

Exploring the Impact of Tree Original Point Cloud Data Leverage in Urban Daylight Simulation

Victoria Tsalapati

Student ID: 5988446

1st Mentor: Azarakhsh Rafiee

2nd Mentor: Eleonora Brembilla

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1 Introduction

The light from the Sun is invaluable, since it fuels the entire ecosystem on Earth with energy. In this sense, natural light is widely acknowledged to greatly benefit people’s health. Specifically, it supports the human circadian system, which regulates biological rhythms. Disruptions in these rhythms can lead to various health problems, including neurobehavioral disorders, cardiovascular problems, immune dysfunction, and hormonal imbalances (Hraska, 2015) [14]. In addition, mental health is also affected by natural light. People who are not exposed to adequate hours of daylight are prone to experience sadness, fatigue and clinical depression. Also, interaction with natural light reduces symptoms of Seasonal Affective Disorder (SAD), which is type of depression related to reduced daylight during winter period (Bertani et al., 2021) [6].

Urban designers recognize the importance of natural light and therefore integrate it into urban planning and architectural design. Beyond enhancing well-being, it mitigates the environmental footprint of buildings. Insufficient exposure to sunlight increases energy consumption for artificial lighting and heating (Bazir et al., 2024) [5]. The interest in energy efficiency was sparked in the advent of the 1980s oil embargo leading to the development of building performance simulation (BPS), supported by advances in personal computers. Over the following decades, continuous improvements in computer hardware further enhanced BPS accuracy and usability and resulted in making BPS substantial for design decision making (Ayoub, 2019) [2].

On the other hand, trees play a vital role in the urban environment by shaping microclimates. Their shade and cooling effect contribute to lower temperatures, improving thermal comfort for city residents. From this perspective, the inclusion of trees in urban daylight analysis is essential to accurately estimate daylight availability. However, there are some challenges due to the complexity of accurately creating 3D representations of trees involving the size, shape, and permeability of their crown. In addition, trees undergo seasonal changes depending on their species, causing extreme variations in tree foliage. These factors are often ignored by using simplified 3D models to represent trees, affecting the accuracy of simulation results (Balakrishnan and Jakubiec, 2022) [3].

This research will aim to investigate how a tree point cloud can be leveraged in daylight simulation within an urban environment and examine the results in terms of their accuracy and alignment with the real-world conditions. The report is organized into five sections. The first section provides an overview of data collection methods of point cloud previously undertaken, approaches for shaping tree geometries, and essential information about the ClimateStudio plugin, which will serve as the primary tool for the daylight simulations for this thesis. Next, in the second section the research questions are specified, which be addressed throughout the investigation. The third section outlines how data collection and data processing and the evaluation of the simulation results will be applied in this research. It also explains the procedures that generate the preliminary results and their evaluation. Then, the forth section presents the Gantt chart of the workflow for this research. Lastly, in the fifth section the tools and datasets, which have been already or will be used as the research advances, are demonstrated.

2 Related Work

This section reviews past research relevant to the topic of this thesis. The information collected will provide knowledge, inspiration and valuable information for decisions regarding the methodology and approaches to addressing the challenges in this research. This section will focus on three main components: the data collection methods previously used for tree point cloud, a discussion of common approaches to 3D tree representation and reconstruction, including state-of-the-art methodologies and the background of daylight simulation.

2.1 Data collection methods

The first step for 3D tree reconstructions is the data collection. According to Okura (2022) [17] one of the typical approaches for 3D shape reconstruction is implemented via 3D laser scanners, which measure the distance travelled by emitted light using phase differences. The output of this method is either a point cloud or a depth map.

3D laser scanners take on different forms. Du et al. (2019) [11] and de Groot (2020) [10] utilized the AHN 3 point cloud data from the open-source airborne Light Detection and Ranging (LiDAR) datasets of the Netherlands for their research on automatic 3D tree reconstructions. In contrast, Peynaud and Takoudjou (2024) [18] obtained point clouds of the cocoa trees in their study areas via Leica ScanStation C10 terrestrial LiDAR. To address occlusion, they performed 3D scanning from multiple positions, ensuring these positions form a pathway (Figure 1).

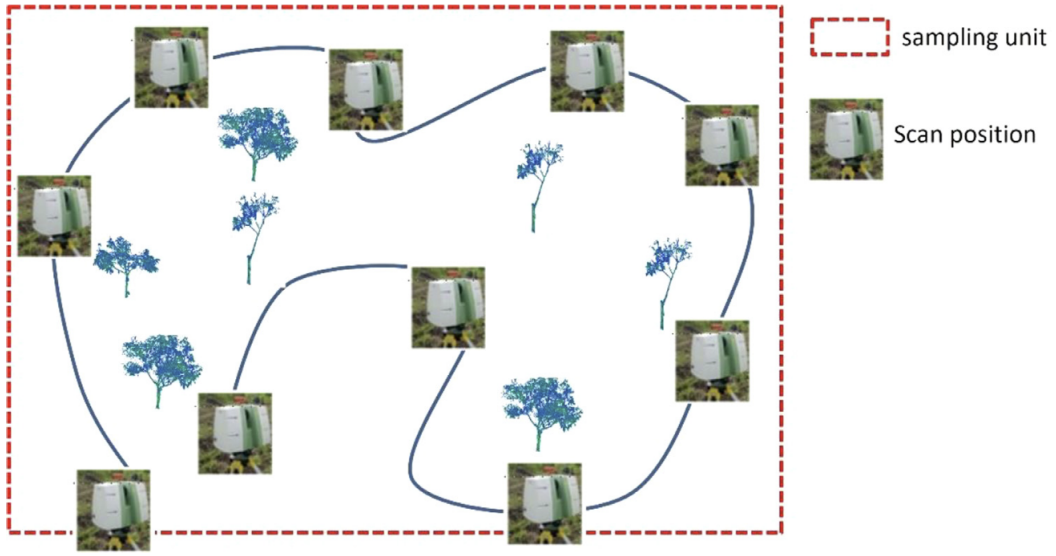


Figure 1: Pathway of scanning positions in a plot (Peynaud and Takoudjou, 2024)

In addition, to ensure alignment between the point clouds captured at each scan position of the pathway, two spherical red targets were placed at the previous and next scanning positions for each current position (Figure 2). These targets served as reference points to facilitate the connection of the point clouds. For the co-registration of the point clouds, Peynaud and Takoudjou (2024)[18] used Leica Cyclone software version 9.4.2.

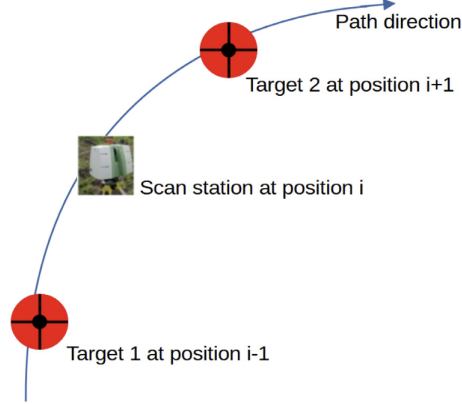


Figure 2: Scheme of the two spherical red targets for each scanning position in the pathway (Peynaud and Takoudjou, 2024)

Furthermore, other two relevant to this thesis methods for 3D shape reconstruction, mentioned by Okura (2022) [17] are Structure-from-motion (SfM) and Multi-view stereo (MVS). SfM involves estimating a sparse point cloud of a scene by utilizing a collection of 2D images and their corresponding camera poses, while MVS is applied for a dense point cloud of 3D mesh from known camera poses. However, approaches involving multi-view images are limited in handling similar textures, which often characterize tree structures. Since this can result in low-quality outputs or complete reconstruction failures, the image collection should be performed meticulously. Multiple experiments may be necessary to refine the procedure and establish the correct workflow, ensuring that the examined plant is captured with maximum accuracy. For instance, to address this problem, Wang et al. (2018) [26] made several suggestions, specifically for MVS image acquisition, for maize plant 3D reconstruction concerning many factors, including the camera positioning and optical distance between the camera and the plant and the number of images based on the plant height.

The synergy between diverse geomatics instruments for 3D tree reconstruction is not only feasible, but also enhances accuracy. This was indicated by Balestra et al. (2023) [4], who combined images from an unmanned aerial vehicle (UAV) equipped with cameras and a single-lens reflex (SLR) camera, the former for capturing canopy images and the latter for images of the trunk. Then, UAV and SLR images were processed using Structure from Motion (SfM) to generate dense point clouds. At the same time, Mobile Laser Scanning (MLS) was operated to capture the entire tree structure from multiple angles, particularly the stem and main branches. After georeferencing the MLS point cloud and the UAV and SLR dense point clouds, these data were aligned into a common coordinate system with sub-decimeter accuracy.

2.2 Approaches to 3D tree representation and reconstruction

Subsequently, the geometrical representation of trees can be achieved in various ways. Okura (2022) [17] analyzes the diverse tree shape representations, including the point cloud, voxel, mesh, parametric surface and primitive-based representations.

In regard to the point cloud representation, it is widely used and contributes to the explicit depiction of trees, like all 3D objects. About voxel representation, it describes objects in 3D grids (voxels) and supported early applications of 3D reconstruction of botanical trees. In addition, mesh representations employ interconnected

polygons (typically triangles) to form surfaces. Point/voxel-based representations are often transformed to polygon meshes.

In addition, trees can be represented by parametric surface or primitive-based representations. The former is related to leaf 3D reconstruction and is about global shape constructions using curved surface representations with fewer parameters than mesh models, while the latter refers to object constructions utilizing primitives shapes like cylinders or cuboids and has benefited tree branch 3D reconstructions.

de Groot (2020) [10] contributed valuable insights into constructing 3D tree model in various Levels of Detail (LODs). The first step was filtering vegetation from non-vegetation points based on standard deviation in height within neighborhoods (high values portrait vegetation points) and height offset of 2 meters and above. Next, Watershed Segmentation methodology was applied to segment individual trees from classified vegetation, using DEMs as input. Lastly, after cleaning the processed data using a plethora of methods, such as RANSAC, DBSCAN and analysis of return values, tree models used for different LODs were proposed depicted in **Figure 3**. For this research, LOD3.0 and LOD3.1 are relevant, since they focus on constructing the trunk implicitly using cylinders, while explicitly modeling the crown from point cloud data leading to more detailed tree 3D model compared to the other LODs.

	3D view	Front View	Top View
LOD ₀			
LOD ₁			
LOD ₂			
LOD _{3.0}			
LOD _{3.1}			

Figure 3: Proposed LODs by de Groot (2020)

Another common approach to 3D tree representation focuses on the tree’s structural representation, as the form of branches is a fundamental characteristic of trees. Many implementations are graph-based, using point

cloud as input and following skeletonization methods. These methods rely on connecting neighboring points and constructing branch structures by solving the shortest path problem (Okura, 2022) [17].

A notable example of skeletonization is the method developed by Du et al. (2019) [11], who generated an automated algorithm, namely AdTree, to implement tree 3D reconstruction using an individual tree point cloud. This method begins by extracting the initial tree skeleton applying Minimum Spanning Tree (MST) algorithm. The skeleton is then simplified by merging vertices, which were located quite close to each other, Cylinders are fitted to approximate the geometry of the branches and trunk, followed by the addition of synthesized leaves to enhance realism.

Lastly, regarding to the processing steps Peynaud and Takoudjou (2024) [18] took, the trees of interest were isolated from the raw point cloud using 3DForest software version 0.5 (Trochta et al., 2017) [24]. After this, the trees which could not be fully captured because of occlusion caused by neighboring trees were removed. Finally, segmentation between the points representing the leaves and branches/trunk was performed using LeWoS software (Wang et al., 2019) [25].

2.3 Daylight Simulation

In the context of daylight simulation, the one of the most important metrics is illuminance. It describes the quantity of incident light that falls onto or illuminates a specific surface area. In SI units, illuminance is measured in lux (lx), which is equivalent to lumens per square meter ($\text{lm} \cdot \text{m}^{-2}$) (Illuminance [28]).

For internal daylighting it is necessary to involve modeling the sky’s celestial hemisphere, which produces two location-based components: direct sunlight and diffuse daylight (Ayoub, 2019) [2]. For this purpose, a specific sky model, which is a mathematical model of the real sky’s luminance distribution or cumulative sky is applied to represent solar irradiance over a prolonged period (Murdoch, 1985) [16]. Ayoub (2019) [2] refers to the sky models by the chronological order they were developed. Among them here are the ones that will be relevant for this research:

1. **Uniform Sky:** It was based on a simplified luminance distribution and did not take any direct sunlight into account.
2. **CIE Standard Overcast Sky:** It is Widely used for Daylight Factors in cloudy European climates and disregards direct sunlight due to prevailing cloudy conditions.
3. **CIE Standard Clear Sky:** It represents sunny conditions.
4. **Intermediate Sky:** Since both CIE Standard Skies depict two extreme conditions, Intermediate Sky satisfies the transition between clear and overcast skies and supports a more complex luminance distribution.
5. **Perez All-Weather Model:** It is popular among implementations of daylight simulation, predicts solar irradiance and is consistent with weather data files.
6. **Utah Sky:** It is a physically-based color gradient model and models and accounts for non-visual effects of daylight.

Subsequently, especially for the external luminance estimation, solar irradiance measurements are exploited, commonly acquired from weather stations along with other meteorological data (Crawley, 2007) [9]. These weather datasets provide typical single-year records representing historical data at various temporal resolutions for particular locations over long time periods. They include hourly records of diverse weather elements, among which direct normal irradiance and diffuse horizontal irradiance are needed to estimate diffuse daylight.

Typical Meteorological Year (TMY) weather datasets are widely used for daylight simulations (Ayoub, 2019) [2].

Concerning the practical implementation, a commonly used tool for performing daylight simulations is the ClimateStudio plugin for Rhino software. It contains a variety of Climate-Based Daylight Modeling (CBDM) workflows, for all of which based on the defined TMY weather file direct and diffuse irradiation from the sky conditions at each hour (SOLEMMA-sky conditions [22]).

The workflows of ClimateStudio plugin which will be utilized are Point-in-time Illuminance and Daylight Availability. Through Point-in-time Illuminance, illuminance distributions are calculated at particular moment in time, while with Daylight Availability, various metrics are computed to evaluate indoor illuminance distributions caused by daylight, either under specific conditions or during a whole year. The parameters, which are needed to be specified, are the following:

1. **Location:** The TMY file which corresponds to the location of the study area is specified here.
2. **Sky (only for Point-in-time):** The sky model and the time parameters (month, day and hour) are determined here.
3. **Materials:** The materials of the objects, of which the scene for the lighting simulation consists, are assigned here.
4. **Occupied Areas:** The surfaces, on which the simulation will be performed, are specified here.

3 Research Question

This section presents the main research question and sub-questions that will be answered through this MSc thesis. The primary research question is:

To what extent can the leverage of tree original point cloud data increase the accuracy of daylight simulations?

The sub questions that emerge are:

1. **How can point cloud data be used for 3D tree representation in urban daylight simulation?**
2. **What is the difference in accuracy of the results of the daylight simulation between using conventional abstractions and state-of-art approaches?**
3. **How can the results of daylight simulation be evaluated?**
4. **What is the impact of seasonal alterations of the tree canopy in urban daylight simulation?**

This research is based on the hypothesis that incorporating detailed tree point cloud data into daylight simulations, when used optimally, can enhance result accuracy compared to simplified 3D tree model abstractions, as it allows for more precise interactions between light and tree geometry.

4 Methodology

This section describes the methodology which will be implemented for this thesis. It consists of the data collection, data processing, evaluation of the results.

4.1 Data Collection

For this research, the study area will be the forestry area around the Co-Creation Centre (CCC) Building in the Green Village of TU Delft Campus, which is a sustainable glass building, where a diversity of research projects is supported (**Figure 4**).



Figure 4: Co-Creation Centre (CCC) Building and nearby forestry area (source: Co-Creation Centre and Nonohouse [15])

On the roof of CCC Building four illuminance sensors are installed namely global horizontal sensor, roof east sensor, roof west sensor and roof south sensor and their distribution. Theodoropoulou (2023) [23] provided the insightful scheme shown at **Figure 5** depicting the positions of the sensors. These sensors measure illuminance at their respective positions every five minutes.

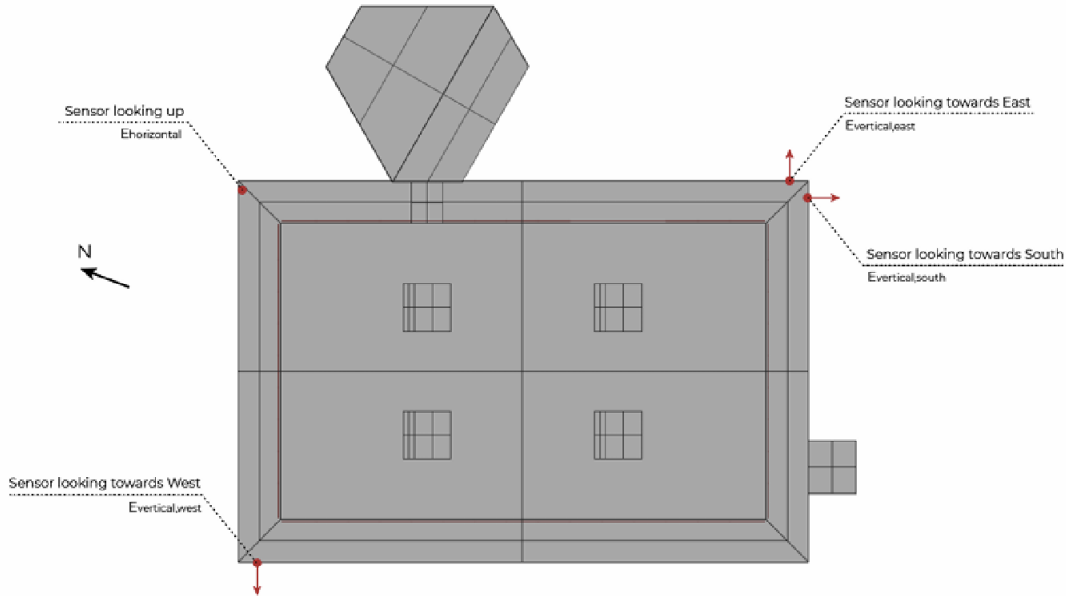


Figure 5: Scheme of the distribution of the sensors on the roof of CCC building (Theodoropoulou, 2022)

The information about the trees species in the study area was first searched on Bomen in beheer door gemeente Delft [12], which is a dataset of tree species within the municipality of Delft. However, since there was no tree registration for the study area, some visits there occurred and three mobile phone apps, Plantify [8], PlantNet [20] and PictureThis [19], were used for the tree identification. The result, which came from all the apps was *Acer platanoides*, also known as the Norway maple.

The forestry area consists of approximately 50 *Acer platanoides*. The exact number is known yet, because of construction work happening at this area at the time of conducting this report. It is a medium to large deciduous tree that can grow to a mature height of up to 40 meters, depending on the conditions in which it is cultivated (Invasive Species Spotlight: Norway Maple [7]). Leaf drop begins in autumn, when day lasts approximately 10 hours. Before the leaves, the flowers appear in spring for two to three weeks. Then, *Acer platanoides* seeds need just three months of exposure to temperatures below 4 °C to germinate and typically sprout in early spring. Lastly, its leafout generally begins, when air temperatures reach approximately 12°C and daylight extends to at least 13 hours (*Acer platanoides* [27]).

The spatial data already obtained the AHN 4 point cloud LAZ file, 37EN2.16.LAZ, which includes the study area and was downloaded from Geotiles.nl [13]. Based on the datasets of flight lines and their corresponding scanned areas provided by Dataroom [1] these point cloud data were acquired on March 16, 2020. Since AHN 5 data were recently added to this website, they are planned to be downloaded and processed as well. Furthermore, a DWG file, that contains a highly detailed representation of the CCC Building, a simplified and abstract representation of the trees from the nearby forest and the surrounding area was provided by Eleonora Brembilla (**Figure 6**) for the processing steps.

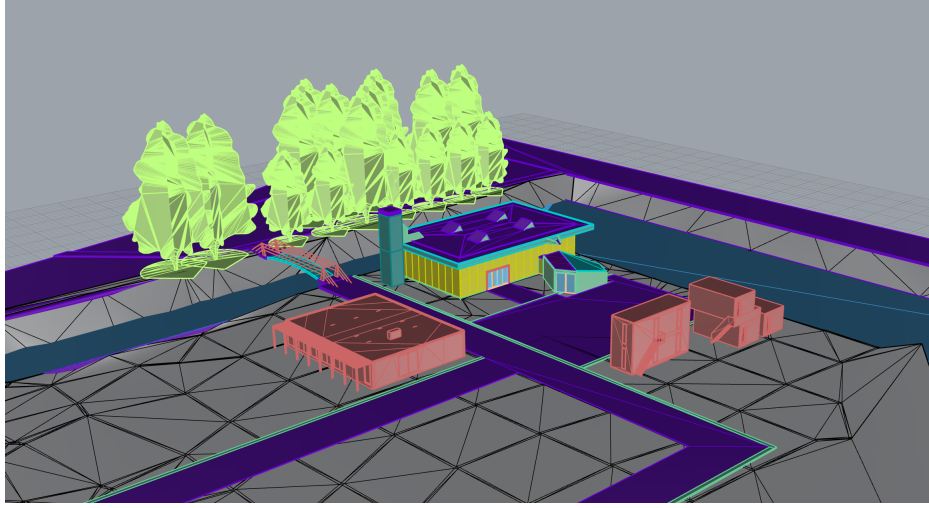


Figure 6: Scene of study area in Rhino

Additionally, to study the influence of seasonal changes in the foliage of trees in the study area, field measurements will be conducted on predetermined days. In particular, TLS will be performed following the data acquisition method of Peynaud and Takoudjou (2024) [18]. Furthermore, it is highly likely that UAV image acquisition will be necessary for this research, given the height of the trees. The field data collection dates will be scheduled to capture the key stages of *Acer platanoides* foliage development. Measurements will first occur in the 8th week to capture the 'no leaves' stage, followed by the 15th week for the 'seeds and first leaves' stage, and finally in the 23rd week to capture the 'mature leaves' stage.

Furthermore, the illuminance records from the sensors of the CCC Building, corresponding to the dates of the AHN 4, AHN 5, and field measurements, will be obtained from the university staff responsible for managing this data. By this stage, records of a week in October 2024 have been obtained.

Finally, based on the location of the study area, **TableNLD_ZH_Rotterdam.The.Hague.AP.063440_TMYx.2004-2018.epw** is the most suitable for the simulations of this research. However, it contains yearly meteorological data acquired from many years, which are not representative for the study area specifically. For this reason, SoDa Service [21] should be employed. This service offers historical solar radiation and weather data for any location worldwide. Using these data, the TMY file can be adjusted to better reflect the actual conditions of the study area. As the research progresses, more information on this task will be gathered to refine this process and facilitate the practical implementation.

4.2 Data Processing

Following data collection, a specific processing procedure will be performed to extract the points representing only the trees, depending on the data collection method. Initially, the open AHN 4 and AHN 5 point clouds, which will be used in the first experiment on processing steps, will be modified using Python scripts developed for this thesis. These scripts are available in the Thesis GitHub repository and include the following processing steps:

1. **Cropping:** The point cloud is cropped to the boundaries of the study area.

2. **NDVI Filtering:** Points representing the trees are isolated by setting a threshold for the calculated NDVI.

3. **Point Extraction:** Points with an NDVI greater than 0.2 are extracted.

Regarding the TLS data, to isolate the tree points, the point cloud will be processed either manually using CloudCompare software or through a Python script designed to differentiate points based on characteristics such as height. Alternatively, other software approaches, similar to the method used by Peynaud and Takoudjou (2024) [18], may also be employed. In addition, in case images from UAV are integrated, the point cloud will be extracted using Structure-from-Motion with COLMAP software and then effectively combined with the point cloud from terrestrial 3D laser scanning.

The analysis plan involves several cases that examine various methods of representing tree geometry during daylight simulations. Specifically, for each case, a DWG file will be created, including the representation of the CCC Building and objects in the surrounding area, while excluding layers that do not influence the simulation results, such as neighboring buildings, window glass, and the ropes on the bridge. Each file will also include the corresponding tree representation. **Table 1** presents the tree geometry representations per case that have been decided by this stage:

Table 1: Tree geometry representation cases

Case	Tree Geometry Representation
1	Initial, provided by Eleonora Brembilla
2	Without trees
3	Predefined model trees from ClimateStudio
4	Point cloud
5	Tree crown represented by convex hull
6	State-of-the-art methodology, provided by Du et al. (2019)

In the first case, the initial tree geometrical representation provided by Eleonora Brembilla will be utilized, While in the second case no tree geometries will be included. The third case involves replacing initial tree geometrical representations with predefined 3D tree models available in the ClimateStudio plugin. This plugin allows the addition of realistic 3D tree models by configuring parameters to create trees that closely resemble the ones in the study area. Furthermore, to make the scene more realistic, the positions of these tree models will be determined based on the locations of tree points in the point cloud.

The forth case involves integrating the original tree point cloud data into the scene for daylight simulation. However, due to the operational requirements of Rhino software, the tree point cloud needs to be slightly processed. This involves creating cubes with 2 cm edges around each point, enabling the points to be detected by the daylight simulation functionalities of the ClimateStudio plugin. The fifth case focuses on incorporating the convex hull derived from the points, which represent the leaves and branches of the trees and cylinders constructed according to trunk points of the trees. For this scenario, certain assumptions were made regarding the level of transparency, which was configured using the ClimateStudio plugin. For the forth and fifth case, Python scripts have already developed and can be found at Thesis GitHub repository. However, the corresponding code for the fifth case is incomplete, since the methodology for extracting the leaves/branches and the trunk points separately for each tree individually is not finalized yet. By this stage, after reviewing the point cloud in CloudCompare, it was estimated that all the points with height of 3 meters and above are likely

belong to either branches or leaves, upon which the current code was built. For the sixth case, the AdTree algorithm developed by Du et al. (2019) [11] will be utilized. This case was not included in the preliminary results, because a methodology for segmenting the individual trees has not yet been explored. For this task, insights from de Groot (2020) [10] are expected to be particularly valuable.

4.3 Evaluation of results

For the accurate assessment of the daylight simulations, the calibration of the TMY file needs to be undertaken according to the solar radiation data of the study area.

After calibrating the weather dataset, creating the DWG files and representing accurately the geometry of the trees and CCC Building, ClimateStudio plugin of Rhino Software will be employed for daylight simulation, mainly using Point-in-time and Daylight Availability workflows. Then, it will be examined how the results from each scene align with the records of east sensor both at a specific time and throughout a year.

4.4 Preliminary Results

Since the TMY file has not been adjusted according to the local solar radiation data yet, for the preliminary results a different approach was followed. The AHN 4 point cloud was used to build the following scenes for the daylight simulation using only the Point-in-time workflow:

1. **Initial scene**
2. **Scene without trees**
3. **Scene with trees represented by point cloud (in cubic form as explained previously)**
4. **Scene with the convex hull representation of the crowns of all the trees**

After defining the TMY file, the materials of the objects were specified. Some assumptions were made during this process, as additional experiments are needed to finalize the material properties. The materials currently assigned to each object category are as follows:

Table 2: Material per object category

Object Category	Material	Reflectance (%)
Tree	Grass 5	15.7
Building Parts (walls, roof, columns, floor)	Opaque Roller Shade	43.24
Door	Aluminum Door	44.16
Glass on the Facade	Kalwall 100mm Opt.1 Crystal White Tvis 13%	15
Bridge	Opaque Roller Shade	43.24

In ClimateStudio, the options provided for the sky model are CIE Standard Clear, Intermediate and Overcast sky, Perez All-Weather Model, Uniform Sky and Utah Sky. For the initial daylight simulation implementation, the Point-in-Time workflow was selected for October 15th, 2024 at 16:00 on surface that represents the global horizontal sensor which was located at the northeast corner of the roof and is oriented upwards. The choice of the appropriate sky model was determined by comparing the simulated illuminance value with the actual value recorded by this sensor. This sensor was used as a reference, because it is unlikely to be shaded by any

objects in the study area, ensuring its measurements accurately reflect the overall illuminance conditions. Since on October 15th, 2024 at 16:00 the global horizontal sensor recorded 4.73 klux, comparing this value with the ones on **Table 3**, the sky model, which can be used in this case, is CIE Standard Overcast.

Table 3: Simulated illuminance at global horizontal sensor per sky model

Sky Model	Simulated illuminance at global horizontal sensor (lux)
CIE Standard Clear	4367.932
CIE Standard Intermediate	4905.145
CIE Standard Overcast	4778.571
Perez All-Weather Model	8053.143
Uniform Sky	6080.457
Utah Sky	2265.599

The next step was to implement the Point-in-time simulation for the east sensor on October 15th, 2024 at 16:00, which is mostly affected by the shade from the tree, as it can be estimated by the sun path at **Figure 7**. This sensor is positioned at the northwest corner of the roof and is oriented towards the northwest. The simulation was performed, given the materials and the sky model specified previously.

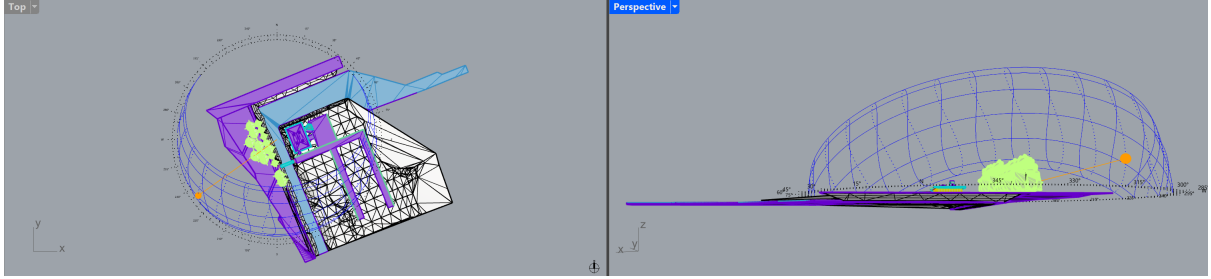


Figure 7: Sun path on October 15th, 2024 at 16:00

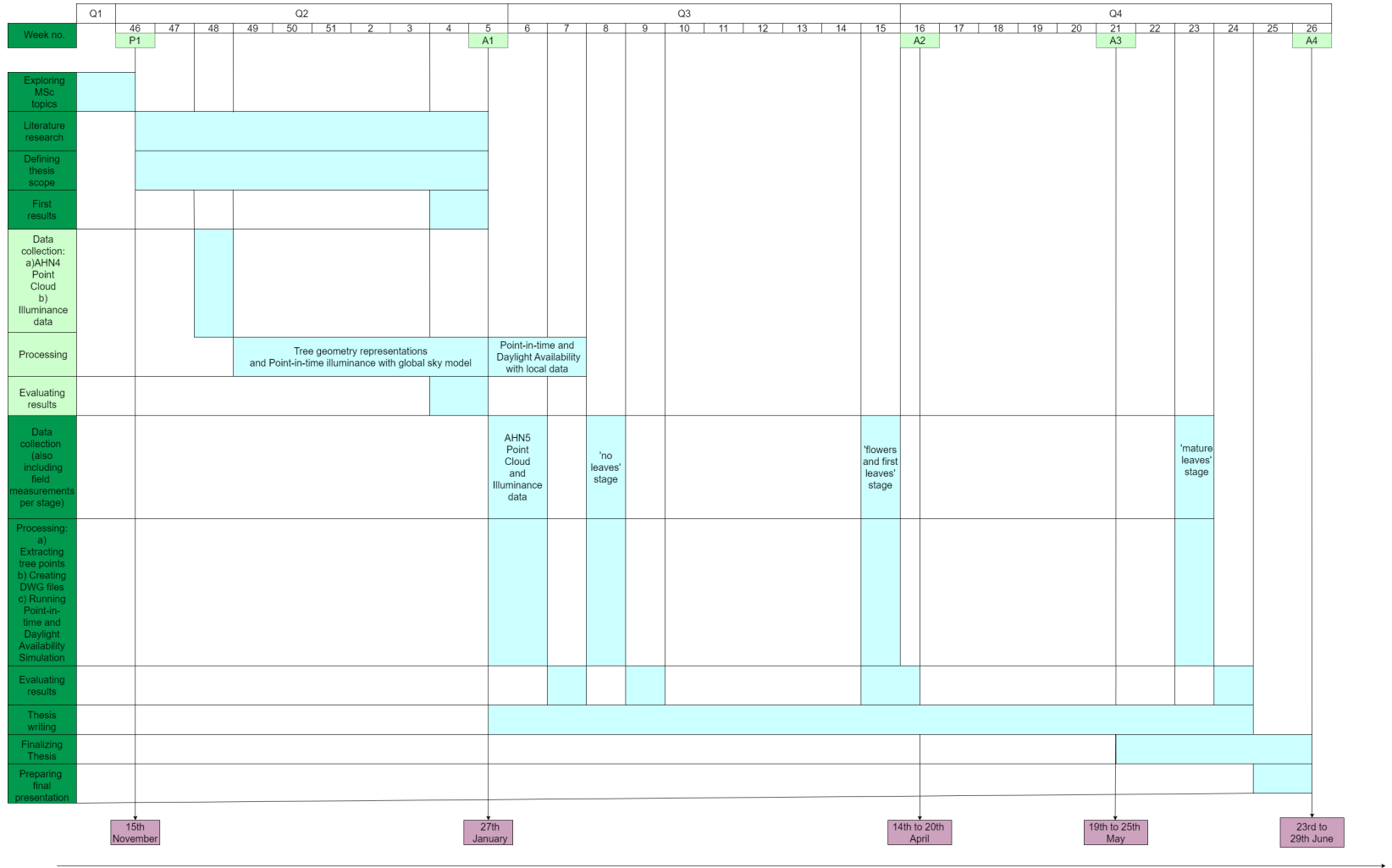
Table 4 demonstrates the simulated illuminance at east sensor per tree geometry case. The recorded illuminance value from the east sensor is 1.07 klux. In this particular case, this indicates that the case of convex hull is closer to the real-world conditions, yet not to a large extent. Nevertheless, the initial scene has little difference compared to the convex hull case. In addition, it is evident that if the trees were not considered, the simulated illuminance value would be about 150% higher than the actual value. Lastly, with this implementation, the point cloud representation has suboptimal results, as it significantly overestimated the simulated illuminance, producing value nearly equivalent to the case without trees. However, these results did not follow the finalized procedure. Not all data were fully integrated, and certain assumptions about the sky model and the materials were made. With further processing and experimentation, the simulation will be refined to ensure the sky model is determined based on local data, and the material properties are accurately defined.

Table 4: Simulated illuminance at east sensor (lux) per case

Case	Simulated Illuminance at East Sensor (lux)
Initial Scene	1740.188
Scene Without Trees	2510.201
Scene with Trees Represented by Point Cloud	2498.047
Scene with the convex hull of the crowns of all the trees	1688.354

5 Time Planning

16



6 Tools and Datasets Used

This section provides an overview of the tools (**Table 5**) and datasets (**Table 6**), which have been already or will be used for this research.

Table 5: Tools

Tools	Usage
Plantify/PlantNet/PictureThis	Tree Identification.
CloudCompare	Viewing or removing outliers from the point cloud.
Python	Scripts for point cloud processing.
C ++	Running AdTree algorithm.
AutoCAD	Forming the scene before Daylight Simulation.
Rhino/Climate Studio plugin	Performing Daylight Simulation.
3D laser scanner	Acquisition of tree point cloud
UAV	Acquisition of images of tree canopy
COLMAP	Performing Structure-from-motion

Table 6: Datasets

Datasets	Usage
Geotiles downloader	First processing steps on point cloud.
CCC Building illuminance records	Evaluating simulation results.
SoDa	Solar radiation data.

References

- [1] AHN (Actueel Hoogtebestand Nederland). Dataroom, 2025. Accessed on January 18, 2025.
- [2] Mohammed Ayoub. 100 years of daylighting: A chronological review of daylight prediction and calculation methods. *Solar Energy*, 194:360–390, 2019.
- [3] P. Balakrishnan and J. A. Jakubiec. Trees in daylight simulation—measuring and modeling light passing through trees. *LEUKOS*, 19(3):241–268, 2022.
- [4] Mattia Balestra, Enrico Tonelli, Alessandro Vitali, Carlo Urbinati, Emanuele Frontoni, and Roberto Pierdicca. Geomatic data fusion for 3d tree modeling: The case study of monumental chestnut trees. *Remote Sensing*, 15(8):2197, 2023.
- [5] Faizah Mohammed Bashir, Yakubu Aminu Dodo, Mohamed Ahmed said Mohamed, Norita Md Norwawi, Nahla M Shannan, and Amirhossein Aghajani Afghan. Effects of natural light on improving the lighting and energy efficiency of buildings: toward low energy consumption and co2 emission. *International Journal of Low-Carbon Technologies*, 19:296–305, 2024.
- [6] D. E. Bertani, A. M. P. De Novellis, R. Farina, E. Latella, M. Meloni, C. Scala, and S. Ferrari. Shedding light on light: A review on the effects on mental health of exposure to optical radiation. *International Journal of Environmental Research and Public Health*, 18(4):1670, 2021.
- [7] Brandywine Conservancy. Invasive species spotlight: Norway maple, 2025. Accessed on January 18, 2025.
- [8] Codeway Apps. Plantapp: Plant identifier and care guide, 2025. Accessed on January 18, 2025.
- [9] Drury Crawley. Creating weather files for climate change and urbanization impacts analysis. 09 2007.
- [10] Rob de Groot. Automatic construction of 3d tree models in multiple levels of detail from airborne lidar data. 2020.
- [11] Shenglan Du, Roderik Lindenbergh, Hugo Ledoux, Jantien Stoter, and Liangliang Nan. Adtree: Accurate, detailed, and automatic modelling of laser-scanned trees. *Remote Sensing*, 11(18):2074, 2019.
- [12] Gemeente Delft. Bomen in beheer door gemeente delft, 2025. Accessed on January 18, 2025.
- [13] GeoTiles. Geotiles: High-quality tile services for mapping and analysis, 2025. Accessed on January 18, 2025.
- [14] Jozef Hrask. Chronobiological aspects of green buildings daylighting. *Renewable Energy*, 73:109–114, 2015.
- [15] Mecanoo Architects. Co-creation centre and nonohouse, 2025. Accessed on January 18, 2025.
- [16] Joseph B Murdoch. Illumination engineering—from edison’s lamp to the laser. (*No Title*), 1985.
- [17] Fumio Okura. 3d modeling and reconstruction of plants and trees: A cross-cutting review across computer graphics, vision, and plant phenotyping. *Breeding Science*, 72(1):31–47, 2022.
- [18] Emilie Peynaud and Stéphane Momo Takoudjou. Terrestrial lidar point cloud dataset of cocoa trees grown in agroforestry systems in cameroon. *Data in Brief*, 53:110108, 2024.
- [19] PictureThis AI. Picturethis: Identify plants, flowers, and trees, 2025. Accessed on January 18, 2025.

- [20] PlantNet Project. Plantnet: A citizen science project on plant biodiversity, 2025. Accessed on January 18, 2025.
- [21] SoDa Service. Soda: Solar data and tools for professionals, 2025. Accessed on January 18, 2025.
- [22] Solemma. Sky conditions faq, 2025. Accessed on January 18, 2025.
- [23] Panagiota Theodoropoulou. Optimized control strategy for venetian blinds in an event space with fully glazed facades. 2023.
- [24] J. Trochta, M. Krůček, T. Vrška, and K. Král. 3d forest: An application for descriptions of three-dimensional forest structures using terrestrial lidar. *PLoS ONE*, 12(5):e0176871, 2017.
- [25] Di Wang, Stéphane Momo Takoudjou, and Eric Casella. Lewos: A universal leaf-wood classification method to facilitate the 3d modelling of large tropical trees using terrestrial lidar. *Methods in Ecology and Evolution*, 11(3):376–389, 2020.
- [26] Yongjian Wang, Weiliang Wen, Sheng Wu, Chuanyu Wang, Zetao Yu, Xinyu Guo, and Chunjiang Zhao. Maize plant phenotyping: comparing 3d laser scanning, multi-view stereo reconstruction, and 3d digitizing estimates. *Remote Sensing*, 11(1):63, 2018.
- [27] Wikipedia Contributors. Acer platanoides, 2025. Accessed on January 18, 2025.
- [28] Wikipedia Contributors. Illuminance, 2025. Accessed on January 18, 2025.