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WP 2: Copernicus Uptake and Spatial Data Lab

# Deliverable 2.2.: StoryMap with various tree maps for Copenhagen & Sofia

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## Disclaimer



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# Table of Contents





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## Table of tables



## Table of figures





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# Executive Summary

Deliverable 2.2 documents the development of ArcGIS StoryMaps to showcase the tree mapping results derived from remote sensing data in Copenhagen and Sofia by Eurosense and DHI. This deliverable is the outcome of tasks 2.2 (Automated Detection of Trees and Interference Analysis) and 2.3 (Classification of Tree Vitality Using Color-Infrared Imagery and Deep Learning (AI)). Additionally, the project incorporates other initially unforeseen but relevant datasets related to tree mapping, such as the Leaf Area Index (LAI), Land Use Land Cover maps, and the Normalized Difference Vegetation Index (NDVI).

This document serves as a background reference, with the primary focus being the content within the ArcGIS StoryMaps itself. Following a brief description of the document's purpose, audience, and structure in Chapter 1, Chapter 2 delves into the ArcGIS StoryMaps platform. This chapter includes general information on how to incorporate geographic data, along with details on the structure of our ArcGIS StoryMaps and how it was shared.

Chapter 3 provides an overview of all datasets included in the ArcGIS StoryMaps for tree mapping. This chapter offers more details about the expertise of Eurosense and DHI, who respectively created datasets from aerial and satellite imagery.

It is important to note that the ArcGIS StoryMaps is designed to be continuously updated with new datasets as they are created, making it a flexible tool for sharing information with the public and other stakeholders.



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# 1 Introduction

## 1.1 Purpose and audience of the document

The aim of this report is to present the tree maps developed for Copenhagen and Sofia by Eurosense and DHI to the public via an interactive ArcGIS StoryMaps. Additionally, the StoryMaps serves as a platform to showcase the different tree datasets available to cities that are planning to purchase the 100KTREEs toolbox.

This document provides background information on ArcGIS StoryMaps and details the process involved in its development. Through this report, we aim to offer a clear understanding of the development and functionalities of the StoryMaps, as well as the benefits it provides for sharing geographic data to the broader public.

## 1.2 Structure of the document

In the second chapter, ArcGIS StoryMaps, a tool from Esri, is explained in more detail. This chapter begins with an overview of the tool, followed by instructions on how to add geographical data. It concludes with an overview of the different chapters we created for the ArcGIS StoryMaps in this project and how the StoryMaps was shared with the public.

The third chapter presents the tree datasets included in the ArcGIS StoryMaps created by Eurosense using aerial imagery and by DHI using satellite imagery. It is important to note that this chapter is rather limited, as the technical details of the datasets will be presented in Deliverable 2.3.



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# 2 ArcGIS StoryMaps

## 2.1 Introduction to ArcGIS StoryMaps

ArcGIS StoryMap, developed by Esri, a global leader in GIS technology, allows users to create interactive, engaging narratives by combining maps with multimedia content like text, photos, and videos. This tool helps users tell their stories in a visually compelling way, making complex data more accessible and easier to understand.

For this project, ArcGIS StoryMaps was utilized to present tree data obtained via remote sensing, allowing for a comprehensive and interactive visualization of our results. Figure 2-1 shows the title page of the 100KTREEs StoryMaps.

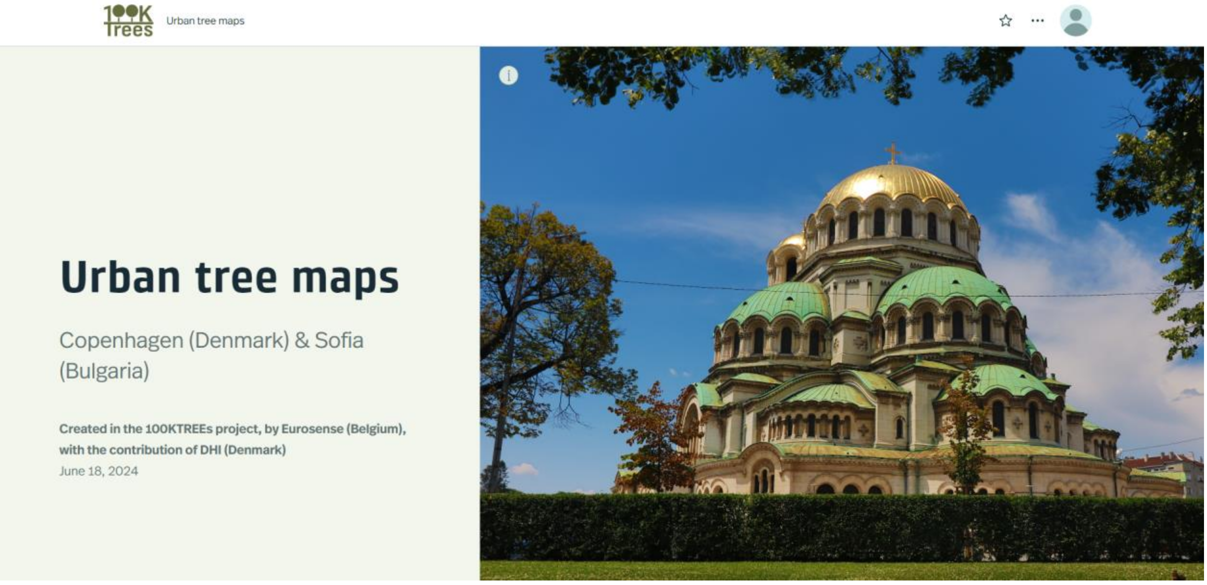


*Figure 2-1 The title page of the ArcGIS StoryMaps created in the 100KTREEs project to show the tree data derived from remote sensing data.*

## 2.2 Incorporating geographic data into an ArcGIS StoryMap

A key feature of ArcGIS StoryMaps is its capability to integrate geographic data. Under the 100ktrees project, we utilized derived datasets from remote sensing data to generate detailed maps that illustrate tree locations and characteristics. For instance, we mapped a crown vitality score for each tree in Copenhagen, ranging from 1 (red), indicating a dead tree, to 5 (dark green), signifying perfect crown vitality (Figure 2-2). A comprehensive overview of all the data can be found in Chapter 3: Datasets presented in the ArcGIS StoryMaps.

The geographical data included in the ArcGIS StoryMaps is hosted on the web GIS platform, ArcGIS Online. We used the following workflow to incorporate geographic data into our ArcGIS StoryMap:

1. First, we loaded the results from both DHI and Eurosense into ArcGIS Pro. These results were in various data formats, such as .geojson and .shp for vector data, and .tif for raster data.
2. This data was then shared to ArcGIS Online as feature layers for vectors and raster tile layers for rasters.
3. To represent 2D data, we created maps in ArcGIS Online, while 3D data was displayed in scenes.



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4. Finally, the maps and scenes were incorporated into the ArcGIS StoryMaps.

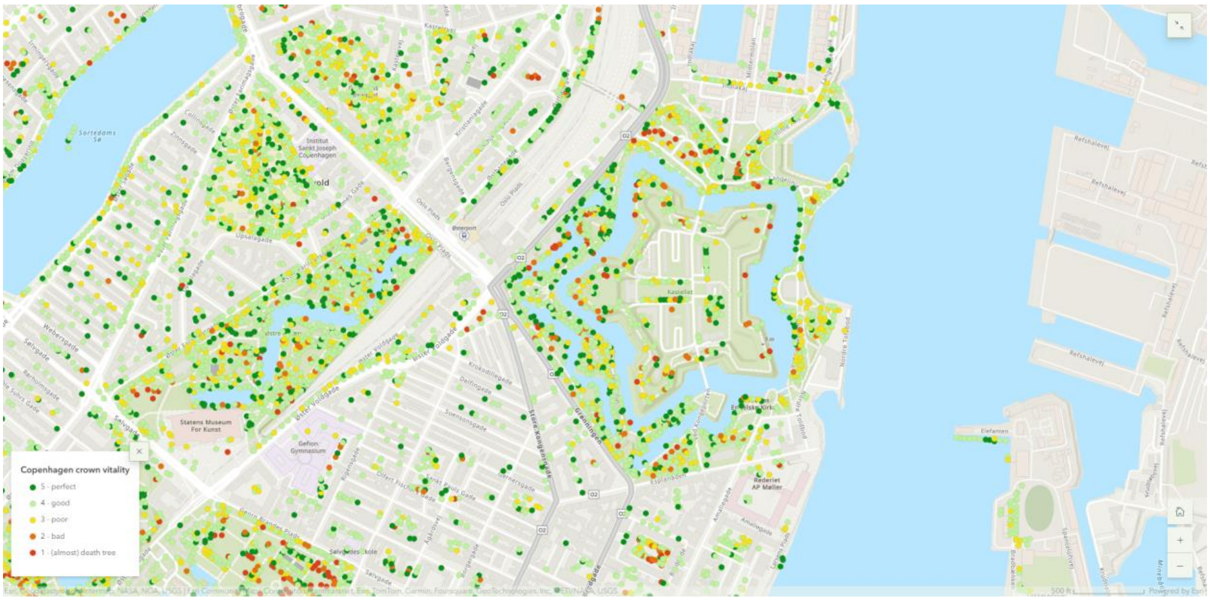


*Figure 2-2 Crown vitality map of the trees in Copenhagen.*

## 2.3 Sharing ArcGIS StoryMaps

ArcGIS StoryMaps can be shared at different levels: privately, within the ArcGIS Online organization, or publicly on the internet. In the draft version of the ArcGIS StoryMaps, it was shared within the Eurosense ArcGIS Online organization, allowing colleagues to collaborate on creating the StoryMaps. In the final version, the ArcGIS StoryMaps will be publicly accessible via QR-code and link on the 100KTREEs website (Figure 2-3).

https://storymaps.arcgis.com/stories/816bf7c42b734a3cbed64d1954b443ca

*Figure 2-3 QR-code and URL to access the ArcGIS StoryMaps created in the 100KTREEs project.*

The ArcGIS StoryMaps is hosted on the ArcGIS Online platform of Eurosense, and edits can only be performed by Eurosense.

As an appendix, you will find a PDF copy of the ArcGIS StoryMap. Please note that the best user experience is achieved by viewing the ArcGIS StoryMap online. The printed version does not optimally display the layout of the visuals, maps, and text.



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## 2.4 The structure of our ArcGIS StoryMaps

A well-structured StoryMap is essential for guiding the reader through the narrative. Users can scroll through the entire StoryMap at once or navigate through tabs indicating different chapters. The 100ktrees StoryMap begins with an introduction that sets the context of the study, followed by a series of map-based sections (tree maps, tree health, distance analysis, tree planting spots) presenting core data and analyses (Figure 2-4). Finally, we conclude with a discussion on upscaling our methodologies. Within these sections, we integrated text, images, maps, and interactive elements to enhance the storytelling experience. Consistent use of themes, colours, and fonts maintains visual harmony, while interactive maps engage the user with the content.

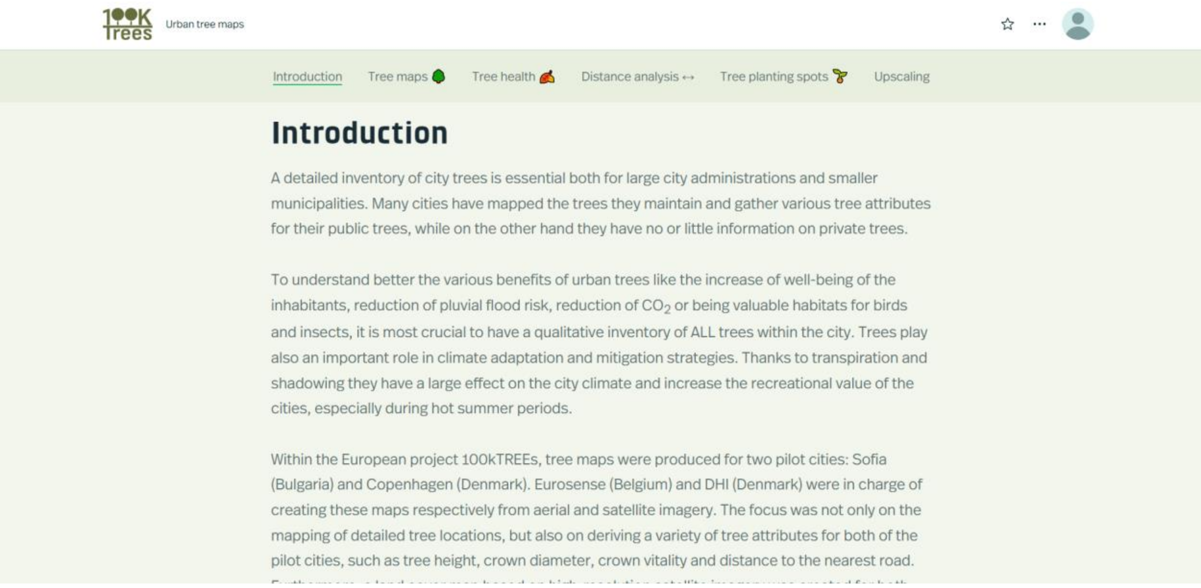


*Figure 2-4 The ArcGIS StoryMaps is divided into different chapters visualized via tabs.*



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# 3 Datasets presented in the ArcGIS StoryMaps

Both DHI and Eurosense created tree datasets using remote sensing technology for the 100KTREEs project. Eurosense utilized data from aerial imagery, while DHI used satellite imagery. The following sections provide an insight into the remote sensing expertise of both data providers and an overview of the datasets they presented in the ArcGIS StoryMap. For a more detailed description of each dataset, please refer to Deliverable 2.3.

## 3.1 Data derived from aerial imagery

### 3.1.1 Eurosense

Eurosense is a provider of geospatial solutions across Europe, specializing in aerial photography, remote sensing, and GIS. Renowned for their expertise in spatial data analysis, Eurosense supports industries like urban planning, environmental management, and infrastructure development.

Eurosense is actively engaged in enhancing urban green spaces through tree health monitoring and comprehensive tree mapping. Their tree teams investigate the health and stability of trees on the ground, and combining this terrain data with high-resolution aerial imagery to provide valuable insights and tools that aid city planners in better tree management.

In the 100KTREEs project, Eurosense applied their expertise in aerial imagery and tree monitoring to map trees and their characteristics using Light Detection and Ranging (LiDAR) technology and aerial photography.

### 3.1.2 Datasets from aerial imagery in Copenhagen

As documented in Deliverable D2.1, no up to date and complete tree dataset of Copenhagen is available, therefore there was a significant need to develop a comprehensive tree map of Copenhagen, encompassing both public and private trees. Furthermore, this complete tree map of Copenhagen was essential as input for the models created in Work Package 4.

Since LiDAR data was available for Copenhagen, it enabled determination not only of the tree locations and crown diameters for all trees in Copenhagen, but also their heights. This allowed us to create a 3D tree map. With this dataset, crown vitality scores and leaf area index based on training data and aerial imagery could be linked to the trees. Moreover, the Normalized Difference Vegetation Index (NDVI) was calculated, serving as an indicator of tree health and stress. Table 3-1 provides an overview of the datasets created for Copenhagen.

| | Copenhagen | | | |
|---|---|---|---|---|
| **Data** | Attributes | Methodology | Produced by | Data source |
| **3D Tree Map** | Tree location | Individual Tree Detection via segmentation of LiDAR point clouds. Average X and Y | Eurosense | LiDAR (2019, dataforsyningen) |



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| | | | | |
|---|---|---|---|---|
| | | from the segmented point cloud. | | |
| | Crown diameter | Maximal crown diameter from the segmented point cloud. | Eurosense | LiDAR (2019, dataforsyningen) |
| | Tree height | Point within the point cloud with the largest distance above ground. | Eurosense | LiDAR (2019, dataforsyningen) |
| **Crown vitality** | Crown vitality score (1-5):<br>5: Perfect crown vitality (No discoloration in crown)<br>4: Good crown vitality (Some discoloration in crown)<br>3: Poor crown vitality (Almost half of the crown shows signs of discoloration)<br>2: Bad crown vitality (More than half of the crown has discoloration)<br>1: (Almost) death tree (Few to no leaves) | A Convolutional Neural Network was trained using photo interpretation of False Color Composites of RGBIr orthophotos of tree crowns in Brussels, assigning scores ranging from 1 to 5. Subsequently, this trained algorithm was applied to the RGBIr summer orthophotos from 2017 in Copenhagen. | Eurosense | RGBIr summer orthophotos (2017, provided by DHI) |
| **Leaf Area Index (LAI)** | The Leaf Area Index (LAI) is an indicator for the quantity of leaf surface in a certain area. It is expressed by the formula (Watson, 1947):<br><br>LAI = Leaf area ($m^2$)/ground area ($m^2$)<br><br>This parameter has a strong impact on | A least squares regression analysis was performed using LAI field data collected with the PocketLAI application and RGBIr summer orthophotos from Brussels in 2023. Subsequently, this regression model was applied to RGBIr summer orthophotos from Copenhagen in 2017. | Eurosense | RGBIr summer orthophotos (2017, provided by DHI) |



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| | | | | |
|---|---|---|---|---|
| | the ecosystem services where the leaves play an important role in, such as air pollution reduction, cooling effect, floods risk and noise abatement. | | | |
| **Normalized Difference Vegetation Index (NDVI)** | The NDVI represents the normalized ratio between the NIR and red band. High NDVI values result from the combination of a high reflectance in the NIR and a lower reflectance in red, which is characteristic of the Spectral Response Pattern of green vegetation. The information derived from the NDVI index concerns mainly the presence of vegetation cover and its state. | The NDVI was calculated in ArcGIS Pro based on the RGBIr summer orthophotos. Resulting in a raster-image.<br>**NDVI = (NIR-band + RED-band)/(NIR-band + RED-band)** | Eurosense | RGBIr summer orthophotos (2017, provided by DHI) |

*Table 3-1 Tree data derived from aerial imagery in Copenhagen.*

### 3.1.3 Datasets from aerial imagery in Sofia

At the time of the project, no LiDAR data or stereoimages were available for Sofia. Therefore, Eurosense's approach based on individual tree detection on point clouds could not be executed. Sofia has already established a comprehensive tree cadastre using the DeepForest algorithm [1], which performed segmentation on 2020 orthophotos.

The decision was made to enhance this existing 2D tree map from Sofiaplan by incorporating a height parameter, thus transforming it into a 3D tree map. Utilizing data from the 2020 Digital Surface Model (DSM) and Digital Terrain Model (DTM), tree height calculations could be performed.



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| Sofia | | | | |
|---|---|---|---|---|
| **Data** | Attributes | Methodology | Produced by | Data source |
| 3D Tree Map | Tree location | Central position of the tree crown | Sofiaplan | RGB summer orthophotos (2020) |
| | Crown diameter | Average diameter of the crown | Sofiaplan | RGB summer orthophotos (2020) |
| | Crown area | Crown projection | Sofiaplan | RGB summer orthophotos (2020) |
| | Type of tree | Coniferous, Deciduous or undetermined. | Sofiaplan | RGB summer orthophotos (2020) |
| | Tree height | Highest DSM value within the crown diameter minus the DTM value of the tree available in the attributes of the tree dataset of Sofia. | Eurosense | DSM (2020, Ministry of Agriculture - Eurosense)<br>DTM (Sofiaplan) |
| Crown vitality | Crown vitality score (1-5) (see Table 3-1) | (see Table 3-1) | Eurosense | RGB summer orthophotos (2020) |
| Leaf Area Index (LAI) | LAI (see Table 3-1) | (see Table 3-1) | Eurosense | RGB summer orthophotos (2020) |

*Table 3-2 Tree data derived from aerial imagery for Sofia.*

## 3.2 Data derived from satellite imagery

### 3.2.1 DHI

DHI is a global leader in water and environmental consultancy, specializing in providing integrated solutions using advanced technologies and scientific methodologies. With expertise in remote sensing, hydrology, and environmental data management, DHI plays a crucial role in projects ranging from water resource management to climate change adaptation.

DHI possesses extensive expertise in vegetation and tree mapping, particularly through the use of satellite imagery. In the 100KTREEs project, DHI leveraged their capabilities to create



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a detailed 2D tree map using very high resolution (VHR) satellite imagery for both Copenhagen and Sofia. Additionally, they utilized this satellite imagery to calculate the Normalized Difference Vegetation Index (NDVI) and to develop a Land Use – Land Cover (LULC) dataset for both Copenhagen and Sofia.

### 3.2.2 Datasets from satellite imagery in Copenhagen & Sofia

DHI acquired Airbus Pléiades Neo imagery, with a resolution of 30 cm, captured during the summer of 2022 for Copenhagen and summer of 2023 for Sofia. This high-resolution imagery was used to create derived datasets, as presented in Table 3-3.

| Copenhagen & Sofia | | | | |
|---|---|---|---|---|
| **Data** | Attributes | Methodology | Produced by | Data source |
| 2D tree map | Tree location | A deep convolutional neural network was used to create density maps for approximating tree locations. | DHI | RGBIr summer VHR satellite imagery (2022, Airbus Pléiades Neo) |
| NDVI | (see Table 3-1) | NDVI = (NIR-band + RED-band)/(NIR-band + RED-band) | DHI | RGBIr summer VHR satellite imagery (2022, Airbus Pléiades Neo) |
| Land Use – Land Cover map | Different classes were obtained:<br>- Deciduous trees<br>- Coniferous trees<br>- Grass/herbaceous<br>- Paved surface<br>- Buildings<br>- Water<br>- Bare soil | Semi-supervised classification | DHI | RGBIr summer VHR satellite imagery (2022, Airbus Pléiades Neo) |

*Table 3-3 Tree data derived from satellite imagery for Copenhagen & Sofia.*

## 3.3 Data derived from GIS-analysis with other spatial data

In the scope of the 100k trees project a GIS analysis was done in Copenhagen to identify the public or private street trees and to calculate the distance of the trees to the middle of the nearest road. This information was important for the city of Copenhagen to have an overview of the trees under their maintenance and to see if they could cause potential interference.

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# 4 Conclusions

In conclusion, ArcGIS StoryMaps significantly enhance public access to comprehensive geographic data. For the 100KTREEs project, Eurosense and DHI effectively showcased their tree datasets, derived from remote sensing technologies, through ArcGIS StoryMaps. The well-structured presentation successfully communicates the results and insights to urban planners, policymakers, and the public. Ongoing maintenance and updates will ensure the StoryMap remains relevant and valuable over time.

This report provided background information on the use of ArcGIS StoryMaps for urban tree mapping, highlighting the creation process, the platform's functionalities, and detailed information about the presented datasets.



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# 5 References

[1] ‘Trees index’. [Online]. Available: https://sofiaplan.bg/portfolio/trees-index/



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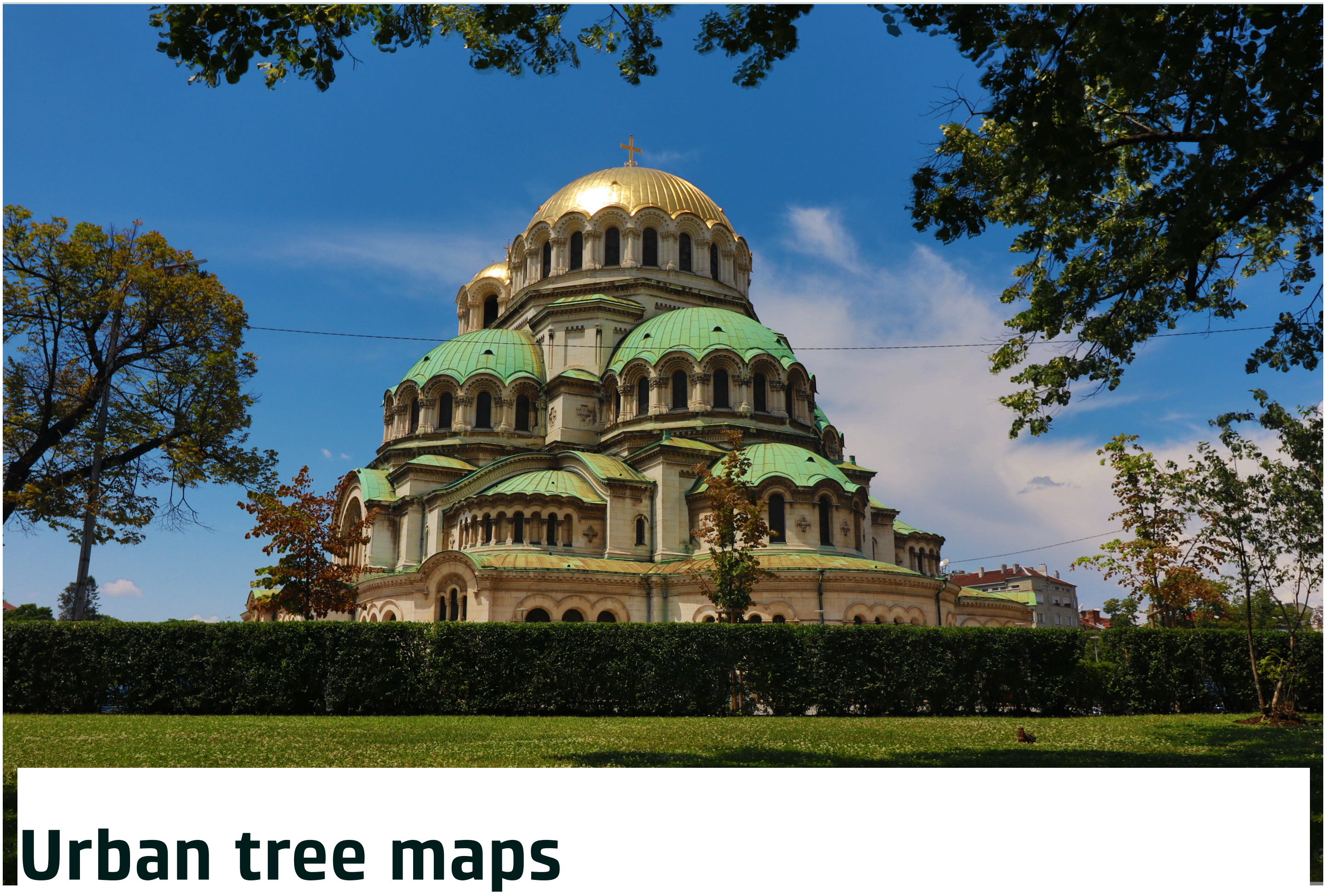
Urban tree maps



# Urban tree maps

Copenhagen (Denmark) & Sofia (Bulgaria)

**Developed as part of the 100KTREEs project, by Eurosense (Belgium) and DHI (Denmark)**

**June 25, 2024**

## Introduction

Understanding and managing city trees is crucial for both large urban centers and smaller communities. Many municipalities have already mapped their public trees, collecting data on various attributes, however, for the main part, information on private trees remains sparse.

To fully appreciate the benefits that urban trees provide–such as enhancing residents' well-being, reducing flood risks, lowering CO2 levels, and offering habitats for birds and insects–a comprehensive inventory of all trees within a city is essential. Trees are vital in climate adaptation and mitigation strategies. Their role in transpiration and shading significantly impacts the urban climate, enhancing the recreational value of cities, especially during hot summer months.

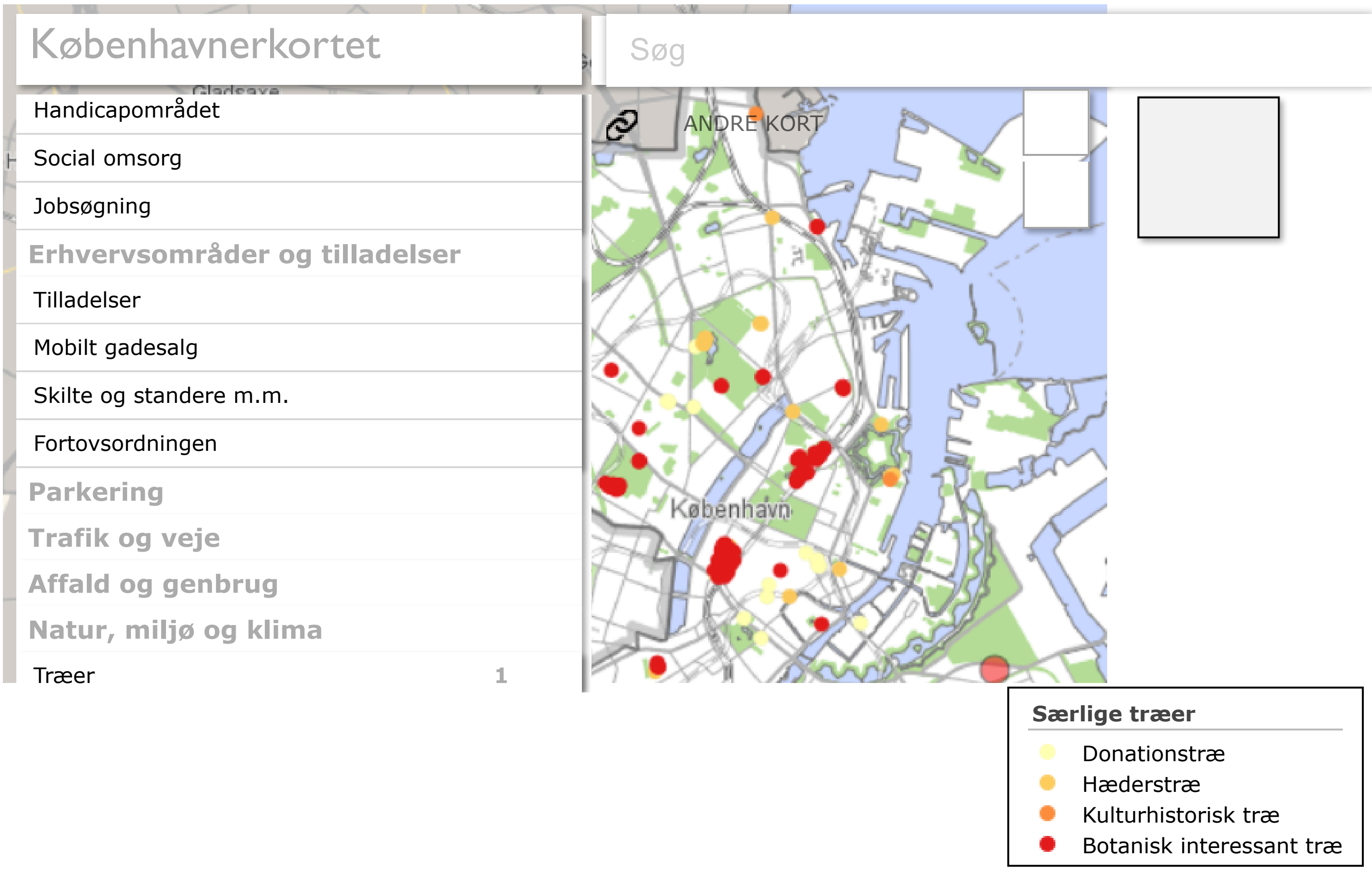
Through the European project 100kTREEs, detailed tree maps were created for Sofia, Bulgaria, and Copenhagen, Denmark. Eurosense (Belgium) and DHI (Denmark) led the efforts, using aerial and satellite imagery respectively. These maps not only pinpointed tree locations but also detailed various attributes like tree height, crown diameter, vitality, and proximity to roads. Additionally, high-resolution satellite imagery was used to develop comprehensive land cover maps for both cities.

This ArcGIS StoryMap describes the methodologies and findings of the 100kTREEs project tree mapping activities. In the following chapters, we explore the tree maps and their attributes in depth, concluding with strategies for scaling these methods to other municipalities and cities.

## Tree maps

Creating a  detailed tree map requires  precise identification of individual tree positions. This has led to exploration of automated solutions using aerial and satellite data, as alternatives to traditional manual in situ based methods which are both time consuming and cumbersome. Many cities have archives of high-resolution aerial imagery and commercial satellite data, but lacks the skills and capacities needed to make use of these datasets to derived detailed tree inventories in a accurate and efficient way. In this chapter, we will present some of the existing tree datasets available for Copenhagen and Sofia as well as information about  how these datasets can be complemented with automated detection of trees via aerial and/or satellite imagery.

## Copenhagen, Denmark

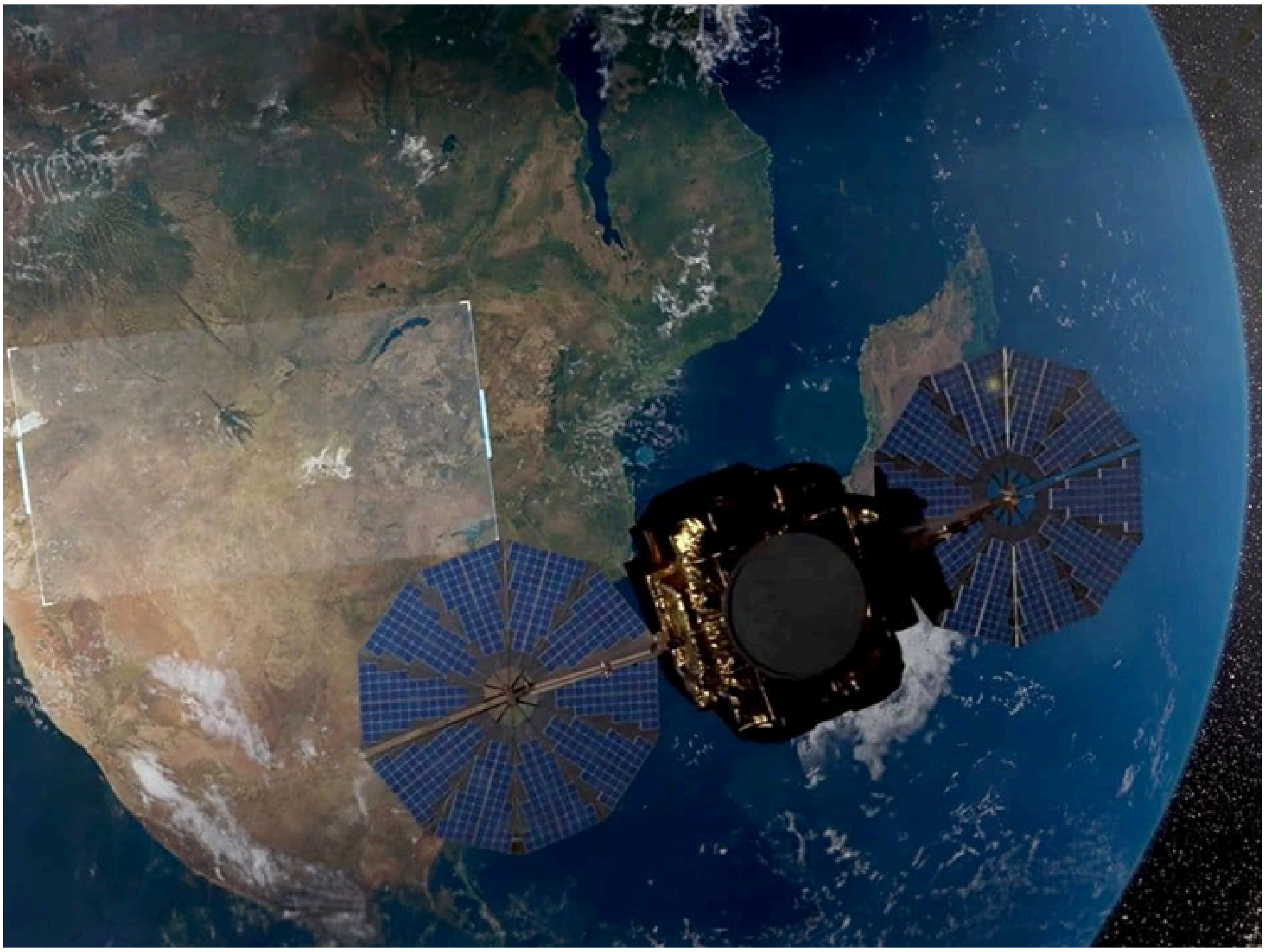



Kort og data er vejledende, © Københavns Kommune Koordinat for markør Målforhold 1:81269

### Copenhagen Tree Maps

The municipality of Copenhagen has existing tree datasets available which includes relevant metadata, e.g. on remarkable trees (Ikoniske traeer) and protected trees (Fredede traeer).

However, these tree datasets only includes the trees managed by the municipality. In order to have all trees in the city - both public and private trees - analyses on aerial and satellite imagery are needed. We discuss both approaches to do this in the following paragraphs.



**Approach 1: Tree detection on very high resolution satellite imagery**

While commercial satellite imagery offers spatial resolutions as high as 30 cm, enabling the detection of individual trees in urban areas, accurately estimating the number and location of trees within larger clusters, like parks and urban forests, poses a challenge due to overlapping foliage and varying tree densities.

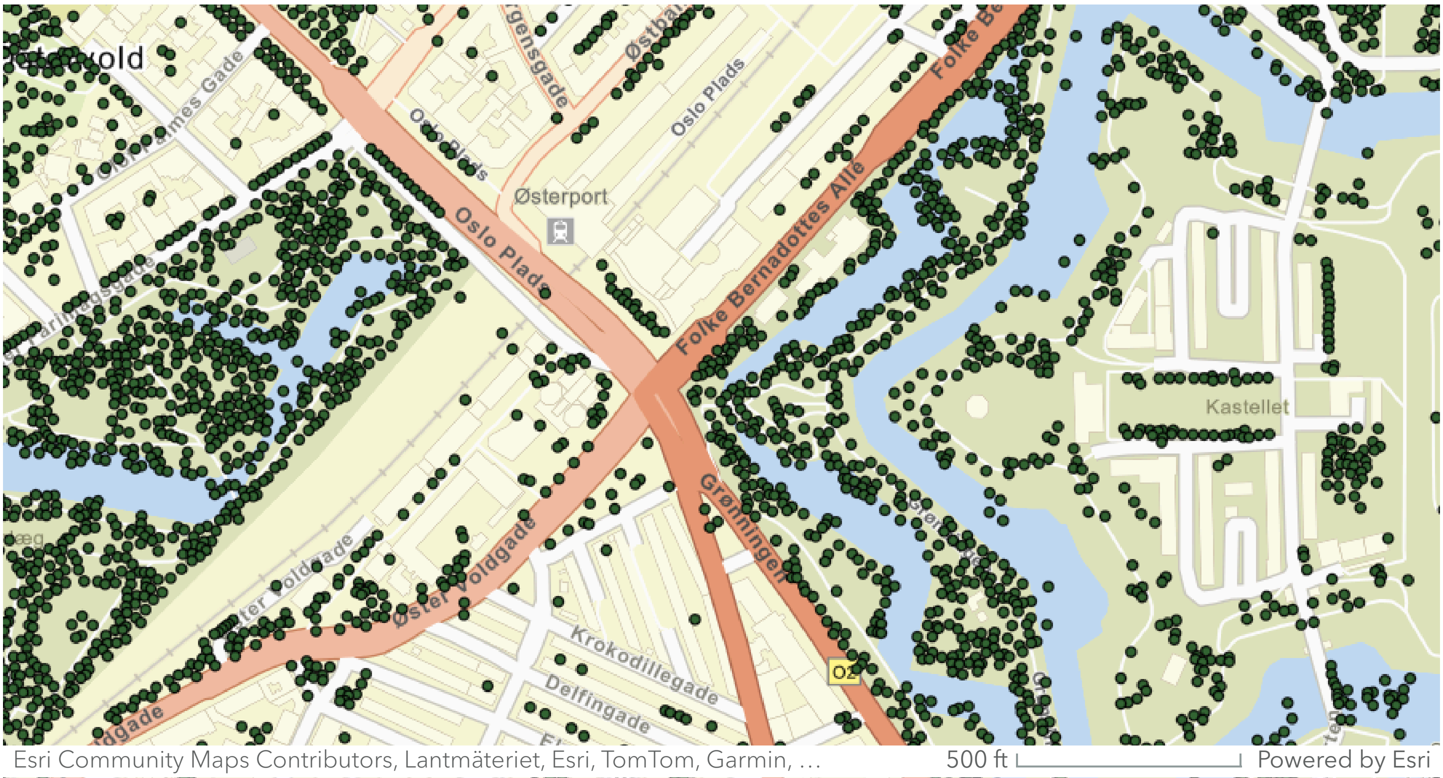
DHI has addressed this challenge by harnessing 30 cm satellite imagery alongside state-of-the-art deep learning technology to develop a groundbreaking algorithm for conducting exhaustive tree inventories across cityscapes. This algorithm excels at identifying most individual trees with canopy sizes of 1.5 m and above, while also providing estimations of the number and location of trees within larger groups. With this new method, exhaustive tree inventory assessments can now be conducted in a cost-efficient and effective way.

Under the umbrella of 100ktrees, we utilized the latest Airbus Pléiades Neo (30 cm) imagery captured during the summer of 2022 to map all trees within Copenhagen's central districts.

**Methodology**

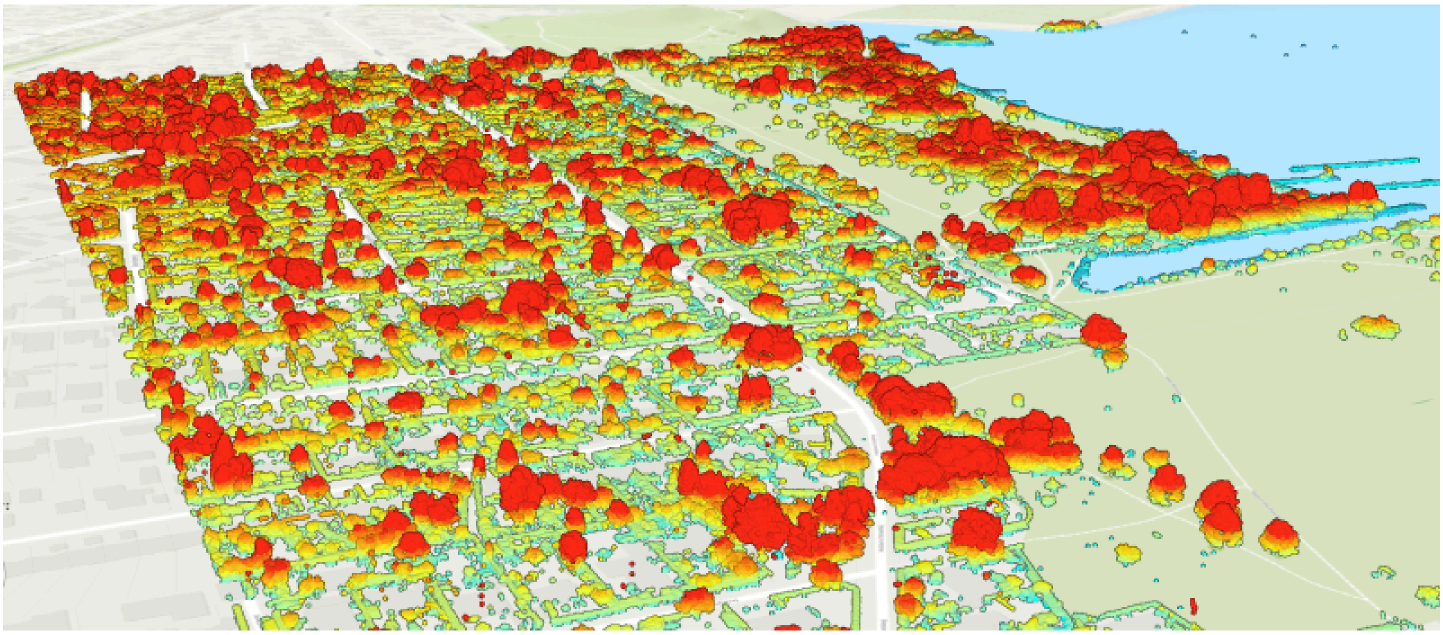
The VHR tree inventory method uses a deep convolutional neural network to create density maps for approximating tree locations. It employs a standard U-Net model without a backbone for greater flexibility in terms of input data. The model generates a density map by applying a gaussian kernel of approximate size to the respective tree to each labeled tree point/pixel, and then converts the output density map into tree points using local maxima reduction.

This method offers advantages over traditional bounding box object detection: 1) easier access to training data and 2) more accurate estimation of tree clusters due to continuous gaussian distributions. The gaussian distribution's shape resembles a tree, facilitating conversion into binary canopy cover along with tree points.




### Result - 2D tree map

With the VHR derived tree locations, a complete cityscape inventory of trees can be prepared in a cost-efficient and effective way. Here the results for a subset of the tree inventory of Copenhagen is visualized.

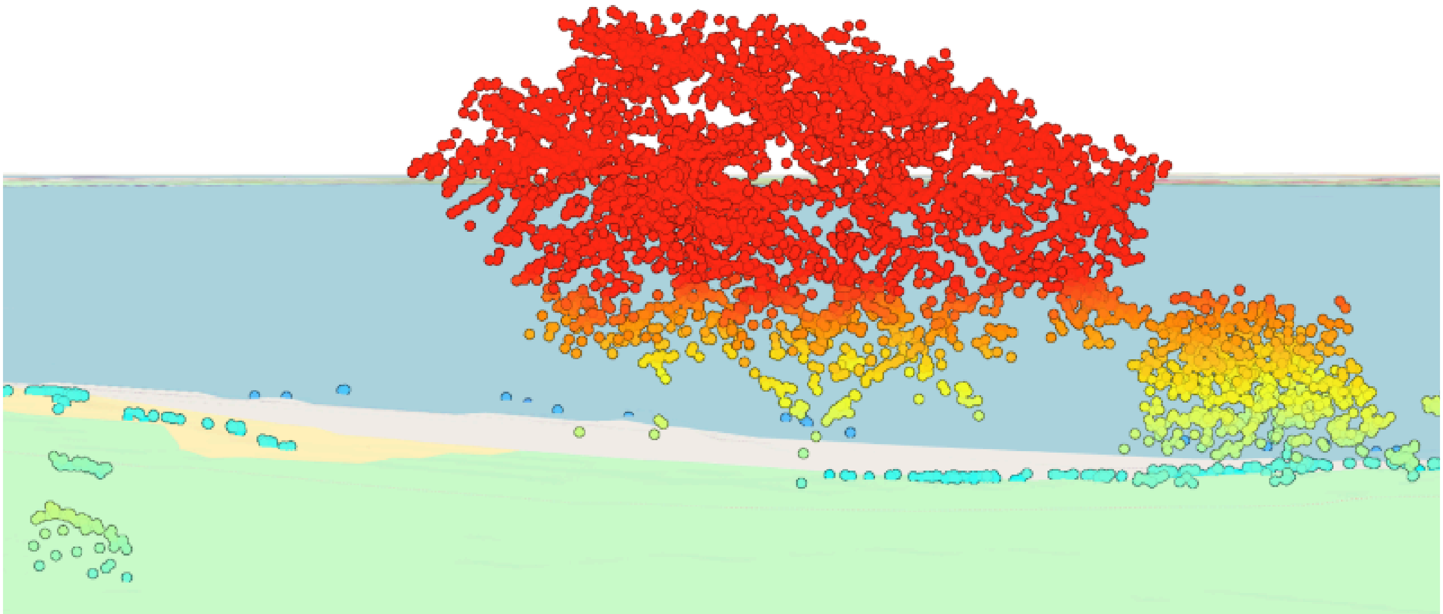


### Approach 2: Tree detection on aerial LiDAR imagery

Eurosense has developed a methodology for the precise detection of individual trees, using aerial LiDAR data.

LiDAR, an acronym for Light Detection And Ranging, is a technology that employs laser light to measure distances, providing highly accurate three-dimensional representations of the landscape in the form of point clouds.

Copenhagen has open-source classified LiDAR data available of 8 points/m². At the time of development of the tree map the most recent LiDAR data was from 2019. In order to identify the trees from other urban objects, only the points classified as vegetation were kept into the 3D point cloud for further processing (see image).



### Methodology

To segment the 3D point cloud of vegetation into individual trees, specific criteria were established. These criteria include a minimum height threshold of 2.5 meters and a minimum requirement of 100 points per group. For each group of points, the following tree attributes were calculated:

- *Tree position*: Average xy position of the points in the group
- *Crown diameter*: Largest width of the tree canopy derived from the group of points
- *Tree height*: Highest point of the group seen from the ground

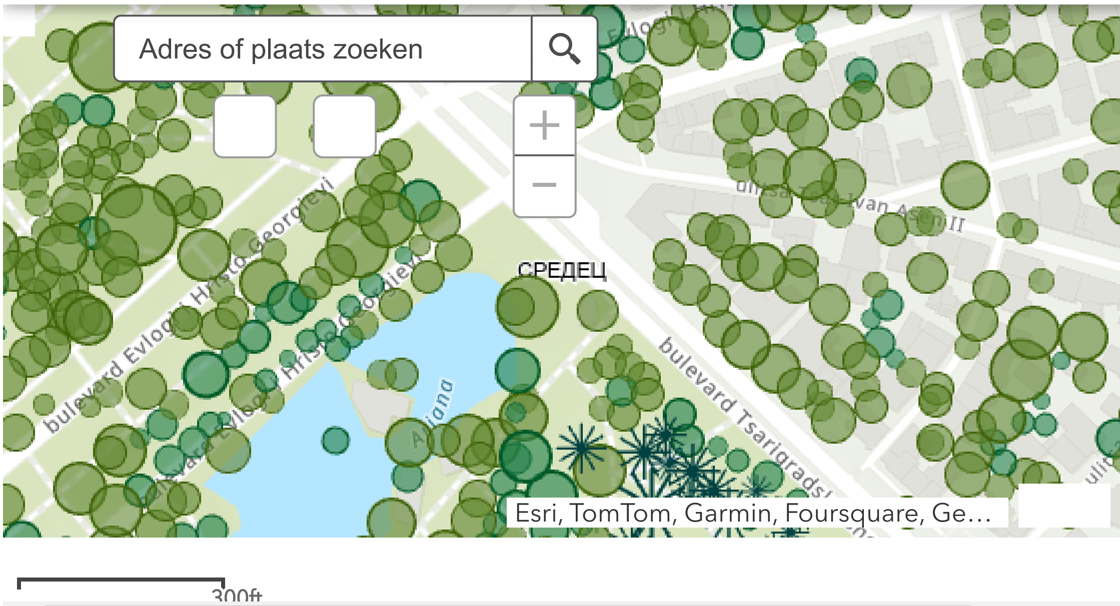

Esri Community Maps Contributors, Lantmäteriet, Esri, TomTom, Garmin, Foursquare, GeoTechnologies, Inc, M… Powered by Esri

### Result - 3D tree map

Given the calculated tree characteristics (tree location, tree height) it is possible to visualize the tree in a 3D tree map. Here a subset of the tree dataset is showed.

## Pilot city 2: Sofia, Bulgaria

Дърветата в Столична община

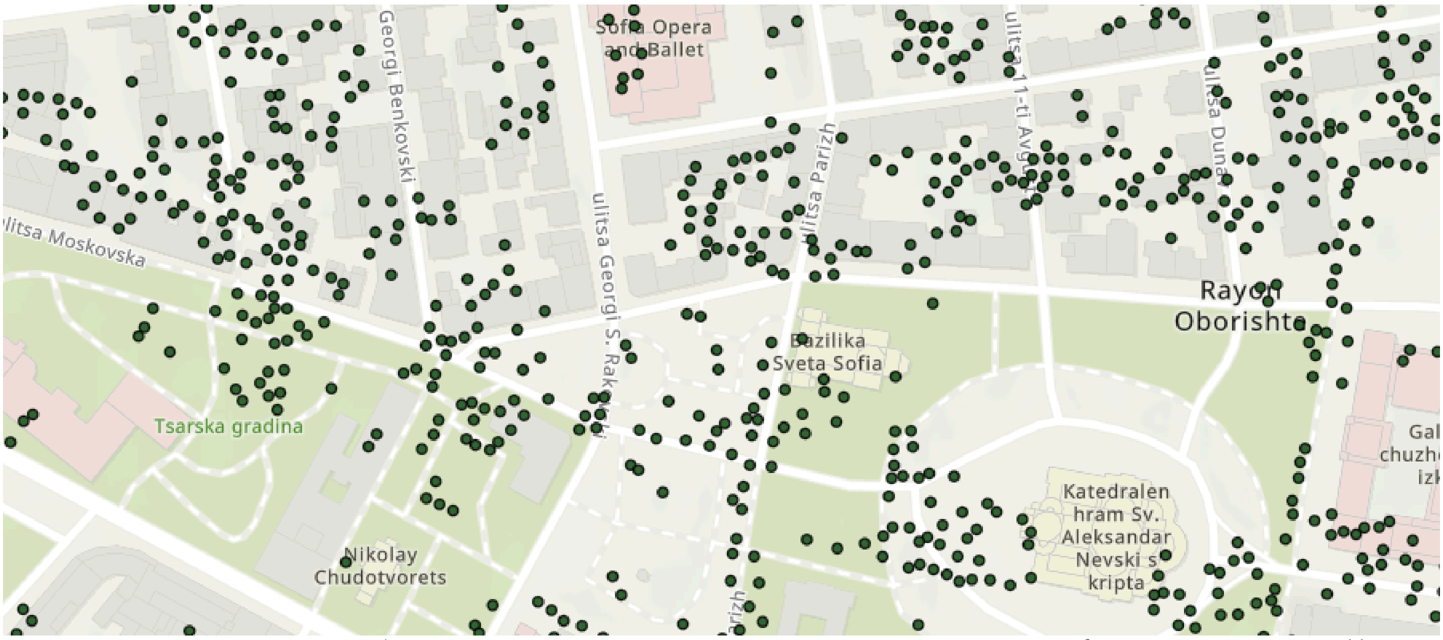



**Sofia tree map**

Sofia has already established a comprehensive tree cadaster using the DeepForest algorithm (Sofiaplan), which performed segmentation on 2020 orthophotos.

The derived tree information from the DeepForest algorithm consists of:

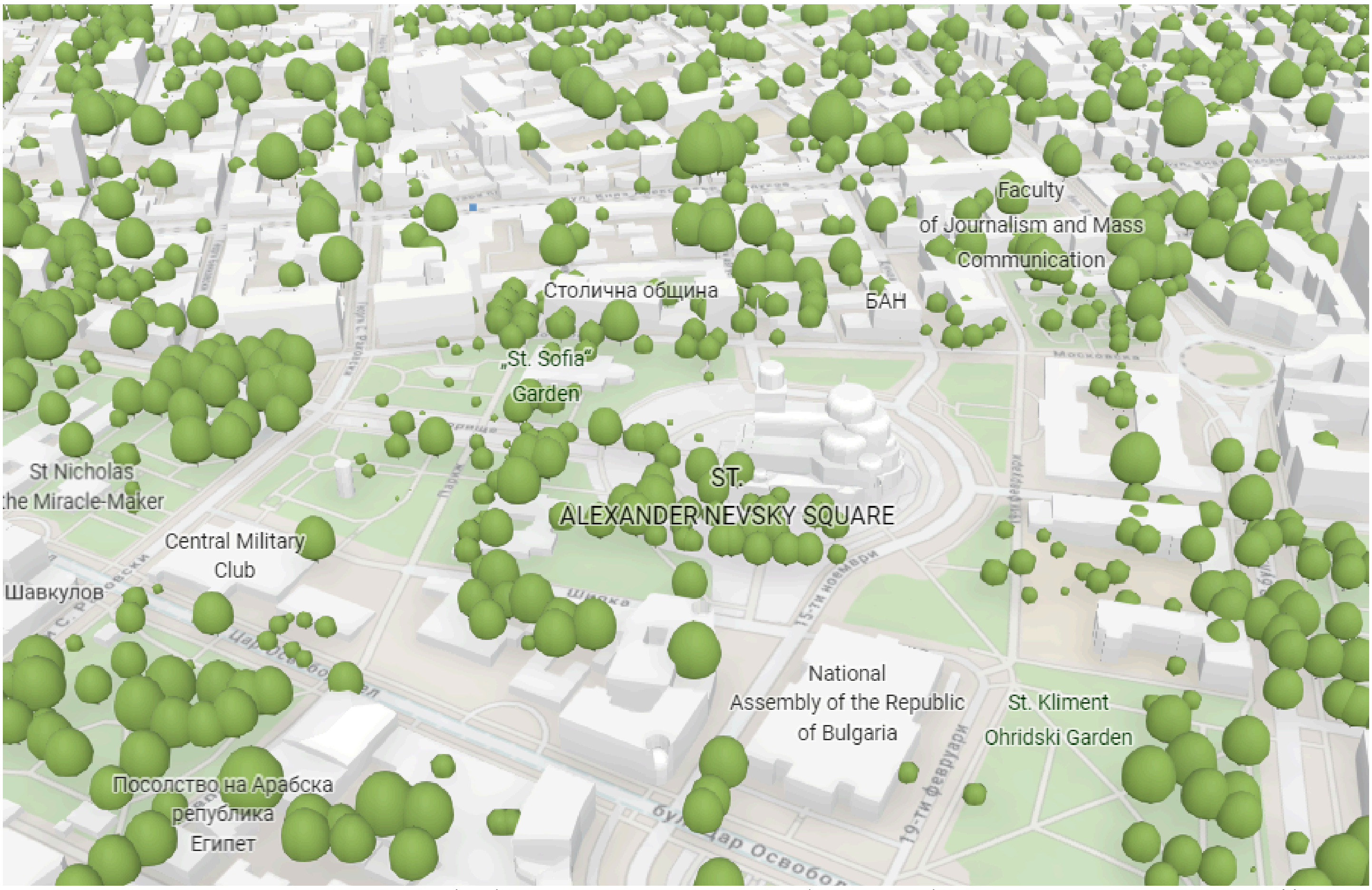
- *Tree position*: Central position of the tree crown
- *Crown diameter*: Average diameter of the crown
- *Crown area*: Crown projection
- *Type of tree*: Coniferous, Deciduous or undetermined.
- *Height*: Height of the base of the tree on the Digital Terrain Model. This is not the actual tree height.




Esri, Intermap, NASA, NGA, USGS | Esri, TomTom, Garmin, Foursquare, Ge… 200 ft Powered by Esri

### Approach 1: 2D tree map based on very high resolution satellite imagery

The same methodology used in Copenhagen was applied to create this 2D tree map for Sofia. Here, the results for a portion of the tree inventory in Sofia are visualized.




Esri, TomTom, Garmin, Foursquare, GeoTechnologies, Inc, METI/NASA, USGS | Source: Airbus,USGS,NGA,NAS… Powered by Esri

### Approach 2: 3D tree map based on aerial imagery

At the time of the project no LiDAR data or stereoimages were available for Sofia. Therefore, Eurosense's approach based on individual tree detection on point clouds could not be executed.

The decision was made to enhance the existing 2D tree map from Sofiaplan by incorporating a height parameter, thus transforming it into a 3D tree map. Utilizing data from the 2020 Digital Surface Model (DSM) and Digital Terrain Model (DTM), tree height calculations can be performed.

## Tree health

Tree health is a critical component of ecosystem stability and functionality, especially in urban environments. Healthy urban trees exhibit structural integrity, disease resistance, and optimal foliage density, facilitating efficient photosynthesis and providing essential ecosystem services. Assessments of tree health involve evaluating indicators such as crown vitality, structural stability, and pathogen presence. These evaluations enable early detection and management of stressors, thereby promoting the longevity and ecological contributions of urban trees, which include air quality improvement, temperature regulation, and enhanced urban biodiversity.

Manual classification of tree health of each individual tree is a time-consuming process, particularly when covering extensive regions. To address this, as part of the 100KTREES project, efforts were made on producing maps using aerial and satellite imagery to prioritize specific areas for further investigation and intervention.

It is important to emphasize that such data can not entirely replace in situ assessments, as the tools largely focus on crown vitality, and hence cannot detect issues like diseases or structural instabilities. Even so, such scalable and cost efficient tools are a crucial first step in urban tree management. By efficiently highlighting areas that may require more detailed examination, these maps allow city planners and arborists to allocate resources more effectively and address potential problems proactively. This combination of advanced imagery and targeted field assessments ensures a more comprehensive and efficient approach to maintaining urban tree health.

## Crown vitality Scores

### Crown vitality scores

Eurosense utilized their 3D tree maps from Copenhagen and Sofia to automatically categorize each tree into five crown vitality scores, ranging from 5 (good crown vitality) to 1 (almost dead tree), using a deep learning model. This categorization was based on the reflectance of the tree crowns in summer orthophotos.

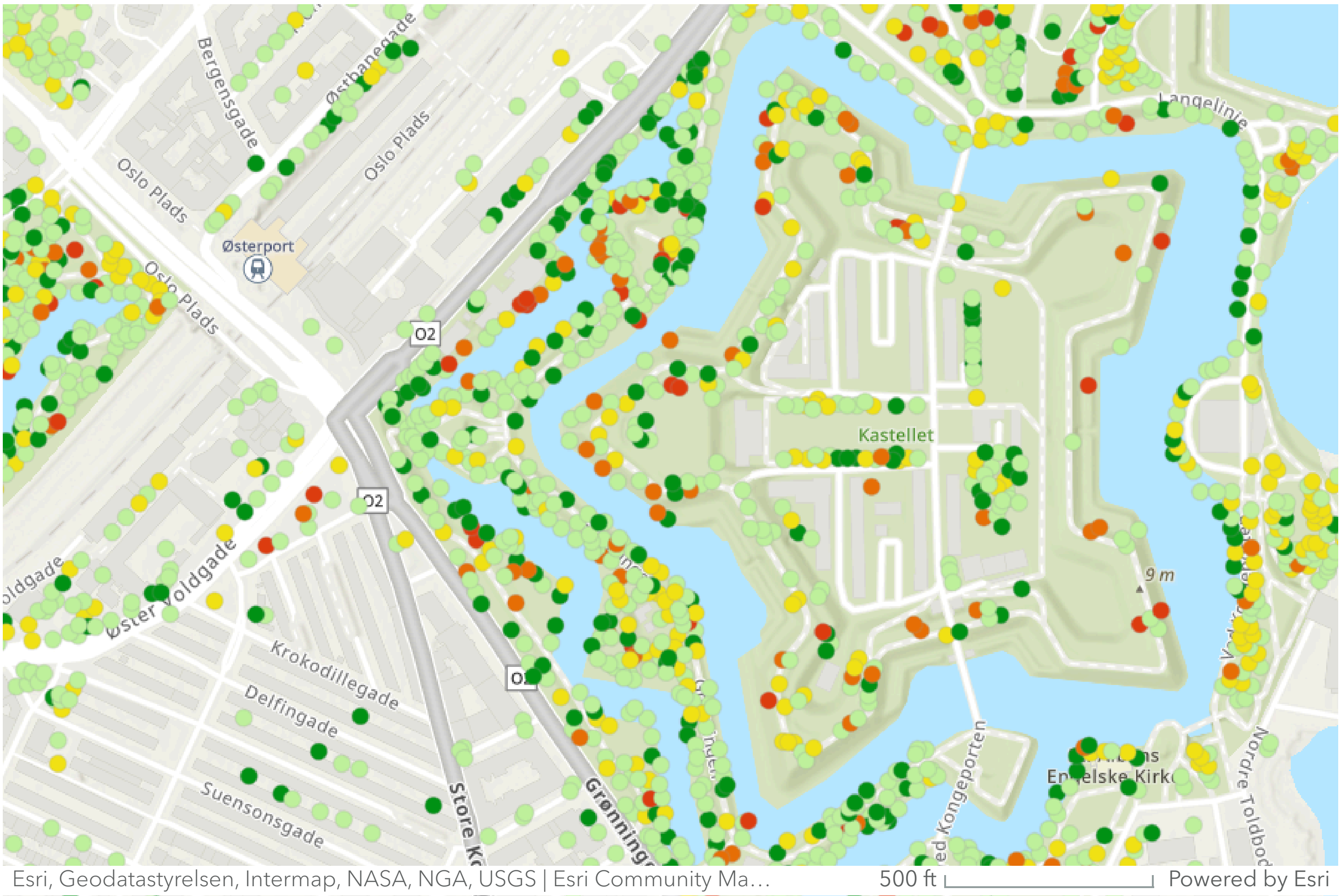
**Training phase**

The training data was sourced from a campaign in Brussels conducted between 2016 and 2017, where trees were assigned scores ranging from 1 to 5 based on the photo interpretation of False Colour Composites (FCC) with the Near-Infrared (NIR) band serving as the primary indicator of crown vitality. Tree crowns with high reflectance in the NIR band appear bright red on an FCC and are classified as healthy. Conversely, tree crowns with poor vitality exhibit low reflectance in the NIR band and typically appear light pink or white on the image. Thus, the different shades of pink determine the score a tree receives:

- 5: perfect crown vitality: no discoloration in crown (fully red on FCC)
- 4: good crown vitality: some discoloration in crown (red with some shades of pink on FCC)
- 3: poor crown vitality: almost half of the crown shows signs of discoloration (More are less half red and half pink in FCC)
- 2: bad crown vitality: more than half of the crown has discoloration (More than half of the crown light pink color)

- 1: (almost) death tree: few to no leaves (white to light pink color)

This training data was than correlated with the orthophotos of 2016 and 2017, and used to train a deep learning model.

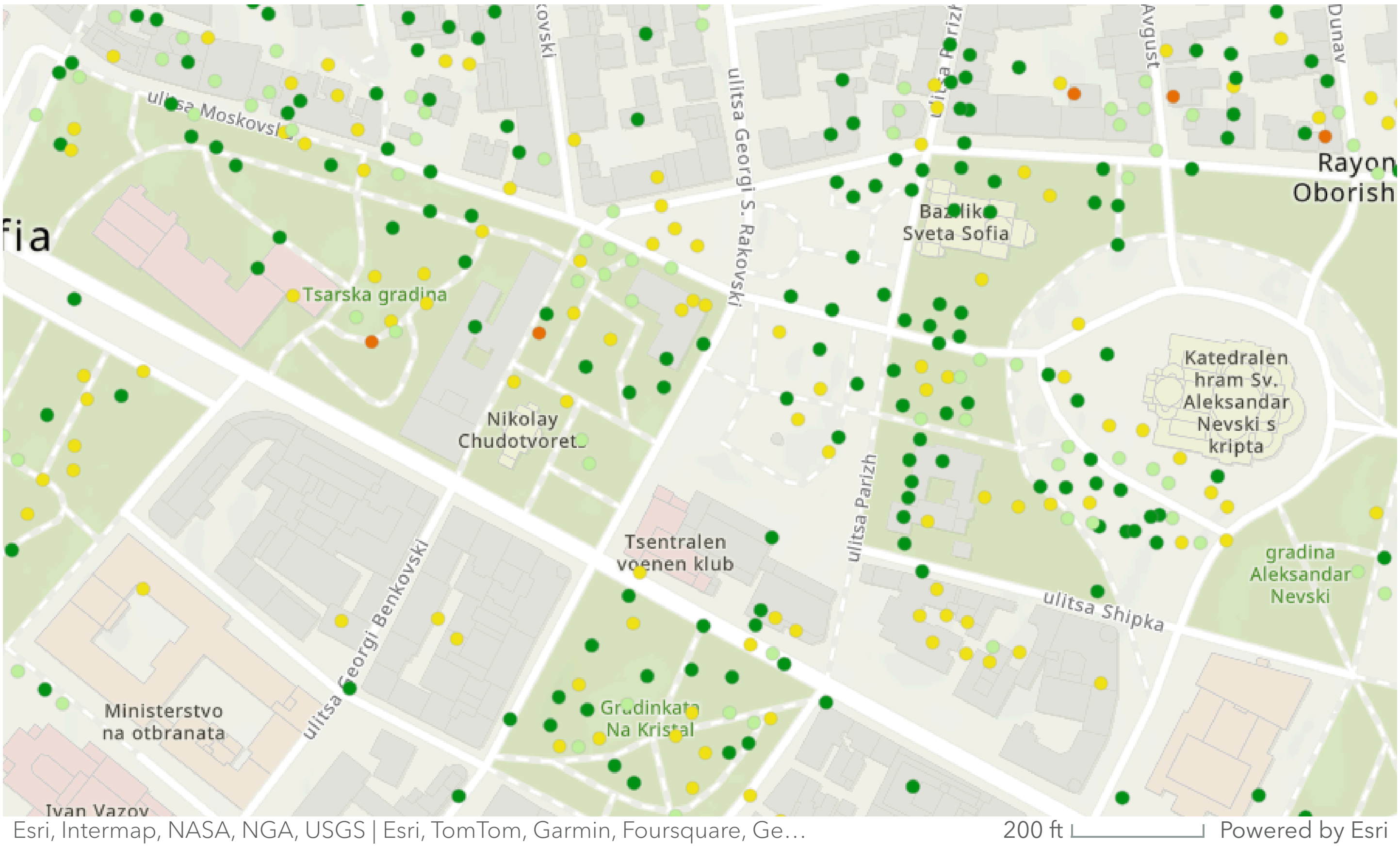



**Crown vitality scores for Copenhagen**

In the final step, this trained model was applied to summer orthophotos of 2017 for Copenhagen. Resulting in one tree health score per tree.

- 5: perfect crown vitality: no discoloration in crown
- 4: good crown vitality: some discoloration in crown
- 3: poor crown vitality: almost half of the crown shows signs of discoloration
- 2: bad crown vitality: more than half of the crown has discoloration
- 1: (almost) death tree: few to no leaves

The 3D tree map based on aerial imagery was used.



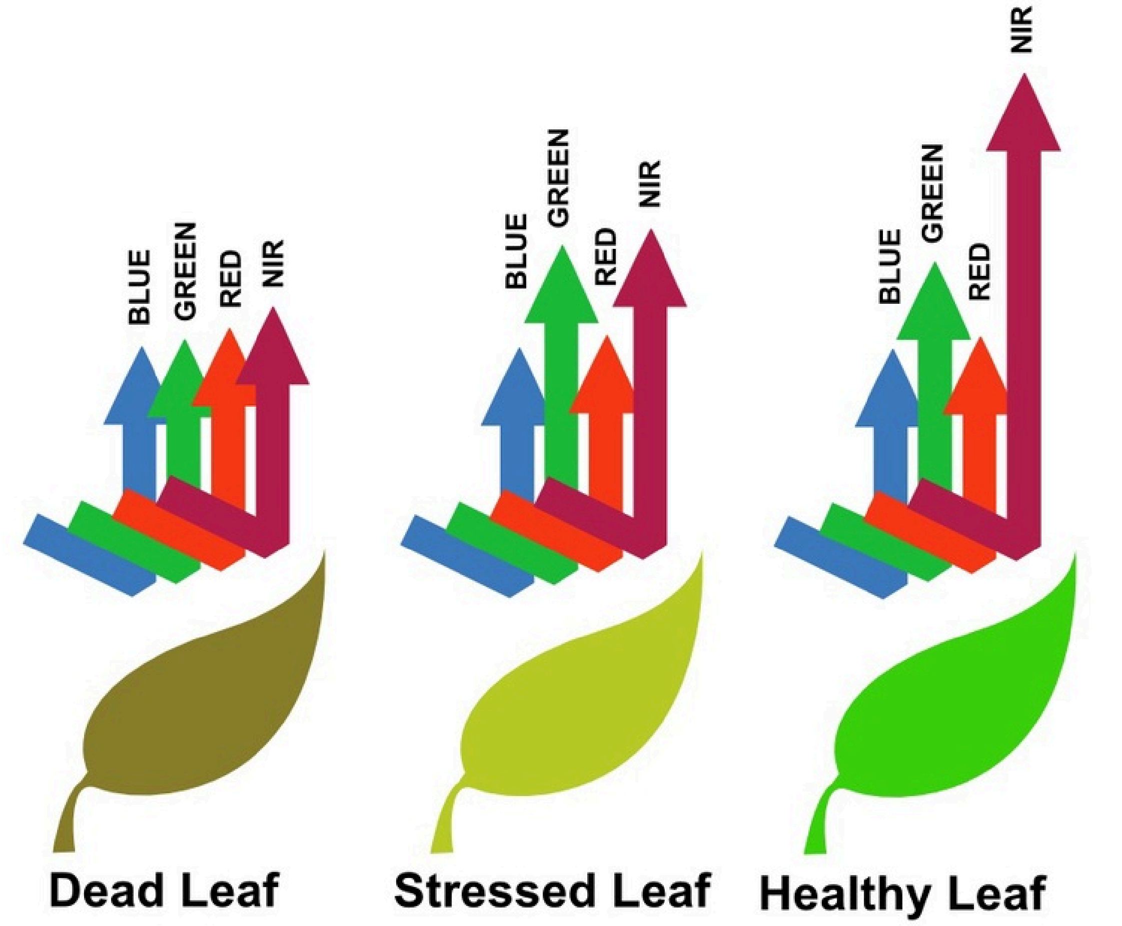

### Crown vitality scores for Sofia

In the final step, this trained model was applied to summer orthophotos of 2020 for Sofia. Resulting in one crown vitality score per tree.

- 5: perfect crown vitality: no discoloration in crown
- 4: good crown vitality: some discoloration in crown
- 3: poor crown vitality: almost half of the crown shows signs of discoloration
- 2: bad crown vitality: more than half of the crown has discoloration
- 1: (almost) death tree: few to no leaves

For Sofia, the 3D tree map based on the one available from Sofiaplan was used.

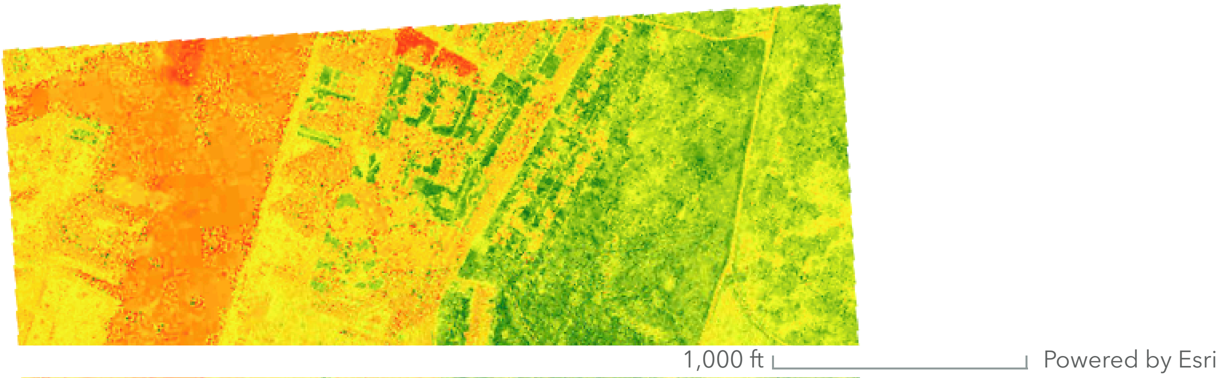
## Normalized Difference Vegetation Index (NDVI)




**Normalized Difference Vegetation Index (NDVI)**

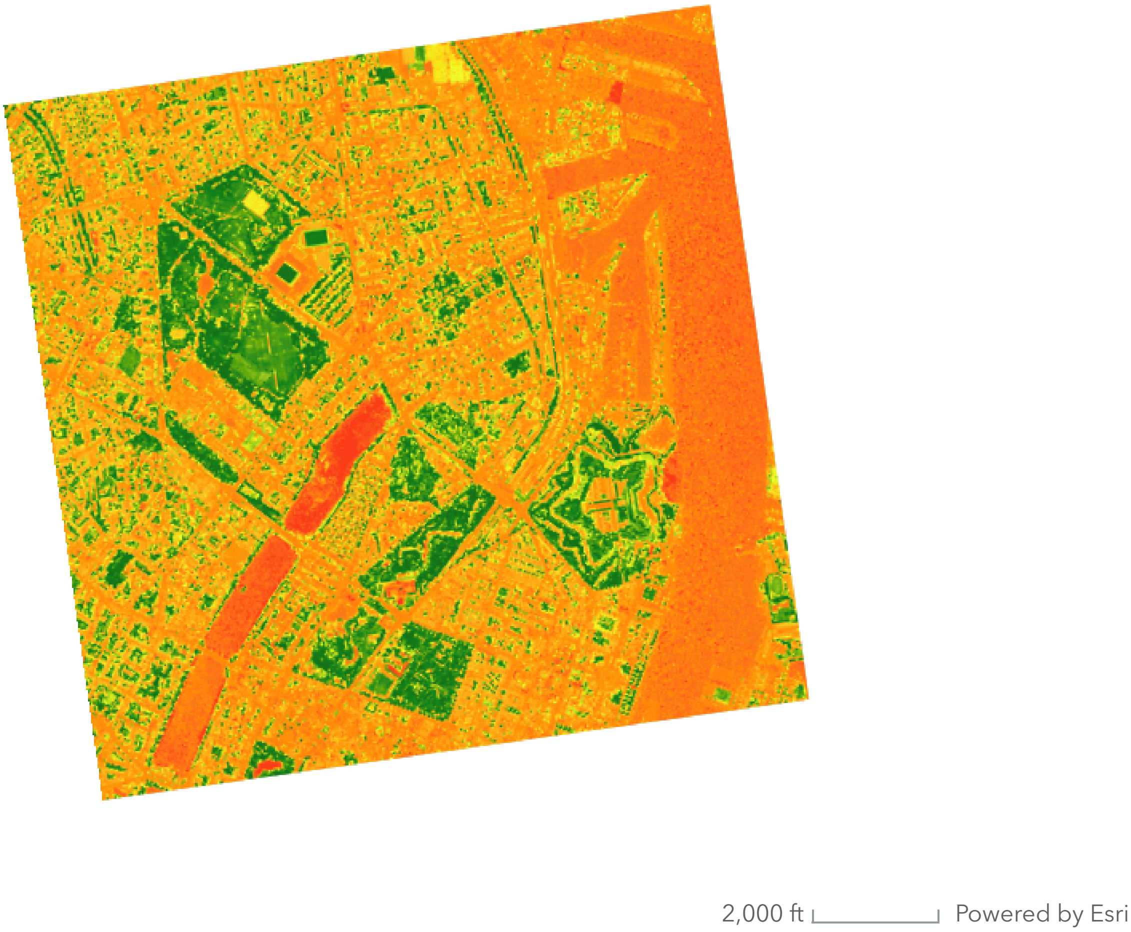
The NDVI represents the normalized ratio between the NIR and red band. High NDVI values result from the combination of a high reflectance in the NIR and a lower reflectance in red, which is characteristic of the Spectral Response Pattern of green vegetation (see image). The information derived from the NDVI index concerns mainly the presence of vegetation cover and its state.

**NDVI = (NIR + RED)/(NIR + RED)**




### Method 1: NDVI on high resolution aerial data

The NDVI was determined on the 2017 RGBIr summer orthophotos for Copenhagen. Using the crown diameter, the median NDVI was then calculated over the crown area.  Since Sofia had no NIR band available in the 2020 orthophotos, the NDVI could not be calculated




### Method 2: NDVI on high resolution satellite data

NDVI was also retrieved for both Copenhagen and Sofia using multispectral Airbus Pléiades Neo imagery in 30 cm resolution.

## Leaf Area Index (LAI)

The LAI represents the sum of the leaf area over a certain ground area. This parameter has a strong impact on the ecosystem services where the leaves play an important role in, such as air pollution reduction, cooling effect, floods risk and noise abatement.

In the 100k Trees project, obtaining Leaf Area Index (LAI) data for every tree in Copenhagen and Sofia is crucial as it serves as an input for the models in Workpackage 4. For Copenhagen, the 3D tree map based on aerial imagery was used. For Sofia, the 3D tree map based on the one available from Sofiaplan was used.

Due to the extensive nature of the data, an upscaling approach was employed using regression models.

**Leaf Area Index (LAI)**

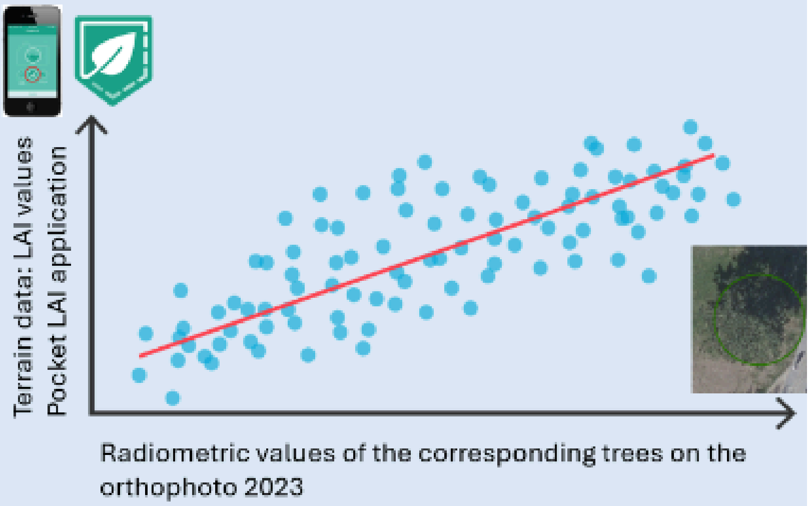
The Leaf Area Index (LAI) is an indicator for the quantity of leaf surface in a certain area. It is expressed by the formula (Watson, 1947):

**LAI = Leaf area ($m^2$)/ground area ($m^2$)**

- **Leaf area**: one-sided leaf area for leaves or half of the needle surface area above a certain ground area, in m²,
- **Ground area**: the ground area above which the leaf area has been measured, in m².


### Collecting field data in Brussels

Field measurements were conducted throughout Brussels during the summer of 2023 using the Pocket LAI field application (Confalonieri, 2014).



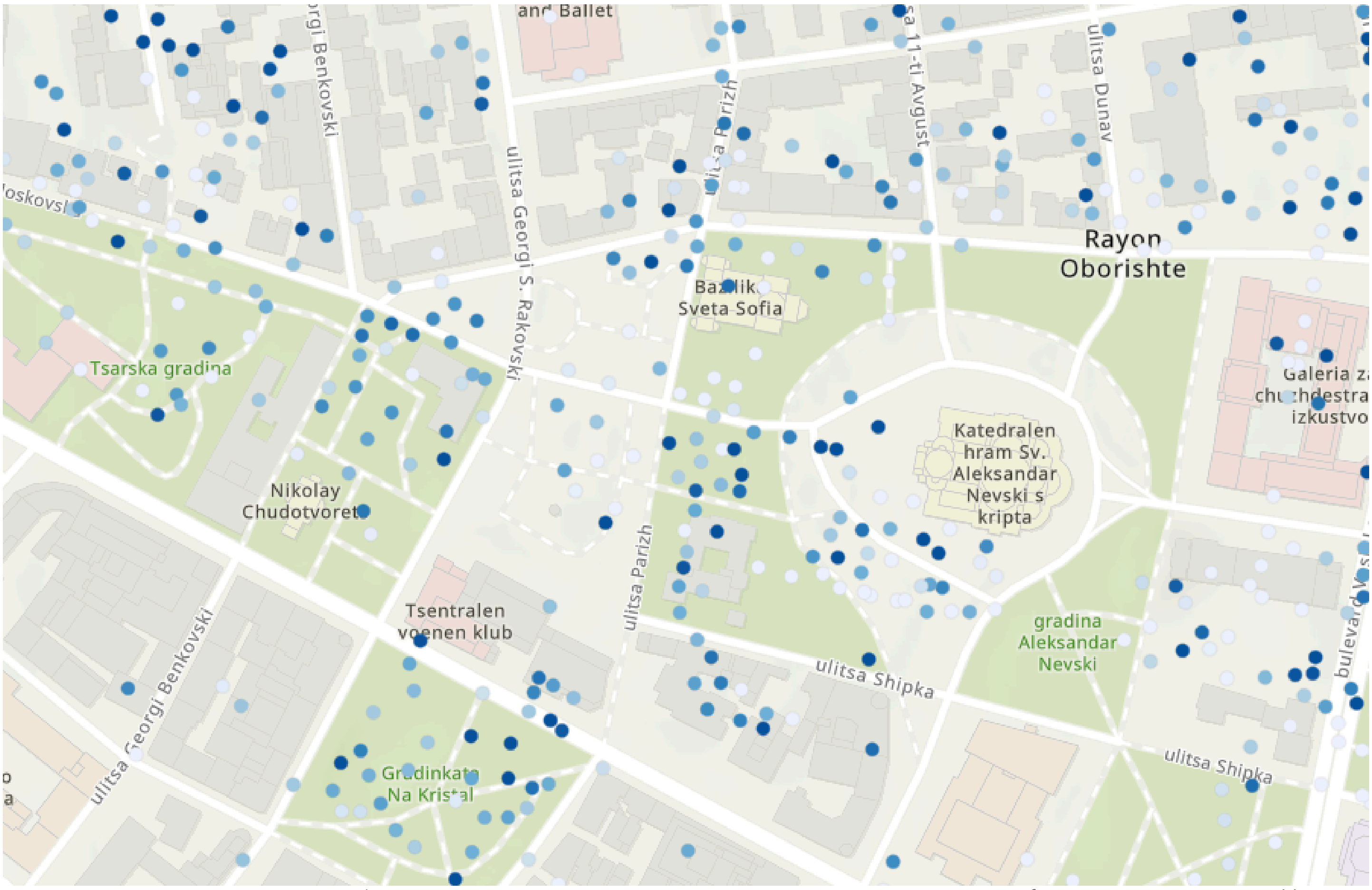

**Training a regression model**

A regression model was developed based on the terrain-based LAI data and corresponding remote sensing data (orthophoto 2023).

Esri, Geodatastyrelsen, Intermap, NASA, NGA, USGS | Esri Community Ma... 200 ft Powered by Esri

#### LAI map for Copenhagen

In the final step, this trained model was applied to the tree populations in Copenhagen, resulting in a map with one LAI measurement per tree.




Esri, Intermap, NASA, NGA, USGS | Esri, TomTom, Garmin, Foursquare, Ge... 200 ft Powered by Esri

#### LAI map for Sofia

In the final step, this trained model was applied to the tree populations in Sofia, resulting in a map with one LAI measurement per tree.

## Distance analysis

The availability of tree characteristics such as the tree position, tree height and the crown diameter makes it possible to determine the relative position of trees in regard to other urban elements such as buildings, streets, railways etc. This information is crucial for maintenance considerations, as trees can pose obstacles if they come too close to passages and 'street furniture.'

In the scope of the 100k trees project a GIS analysis was done in Copenhagen to identify the public or private street trees and to calculate the distance of the trees to the middle of the nearest road. This information was important for the city of Copenhagen to have an overview of the trees under their maintenance and to see if they could cause potential interference.

## Street trees


Esri, Geodatastyrelsen, Intermap, NASA, NGA, USGS | Esri Community Ma… 200 ft Powered by Esri

### Street trees

Firstly, trees were categorized as street trees based on their location.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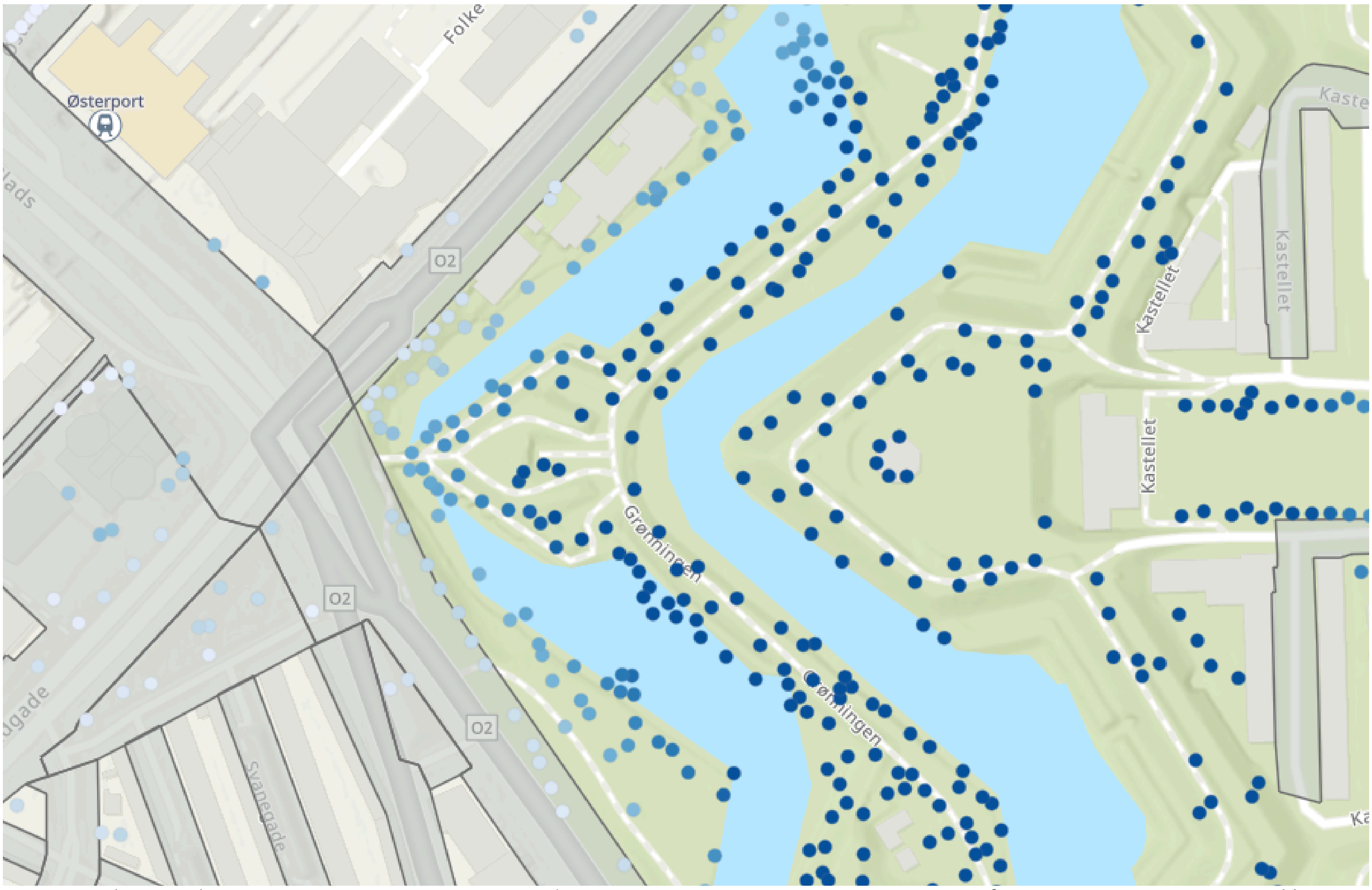
### Public - private street trees

Subsequently, an assessment was conducted to determine whether these streets are public or private. This data holds significance for municipalities in identifying which trees fall under their management jurisdiction.

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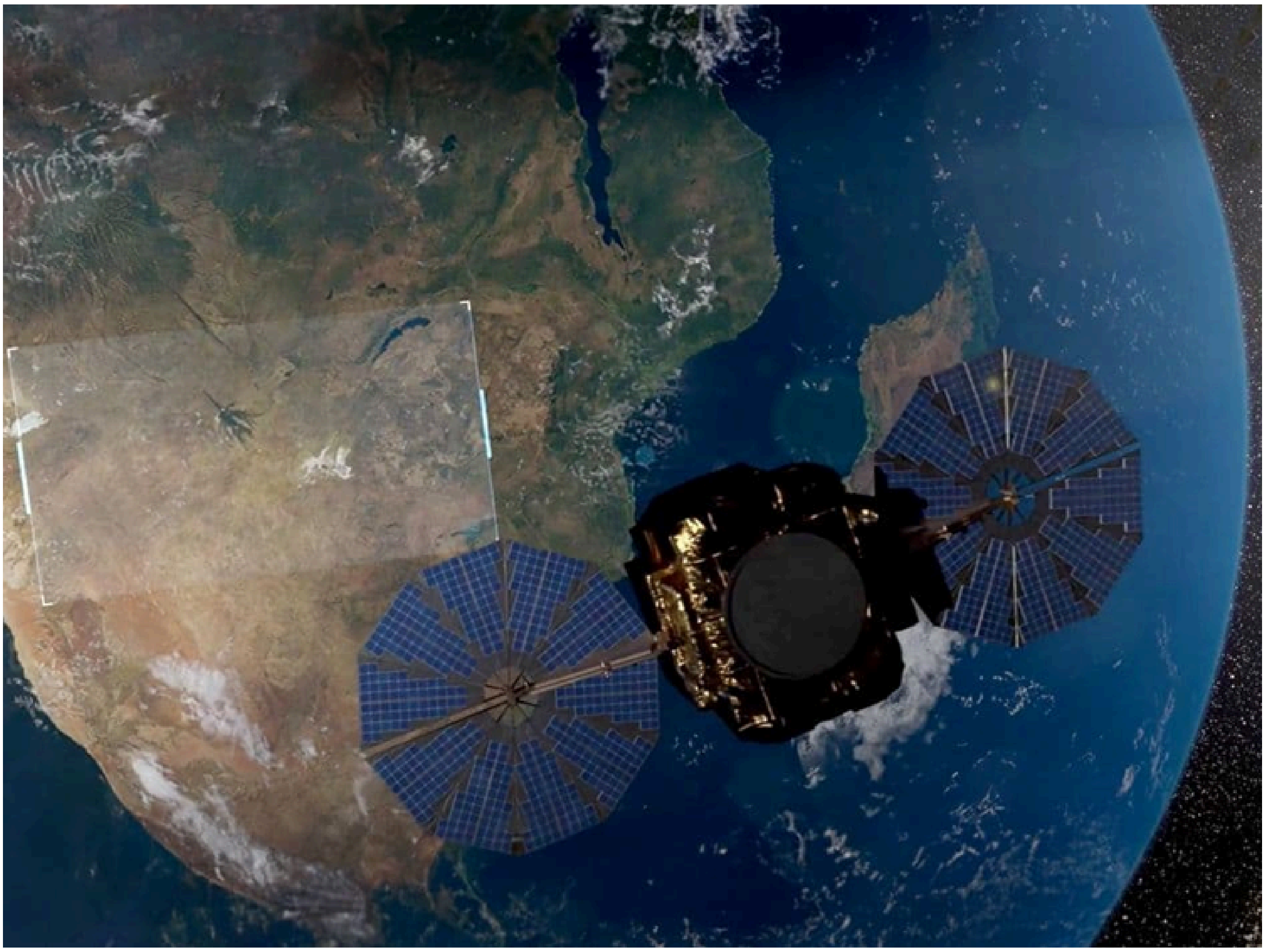
### Distance from the tree to the middle of the nearest road

Knowing the distance between trees and the center of the road can be useful for tree managers, as it helps ensure safety by reducing risks such as falling branches, preserving infrastructure by preventing damage to sidewalks and roads, optimizing growth conditions for healthy tree development, and regulating traffic by minimizing obstacles.

## Tree planting spots

Understanding available spaces for planting new trees is crucial for strategic urban planning, as it enables cities to maximize the benefits of green infrastructure while addressing specific environmental and social needs. By identifying vacant areas, cities can optimize resource allocation, minimize conflicts with existing infrastructure, and ensure the long-term survival of newly planted trees. In the 100k TREEs project land cover datasets were developed for Copenhagen and Sofia based on very high resolution imagery. This Land Use and Land Cover (LULC) data is invaluable as it provides a comprehensive overview of the urban landscape. It helps identify not only potential planting sites but also existing green spaces, impervious surfaces, and other land uses. This information allows urban planners to make informed decisions about where new trees can be planted to enhance ecological connectivity, improve air quality, and increase urban biodiversity. By integrating LULC data with tree health and position maps, cities can develop more effective and sustainable urban forestry strategies.

### Land Use Land Cover (LULC) Map



**LULC-map**

Employing Very High-Resolution (VHR) satellite imagery for land cover classification offers precise information into urban landscapes, including insights about potential tree planting locations.

Through the 100ktrees initiative, DHI utilized Airbus Pléiades Neo imagery (30 cm resolution) to map Copenhagen's central districts, providing an up-to-date comprehensive land cover data. This dataset provides a vantage point to identify potential tree planting areas, e.g. by emphasizing bare soil areas within potential tree planting sites.

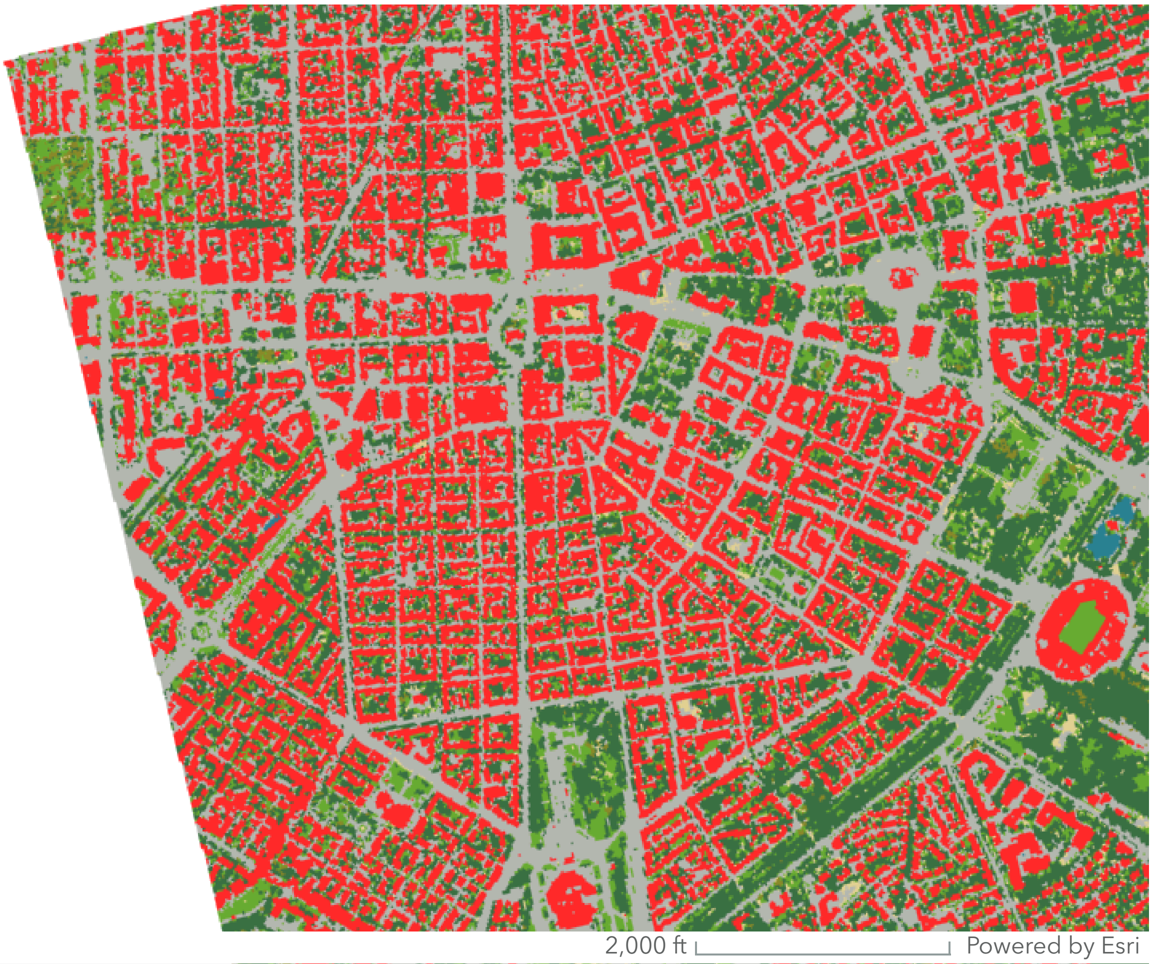
**Methodology**

The land cover classification applies a similar architecture as the VHR tree-counting model but with a classification head and a fixed filter size throughout the down- and up-sampling. The loss function utilizes a masked function, which drastically reduces the efforts required in labeling the data, as none-labeled pixels are not considered when calculating the loss.

The training loop is semi-supervised, starting off with either hand-drawn or 3rd party labels, which is fed to the model in a first pass. The output is validated, corrected, and fed for a second pass to the model. This loop repeats itself for either a single or all classes until the results are satisfactory.


### Result Copenhagen

With the VHR derived land cover classification, an up to date land cover classification from 2022 can be prepared in a cost-efficient and effective way. Here the results for a portion of the tree inventory of Copenhagen is visualized.



**Result Sofia**

With the VHR derived land cover classification, an up to date land cover classification from 2022 can be prepared in a cost-efficient and effective way. Here the results for a portion of the tree inventory of Sofia is visualized.

## Upscaling

In the 100KTREEs project, Copenhagen and Sofia were chosen as pilot cities to test various methodologies using diverse data sources, including aerial and satellite imagery. This approach was adopted with the objective of the 100kTREEs project to scale these methodologies to other cities in the future.

In many cases, cities themselves have aerial data, including LiDAR and orthophotos, readily available. These data sets are often of high resolution and are particularly well-suited for creating detailed tree maps. If these existing data sets are not available, it is possible to organize flights to acquire new aerial imagery. However, these flights can be very expensive and may not fit within the city's budget.

As an alternative free satellite imagery can be used such as those provided under the Copernicus Sentinel programme, e.g. Sentinel 2 optical data. However, free and open data has inherent limitations, particularly in terms of spatial resolution (10 m) which may present an obstacle in urban environments, where greater granularity is needed for more  detailed analysis and modelling, especially in densely populated urban environments. Higher resolution commercial satellite data with resolutions up to 30 cm is becoming increasingly more accessible and affordable, offering a viable cost-efficient alternative to aerial imagery, while addressing the spatial resolution limitations of free and open satellite data. 30 cm data provides the detail level needed to  identify small-scale urban features which are useful for nuanced decision-making.

## This Storymap was created by

| | |
|---|---|
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| **DHI** | Denmark |