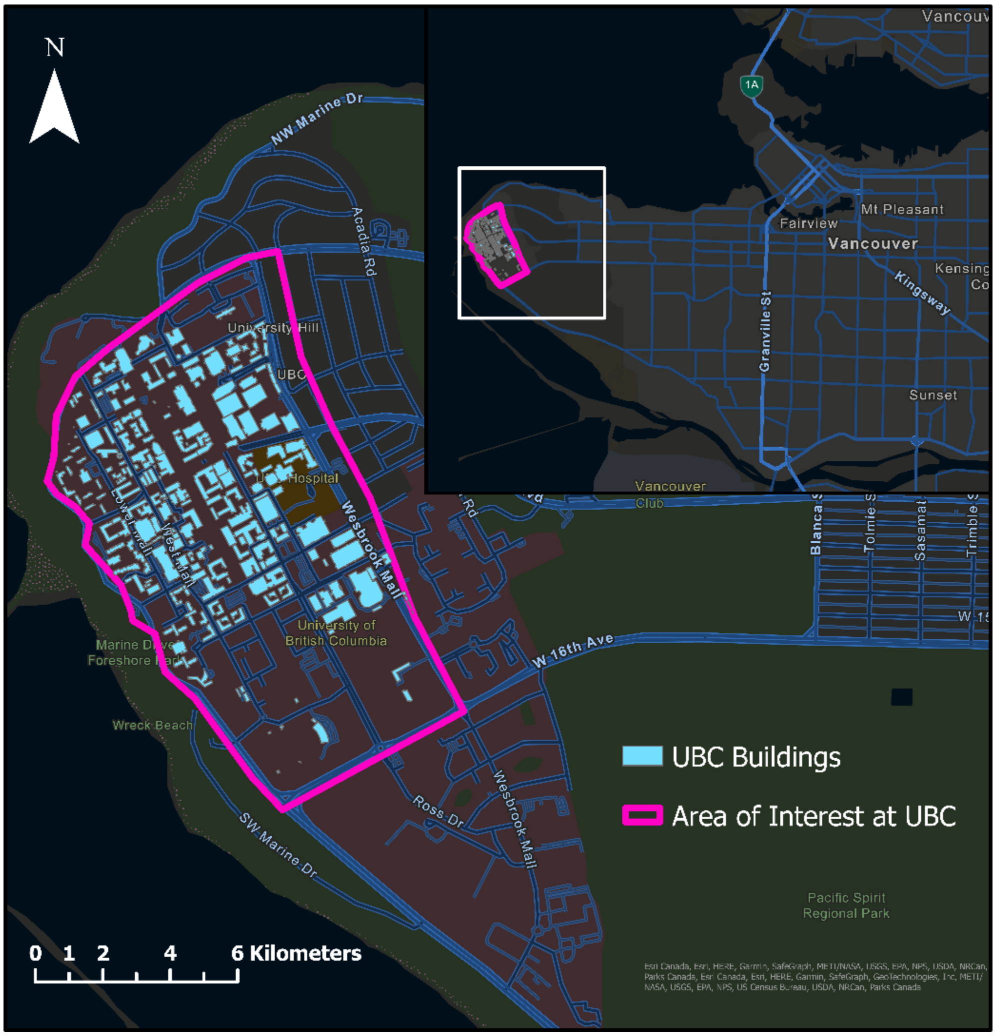

Figure 1:Map of the study area located at the University of British Columbia. The study scope limits can be seen within the yellow boundary. The buildings of interest are visualized as the blue polygons.

Study Area

University of British Columbia

The University of British Columbia is located in Vancouver, Canada, on the traditional, ancestral and unceded territory of the Musqueam people (Musqueam & UBC, 2022). The Point Grey area of Vancouver was chosen as the site for the UBC campus in 1910 with its construction starting in 1914 (A Brief History of UBC | University Archives Blog, n.d.). From the 1910s onwards, UBC has undergone immense changes and growth, with further building development still ongoing. The urbanization of UBC campus has occurred throughout the last decades leading to a decrease of overall greenery from its original landscape. This study will focus on the Point Grey University campus, specifically looking at the roofs of the campus buildings and current green spaces. The UBC campus of interest is located within Pacific Spirit Park which ignites inspiration for the structure of the campus greenery. The park spans a large area of roughly 763 hectares of land and is home to a variety of flora and fauna (Pacific Spirit Park, n.d.). Many of the local species of vegetation are found planted through the campus landscape and emulate the greenery of the surrounding park land.

The scope of the study on the UBC campus is within the pink limit in Figure 1, with individual rooftops represented by the blue polygons. Buildings found in the study area (Figure 1) will be assessed in their suitability for green roof retrofitting. The UBC Green Action plan released in 2018 has outlined goals related to the development of campus in order to combat the effects of increased urbanization in the area (UBC Green Building Action Plan Full.Pdf, n.d.). This suitability study aims to help achieve the objectives of the UBC Green Building Action Plan by locating building rooftops most suitable for green infrastructure, allowing for rooftops to be better used as a green roof or a living lab. The objectives of UBC's development are to have UBC's buildings contributing positively to both human and natural systems (UBC Green Building Action Plan Full.Pdf, n.d.).

Data Summary

Light Detection and Ranging (Lidar)

The consideration of building roof slope, area, shaded regions, structural materials, use, and ownership of the buildings will allow for the determination of UBC buildings suitable for retrofitting to green roofs (Alim et al., 2022; Kaufman et al., n.d.). The data used to assess the rooftop light intensity and the slope is the University of British Columbia Vancouver Campus LiDAR 2021 data set (Abacus Data Network., 2022). This data is open access and was directly downloaded from the Abacus Data Network website. The data were derived from Eagle Mapping on June 23, 2021, by the PA 31 Piper Navajo aircraft. The lidar unit used was the LMS-Q1560, which has a scan rate of 800HZ and a field of view. The flight pattern taken had a 67% overlap and was flown in a cross-hatched pattern, where the flight altitude was 1400 m at a speed of 140 knots. Further meta-data can be found in Table 2. The lidar tiles can be seen mapped in Figure 2. The tiles which overlap the study site for the suitability analysis will be tiles E481_N54 and E482_N54. From these tiles, a Digital Elevation Model (DEM), a Digital Surface Model (DSM), and a Canopy Height model (CHM) will be created to calculate the roof slope. The DSM will be used within the Rayshader package in R to produce a model of light intensity as a function of time of day.

Table 1: A summary table of information from the University of British Columbia, Vancouver, 2021 lidar dataset (Abacus Data Network., 2022).

Extent	x-min=48,800,411.1, x-max=486,200, y-min=5,451,920 and y-max=5,458,722
Coordinate reference	NAD83(CSRS)/NAD83(CSRS)/UTM 10N + CGVD2013
Area	22.03 km^2
Points	1.27 billion points
Point density	57.7 points/m^2
Pulse density	33.4 pulses/m^2

Planet Scope Multispectral Imaging

Planet Scope Multispectral Imaging is derived from a constellation of over 130 DOVE satellites (European Space Agency, n.d.). The Planet Scope cameras are located on each DOVE satellite and operates with eight bands (red edge, red, green, green I, yellow, blue, coastal blue and near-infra-red) and 3 sensor types; DOVEC, DOVE-R and SuperDove (European Space Agency, n.d.). The collection of satellites has the capacity to capture 200 million km^2 of images per day with a pixel size of 3 m^2 (European Space Agency, n.d.). The Planet Scope image of UBC will be used to calculate the average Normalized Difference Vegetation Index (NDVI) of existing softscapes on campus to analyze the health of the current vegetation. Existing vegetation areas of campus are considered softscapes, where an individual polygon is assigned to each continuous green space. From this information, better strategies can be created to facilitate further development of green spaces on campus such as green roofs. The image was collected on August 22, 2021 with the coordinates of UBC being 49 ° 15' 60.00" N Latitude and -123 ° 14' 60.00" W Longitude (European Space Agency, n.d.). These data are not open source and require a Planet Scope account to request images. UBC students, faculty members and some affiliates are eligible for accounts through an application process via the UBC library.

UBC Geodatabase

The UBC geodatabase is a collection of campus geographic datasets in the form of points, lines, and polygons held in a common location. The data can be found on the freely available Abacus open data portal (Abacus Data Network., 2022). The UBC Campus and Community Planning has collected numerous data layers representing specific feature types such as buildings, water features, softscapes, and more. The two data layers within the UBC Geodatabase that will be used in the green roof suitability analysis are the building polygon layer and the softscape polygon layer. The polygon layer provides the information for each individual building, four of which will be factored in the suitability analysis. The four attributes are building use, management, rooftop area, and materials used during construction. The building management types with further subdivided by construction materials can be seen in the chart in Figure 2.

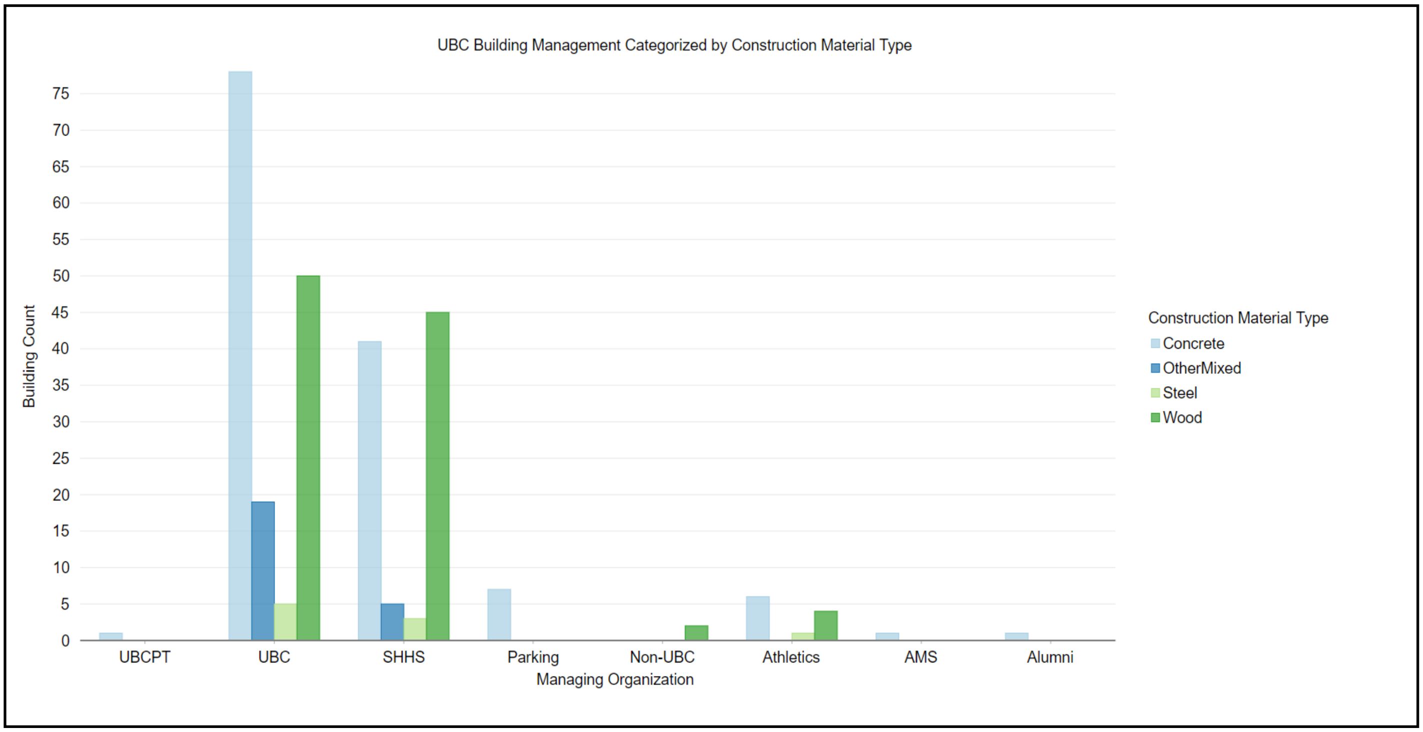

Figure 2: A chart depicting the building counts at each managing organization and further categorized by the construction material type (concrete, other/mixed, steel and wood). There are eight different managing organizations that University of British Columbia buildings fall into; the University of British Columbia Properties Trust (UBCPT), the University of British Columbia (UBC), the Student Housing and Hospitality Services (SHHS), parking, non-UBC, athletics, the Alma Mater Society (AMS) and Alumni (Abacus Data Network., 2022).

Methods

Lidar Processing

The downloaded LiDAR data is imported into RStudio with the lidR package (Roussel et al. 2020). Data cleaning and organization of the LAZ files is accomplished in order to perform the further point cloud analysis in the workflow (Figure 3). The data will be passed through a Progressive Morphological Filter (PMF) to classify of the ground points (Roussel et al., 2020). Then follows the derivation of the Digital Elevation Model (DEM) and the Digital Surface Model (DSM). The DEM and DSM are generated using the Triangulated Irregular Network (TIN) interpolation method and compared with the ground points classified to refine produced image (Ma, 2005). The DSM is a model of the upper most points in the LiDAR point cloud and is compared with the Digital Elevation Model to produce the normalized DSM (nDSM) (Demir et al., 2008).

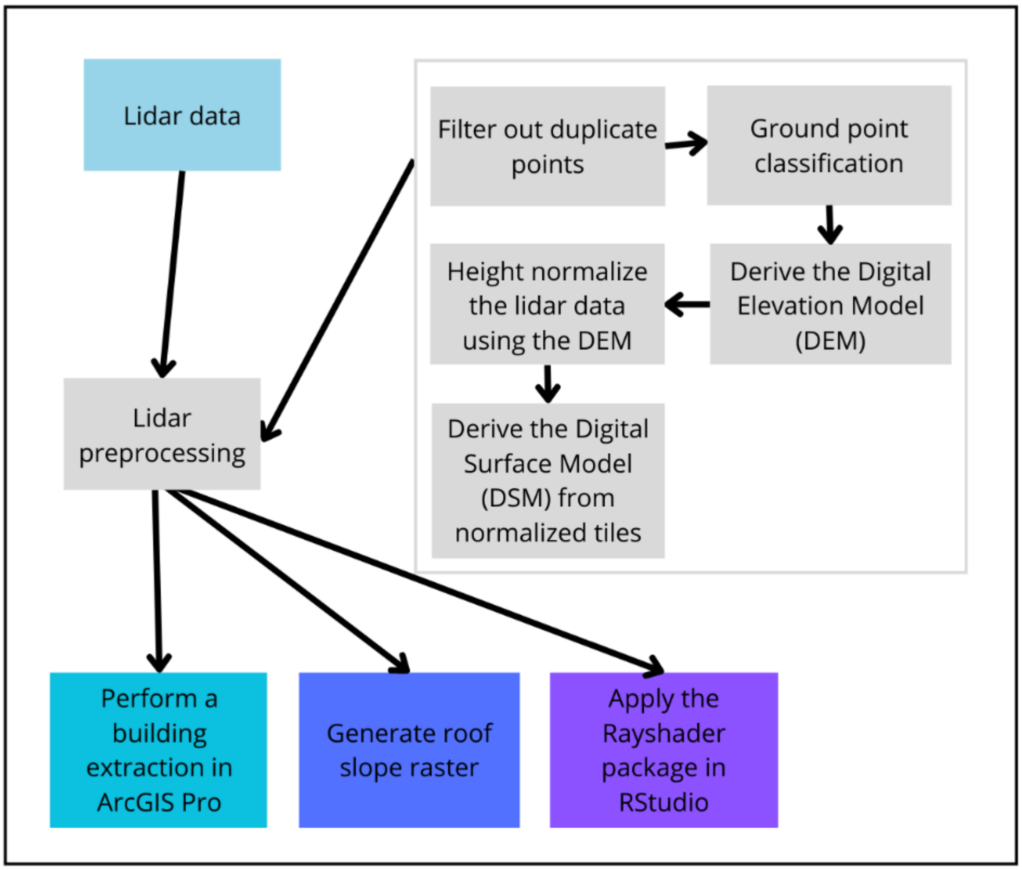

Figure 3: The work-flow using the lidar data in RStudio using the lidR package. Firstly, the Airborne Laser Scanning (ALS) point cloud is imported into RStudio. The raw point cloud then undergoes preprocessing which is divided into five stages (seen in grey), followed by the derivation of the various models (DSM and DEM) in order to isolate building rooftops on UBC campus. The Digital Surface Model (DSM) is then used in three different applications.

Digital Models

The DSM represents the surface of a given area as if a blanket were applied to the landscape, where the highest points are the tops of infrastructure, canopy height, and in some areas the ground. The DSM will be used in the process of determining the roof slope using an analysis of the density of vertical points along the DSM (Demir et al., 2008). Using ArcGIS, we will perform a building extraction producing a layer of 3D buildings from the LiDAR point cloud by the process of classifying the data set, building footprint extraction, and extraction of 3D buildings (Extract 3D Buildings from Lidar Data, n.d.). Once buildings are detected, the slope can be identified using the slope-generating tool in ArcGIS using the DSM raster.

Light Intensity

The Rayshader package in R is applied to determine the light intensity of the areas on the rooftops of interest, which will factor into the suitability calculation (Rayshader Package - RDocumentation, n.d.). Using Rayshader, the light intensity is modelled on the UBC campus for June 14th 2021 at 12 pm, factoring into the suitability criteria. The light intensity raster is used in combination with other data on building construction material, slope, area, usage, and type of management type.

Suitability Calculations

Suitability for UBC campus rooftop retrofitting for green roof purposes is based on a set of weighted criteria (Figure 2):

1) Slope of rooftops: Green roofs are most prominently installed on rooftops with a slope of 2% to 10% in order to gain the benefits of water retention without the risks associated with substrate sloughing and erosion (VanWoert et al., 2005). In the suitability calculation, the slope is weighted double that of the structural material, light intensity, building ownership, and usage due to its importance in the installation of green roofs.

2) Total roof area: The SEEDS Sustainability program at UBC has specifically indicated that the most feasible buildings to install green roof infrastructure are those with a total usable area of at least 1000. In the suitability calculation the area is weighted double that of the structural material, light intensity, building ownership and usage due to its influence behind the capability of the structure of the green roof.

3) Structural material: The structure of the building and the materials used provide limitations on the load capacity of the existing UBC roofs. This constraint must be considered before retro-fitting (Stovin et al., 2010). The different structural types of green roofs have varying substrate depths which adds to much of the overall weight, extensive green roof styles can add 15 – 38 kg per and intensive adding up to 120 – 225 kg per (Baldwin, 2022).

4) Ownership / management of the building: The preferred ownership for UBC buildings in the suitability analysis is that owned and managed by UBC. Rooftop accessibility is required during the roof retro-fitting, green roof installation and to ensure maintenance (Baldwin, 2022).

5) Building use: The use of the buildings on the UBC campus is incorporated into the criteria to promote the participation of students and the UBC community in the rooftop green space.

6) Light intensity: Using the Rayshader, the detection of shade or light intensity in the areas of interest is deduced. Plants require light for photosynthesis; therefore, the usable roof area must have access to sunlight light for a minimum of 6 hours per day.

NDVI from Planet Scope Multispectral Imaging

In order to provide suggestions and strategies for green roof implementation at UBC, a vegetation health assessment of the current green infrastructure is necessary. Planet Scope Multispectral Imaging for the same temporal scale as the LiDAR data is analyzed using the ArcGIS platform to create a NDVI colour map. The identification of healthy vegetation in known softscape areas is analyzed to determine if current installation and maintenance practices on the UBC campus are adequate to promote healthy green infrastructure.

Results

Suitable Rooftop Areas

The total rooftop area on UBC campus is approximate 436,528.46 m^2 over 275 buildings within the study site bounds. The area ranges between 14.93 and 13698.40 m^2. After assessing the six suitability criteria, five buildings were identified as the most suitable for the green roof (Figure 4). The top five buildings with the highest suitability scores are the UBC Life Building, Irving K. Barber Learning Centre, Civil and Mechanical Engineering Laboratories, Civil and Mechanical Engineering Building, and the Forest Sciences Centre. The total rooftop area for the top five most suitable roofs is 31,940.80 m^2 with the maximum area of 8575.16 m^2 on the Forest Sciences Centre and the minimum area of 4802.10 m^2 at the Civil and Mechanical Engineering Laboratories.

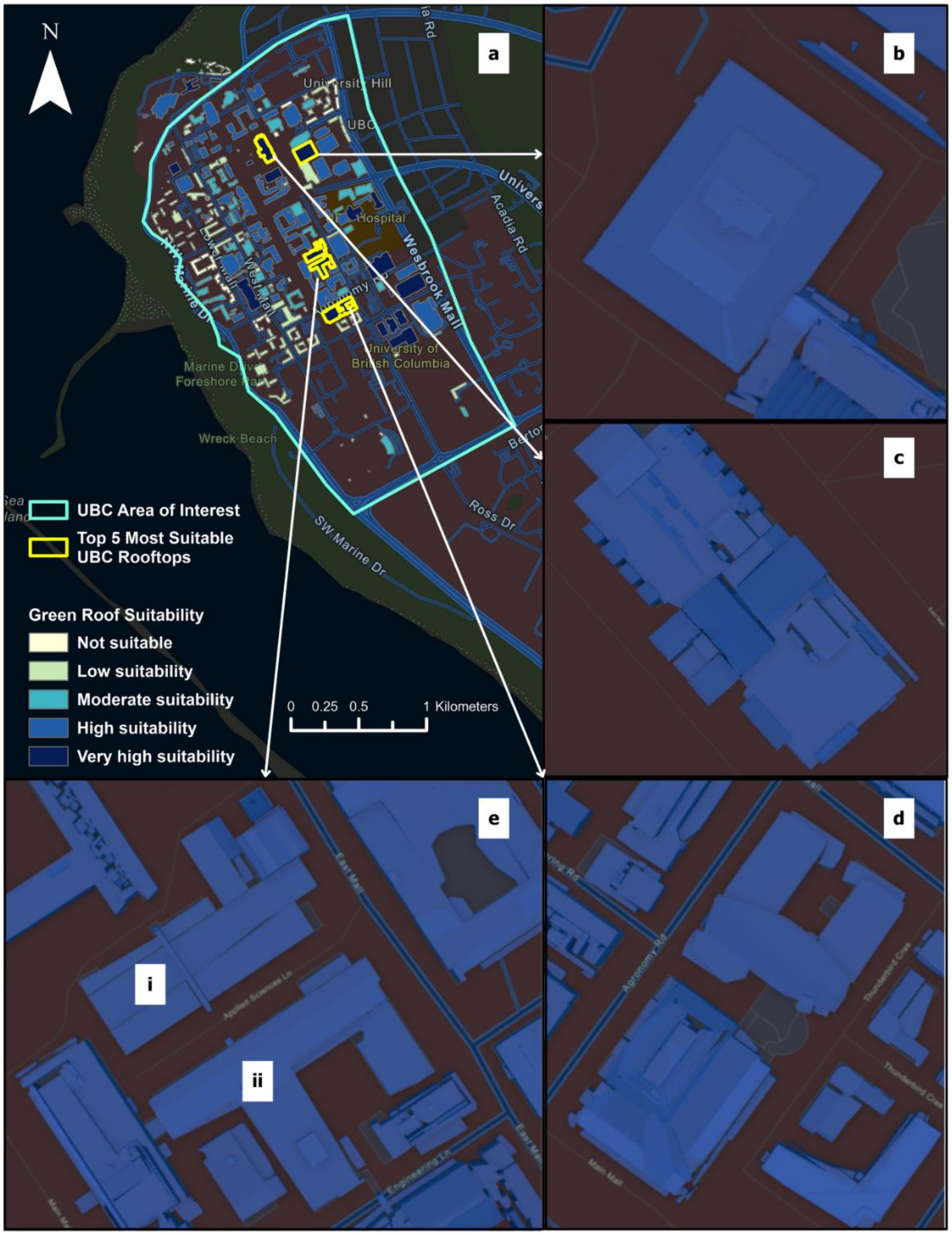

Figure 4: (a) The final map of the UBC campus building rooftops identifying the top 5 most suitability rooftops for the retrofit of green roof infrastructure; (b) the UBC Life Building found along Student Union Boulevard; (c) the Irving K. Barber Learning Centre on East Mall; (d) Forest Sciences Centre; (e) (i) Civil and Mechanical Engineering Laboratories and the (ii) Civil and Mechanical Engineering Building. All of the top 5 buildings are found within the "very high suitability" class of suitability scores.

Suitable Rooftop Slope

The results of processing and deriving surface models from the LiDAR 2021 UBC data set produced a slope raster on campus rooftops at 1 m spatial resolution. The slope raster for the roofs was categorized into two groups; Optimal (0-10 degrees) and Not Suitable (angle greater than 10 degrees). Most of the roof area is within the optimal category of 10 degrees, with small proportions of each roof having a pitch of 90 degrees where structures are located.

Suitable Structural Material

Of the 5 most suitable UBC building rooftops, 4 were constructed from concrete and 1 was constructed for mixed materials. The buildings with the most suitable construction material (concrete) are the UBC Life Building, Irving K. Barber Learning Centre, Civil and

Mechanical Engineering Laboratories and Civil and Mechanical Engineering Building. The Forest Sciences Centre has its structural material categorized as other/mixed based on the UBC Geodatabase data (Abacus Data Network, 2022).

Suitable Building Ownership & Usage

The UBC campus buildings with the highest suitability (Figure 3) are all owned and managed by UBC. All 5 of these buildings are utilized for academic purposes.

Suitable Light Intensity

The buildings found to be most suitable for the retrofit of green roofs have high light intensity on their rooftops at midday. Figure 4 shows the range of mean light intensity for each of the top five most suitable buildings with the light intensity raster as the base layer of the map. The UBC Life building has the highest light intensity of the top five buildings, with the Irving K. Barber Learning Centre having the lowest value for the light intensity. The suitable buildings UBC Life Building, Irving K. Barber Learning Centre, Civil and Mechanical Engineering Laboratories, Civil and Mechanical Engineering Building and the Forest Sciences Centre) have varying numbers of floors (3, 5, 2, 3, 6 respectively) contributing to potential shade cast over the roof (Figure 5).

NDVI of UBC's Existing Green Spaces

The top 5 buildings of the suitability analysis can be visualized in Figure 6, with the mean NDVI values of a 25 m buffer around each building identified for each rooftop area. Each building has various degrees of vegetation surrounding it, found within the exterior softscapes. The NDVI values of the existing campus softscapes are found to be within 0.8 to 1.0, with very little variation between the softscape types (lawn and planted beds). The building with the highest NDVI associated to its surrounding vegetation is the Forest Science Centre and the Civil and Mechanical Engineering Building.

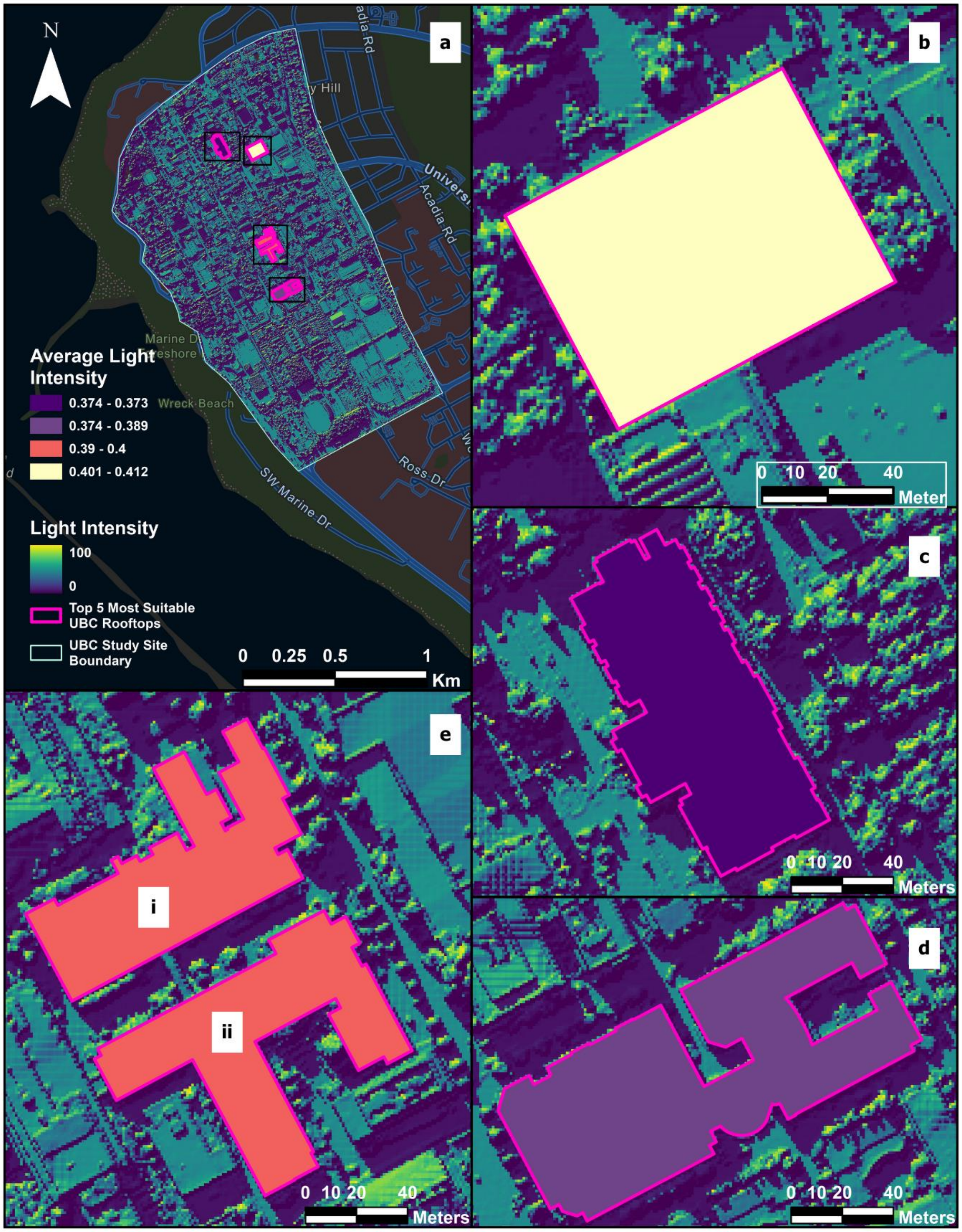

Figure 5: a) A map of the University of British Columbia (UBC) campus with a raster layer depicting the suns illumination on the UBC campus in June at 12pm within the UBC study site boundary. b) An arial view of the UBC Life Building rooftop, which has an avarage light intensity of 0.41. c) An arial view of the Irving K. Barber Learning Centre, this rooftop was found to have an average light intensity of 0.37. d) An arial veiw of the Forest Sciences Centre which produced an average rooftop light intensity of 0.38. e) The Civil and Mechanical Engineering Building (ii) and Laboratories (i) have average light intenisty of 0.39.

Figure 6: a) Above is a map of the University of British Columbia (UBC) campus depicting the existing softscapes on campus with their individual mean NDVI values visualized in a range of blue tones on the map. b) The UBC Life Building has a mean NDVI of 0.5849 for vegetation in a 25m radius. c) The Irving K. Barber Learning Centre has a mean NDVI of 0.6997 for the vegetation in a 25m radius. d) The Forest Sciences Centre has a mean NDVI of 0.7421 for the vegetation in a 25m radius. e) The Civil and Mechanical Engineering Building (ii) and Laboratories (i) have mean NDVI values for a 25m radius around the building of 0.61112 and 0.7078 respectively. The NDVI values associated with the various classes are low vegetation density is 0.5 – 0.6, moderate vegetation density is 0.6 – 0.7, high vegetation density is 0.7– 0.8, very high vegetation density is 0.8 – 0.9, and high vegetation with high moisture content is 0.9 – 1.0.

Discussion

Green Roof Suitability

The UBC Vancouver campus aims to achieve net zero emissions by 2035 as part of the Climate Action Plan 2030 (*UBCV_CAP2030_FINAL.Pdf*, n.d.). In order to accomplish this goal, a variety of sustainable solutions must be considered to progress toward a net-zero goal. The elimination of fossil fuels using efficient electrification and optimization of buildings energy systems can be aided by the retrofit of existing UBC buildings for green roofs. In assessing the six suitability criteria among the UBC Vancouver buildings, five top building rooftops were elucidated to have greater success and feasibility. The criteria were weighted as though the feasibility and structural aspects had greater impact on the suitability score then criteria for successful maintenance and plant care. The slope calculated on the rooftops at UBC showed less diversity than expected, with nearly all roofs having a slope between 0 ° and 10 ° with angles of 90 ° angles found at the edges, vertices, and functional structures such as ventilation. This suggests that the pitch of the rooftops at UBC are in the optimal range for green roof installation. The average area of a UBC rooftop exceeds our minimum suitable value of $1000m^2$ at $1836.4m^2$, however the range of rooftop area is very wide with the minimum value at $14m^2$ and a maximum of $13698.4m^2$. Interestingly the largest of the top 5 most suitable rooftops ranked 9th greatest rooftop area of all of UBC campus buildings.

UBC Life Building

The UBC Life Building found at 6138 Student Union Boulevard was ranked highest in our suitability calculations. Its high suitability rating comes not only from its suitable roof pitch and area but also its usage, ownership, structural materials and light intensity. Although the attribute table specifies the usage to be academic, the UBC Life Building is also home to the ARC Fitness Centre, a Subway, International Student Advising, and the Wellness Centre (*UBC Life Building*, 2022). The building is still under the ownership of UBC and from the limited building data the structural material concrete was used in the construction, which is a favorable construction material when retrofitting for green roof infrastructure (Stovin, 2010).

Irving K. Barber Learning Centre

With a rooftop area of $6581.41m^2$ the Irving K. Barber Learning Centre comes in with the 11th largest rooftop area on UBC campus. The building is owned by UBC and used for academia as a Learning Centre and Library. The building was originally constructed in 1927 with concrete making it of suitable materials (*The Irving K. Barber Learning Centre*, n.d.).

Civil and Mechanical Engineering Building and Laboratories

The Civil and Mechanical Engineering Building and laboratories are a set of two buildings centrally located on the Vancouver University of British Columbia campus. These adjacent mirrored rooftops have areas of 4937m^2 for the Civil and Mechanical Engineering Building and 4802m^2 for the Civil and Mechanical Engineering Laboratories. Both buildings have a suitable concrete construction material despite their varying occupancy dates, the Laboratories dating back to 1969 and the building back to 1976. I found it quite interesting to look back at the data to see that both buildings were classified as having 'poor' conditions. The building conditions did not play a role in the suitability calculations due to the lack of information that the data provided for the category. The category of building condition had "poor', "critical", "good" and "fair" as inputs, this information did not provide enough detail on the buildings physical condition and what the issues may be.

Forest Science Centre

The Forest Science building has the largest rooftop area at 8575m^2 of the top 5 most suitable rooftops for green roof retrofit. This is the only building to make our top 5 list with the construction material type of other/mixed. This is a limitation of the UBC building data, further details or breakdown of structural materials used during construction would greatly aid in determination of suitable rooftops. The condition of this Forest Science Centre is classified as fair, which may be a further line query before starting retrofitting and green roof installation. The Forest Science Centre is made up of a four-storey office block, a four-storey laboratory block, a two-story wood processing facility, and a large skylit atrium (Forestry, 2023). This large skylight was not considered in the suitability analysis, as that area was not separated from the usable area in our data.

Current UBC Green Space

In deciding where to focus the efforts to retrofit UBC campus rooftops for green roofs, an assessment of the current campus softscapes was performed. The normalized difference vegetation index (NDVI) was calculated throughout all of campus during the month of June and the mean NDVI for each softscape polygon was attained (Figure 6). The NDVI values within the known green spaces on campus suggests healthy vegetation throughout most of campus. For each of the five most suitable building roofs, a mean NDVI for all vegetation in a given buffer distance of 25 m. The results of this calculation can be visualized in Figure 6, where each of the top five buildings is shown with their relative mean

NDVI within a radius of 25 m. The Forest Sciences Centre has the highest values of NDVI within its radius suggesting either more vegetation or healthier vegetation surrounding the building. The Civil and Mechanical Engineering Building and the Civil and Mechanical Engineering Laboratories have different mean NDVI values, though they have overlapping buffer areas given their close proximity. The Laboratories have a slightly higher mean NDVI than the Civil and Mechanical Engineering Building; however, both NDVI values suggest moderate to high vegetation levels in the area surrounding the buildings. The UBC Life Building has the lowest mean NDVI value of 0.5849 suggesting low vegetation density. The Irving K. Barber Learning Centre has a similar value for the mean NDVI, suggesting that the building is surrounded by a moderate density of vegetation.

Light Intensity

Light is a necessary component of a successful green roof, as all plant species require some level of light intensity to perform photosynthesis. The light intensity throughout the UBC campus varies over the course of a year and undergoes daily cyclical changes in sun altitude and sun angle. There are a variety of building heights throughout campus that provide the opportunity for rooftops of a lower height to be shaded out by taller buildings around them. The light intensity on 23 June 2021 at 12pm can be visualized in Figure 5, with close-up inset maps of the top five most suitable buildings. The light intensity on each of the five most suitable rooftops is fairly consistent with little average changes to the rooftop luminosity between 9am, 12pm and 3pm. At each time analyzed the UBC Life Building had the greatest average light intensity of the top five most suitable, followed by the Civil and Mechanical Engineering Building and Laboratory. This variance between light intensity could impact the planting decisions and the green roof structure chosen.

Limitations

The largest limitation of this study is the data from the University of British Columbia building. The data collected on the UBC buildings was given attributes that lack detail making some of the criteria of the suitability analysis difficult to gauge their relative importance to green roof retrofitting. Accessibility is one of the categories of attributes which has nearly zero input for each given building leaving that criterion out of our suitability analysis. Green roof retrofit at UBC would require the planning, installation, maintenance and potentially given on the structure type, community visitors. All of these seps require access to the rooftop itself. With only “Null” values for the accessibility category we are greatly limited to the conclusions which can be made about green roof suitability.

Future Directions

An analysis of rooftop material may be necessary to assess retrofit capability. This may be done campus wide using multispectral imaging and performing a classification of rooftop cover types. This would require some rooftop field data collection in order to have ground truth data measurements for rooftop materials. In performing this ground truthing additional data on the rooftop accessibility could be gathered, as well further details on the condition of the rooftop could be noted. These additional data could provide key details on the structure and type of green roof to install. Another possible study is a network analysis for the usage and movement of students, faculty and other campus users throughout the campus, in order elucidate maximum potential viewership and usage of the new green spaces. This may further inform the decision of whether or not to implement a lower maintenance extensive green roof or a more involved intensive green roof.

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