

AUTOMATING THE SELECTION FOR SUITABLE TREE SPECIES IN AN URBAN ENVIRONMENT

Selecting the right tree species for a location

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Automating the selection for suitable tree species in an urban environment

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Preface

This product is created as a bachelor thesis for the study forest and nature conservation at Van Hall Larenstein, Velp. The product was requested by Peter van Ossenbruggen of Sweco, and will be an extension of the online hosting environment provided by Sweco. The purpose of the product is to support municipalities with the design of public space regarding the planting of new trees. I want to thank Jurgen van Tiggelen, who guided the project and helped me getting started at Sweco and Peter van Ossenbruggen, who managed the project and provided me with the opportunity. I also want to thank Erika van Duijl, who supervised the project on behalf of the university and provided the necessary feedback.

Summary

It is difficult to select an appropriate tree for an urban environment because in an urban environment, trees which are planted in unsuitable locations, can be inconvenient for humans and can cause severe health problems or property damage. Trees are planted in unsuitable locations because of difficulties that human decision-makers have in handling large amounts of geographic data and tree species characteristics in a consistent way. Sweco wishes to automate the process of analyzing the outside environment and selecting suitable tree species. In this research a new technique is developed. The technique automatically analyzes the spatial environment surrounding the specific location and returns a list of suitable tree species for that location. The total amount of trees to choose from in a city is reduced with at least 91,2% in 64,4% of the cases, thereby successfully assisting the decisionmakers in their work. FME (a data manipulation program) is used to automate the process. The technique is online accessible for the decision-maker on an interactive map in Sweco's hosting environment, with the only required input being the location for which the new tree is selected. To encourage citizens to participate in the selection of new tree species, the decision-maker can download the list of suitable tree species and send it to the citizens. The overview includes all suitable trees with their characteristics and photo's, sorted on their efficiency of filtering particulate matter from the air. A list with analyzed spatial characteristics is present for decision-makers to verify the result.

Table of Contents

Preface.....	12
Summary	13
List of figures	16
List of tables	16
Glossary	17
List of abbreviations	17
1. Introduction.....	9
1.1. Problem analysis.....	9
1.2. Sweco	10
1.3. Objective	10
1.4. Contribution to sustainability.....	11
1.5. Reading guide	11
2. Methodology	12
2.1. What are the current practices	12
2.2. Which criteria determine the suitability of a tree for a specific location	12
2.3. What is the necessary input	12
2.4. How to encourage citizen participation	13
2.5. How to automate a process	13
3. Results	15
3.1. Current practices	15
3.1.1. Legislation.....	15
3.1.2. Current design process.....	16
3.2. Criteria determining tree suitability	17
3.2.1. Distance to buildings	17
3.2.2. Distance to pavement	18
3.2.3. Distance to other trees.....	18
3.2.4. Distance to Sewers and cables	19
3.2.5. Distance to Street lights	19
3.2.6. Planting strip, pavement or park.....	19
3.2.7. Parking space and playgrounds.....	19
3.2.8. Residential area	20
3.2.9. Soil type	20
3.2.10. Soil moisture.....	21
3.2.11. Soil fertility	22
3.2.12. Water.....	22

3.2.13. Species composition.....	22
3.2.14. Salt sensitivity.....	23
3.2.15. Urban heat island and air pollution.....	23
3.3. What is the necessary data input?	24
3.3.1 Tree species characteristics.....	24
3.3.2. Spatial data.....	26
3.4. How to encourage citizen participation?	27
3.5. How to automate a process?	28
3.5.1. System requirements	28
3.5.2. General operation	28
3.5.3. FME.....	28
3.5.4. Obsurv	29
3.5.5. Multi objective decision-making technique (MDMT).....	29
3.5.5.1. What is a MDMT?.....	30
3.5.5.2. Detailed MDMT description	32
3.5.6. System validation	36
4. Conclusion	38
5. Discussion.....	39
6. Recommendations	40
Bibliography.....	41
Appendices	47
Appendix I. Overview step 1.....	48
Appendix II. Overview step 2.....	49
Appendix III. Overview step 3.....	62
Appendix IV. Database overview.....	67
Appendix V. Obsurv website information	70

List of figures

Figure 1. Model development process.....	14
Figure 2. Water table.....	21
Figure 3. Crown forms grouped into classes according to Van den Berk.....	24
Figure 4. Typical multi objective decision-making process.....	30
Figure 5. Hierarchical structure of objectives with corresponding attributes	31
Figure 6. Schematic MDMT overview	33
Figure 7. HTML output example.....	34
Figure 8. System validation visualization of Oostburg	37

List of tables

Table 1. Guidelines used by municipalities and provinces.....	16
Table 2. Obstacle-free underground according to “Handboek bomen 2018”.....	19
Table 3. Tree species database information	25
Table 4. Input data and source.....	26
Table 5. Suitable locations (n=2377) per tree species (n=1132).....	36
Table 6. Number of suitable tree species(n=1132) per location (n=2377)	36

Glossary

Municipalities	the second-level administrative division in the Netherlands are subdivisions of their respective provinces.
Particulate matter	the term for both solid particles and liquid droplets found in the air with a diameter that is generally less than 10 micrometers.
Urban forester	person responsible for the design of the public space regarding trees.
Multi objective decision-making technique	a sub-discipline of techniques that explicitly evaluates conflicting criteria in decision making.
Urban heat island	the effect of cities being 0.5 to 10 degrees warmer than the countryside.
Hosting environment	online environment hosted by a third party to display and maintain data.
Oracle Database	a database management system.
Crown diameter	the total distance from one side of the tree crown to the other.
Allergic rhinitis	a type of inflammation in the nose which occurs when the immune system overreacts to allergens in the air.
Water table	the water table is the upper surface of the zone of saturation. The zone of saturation is where the pores and fractures of the ground are saturated with water.
Spatial buffer	a spatial buffer creates an area around an object with a specified uniform distance.
Intersect as GIS tool	the overlap between two features.

List of abbreviations

BGT	basic registration large-scale topography
BOFEK2012	soil Physical Units Map
FME	feature manipulation engine
HTML	hypertext markup Language
KNMI	royal Dutch Meteorological Institute
MDMT	multi objective decision-making technique
PDOK	public services on the map, spatial data provided by the Dutch government
RIOGL	spatial sewer data to support sewer management
UCSUSA	union of Concerned Scientists USA
WHO	world health Organization

1. Introduction

Green cities are becoming increasingly important to keep life in the city pleasant because of climate change. Thanks to the effect trees and plants have, a city is less warm. They evaporate water and stop solar radiation from reaching the ground, which lowers the temperature a couple of degrees (Hiemstra, 2018). They also filter air pollutants from the air, which could lead to health improvement for citizens (Hoffman, Planten en luchtkwaliteit, 2009).

1.1. Problem analysis

Although trees have many benefits, they can cause a lot of problems in an urban environment. This is primarily because a tree can be unsuitable for its location, consequently creating unnecessary costs and work to municipalities.

For example, Houten, a municipality in the Netherlands with less than 50.000 citizens, spends an estimated amount of 70.000- to 130.000 euros a year on underground repair work, fixing cable- and pipe damage caused by tree roots (Municipality of Houten, 2017). Recent studies by the Royal Dutch Meteorological Institute (KNMI) and by the Union of Concerned Scientists USA (UCSUSA) show increasing temperatures intensify storms. (Union of Concerned Scientists USA, 2017 & KNMI, 2018). Increased occurrence of storms possibly raises sewer damage because a tree moves more in a storm and this energy is transferred through the tree to its roots. If the sewer pipes are in contact with the roots because the tree is not planted correctly, they suffer damage due to the roots shaking them loose in the ground, causing them to break (Ebben, 2018).

Other examples of problems caused by trees are;

- Trees triggering allergic reactions are planted in residential areas.
- Trees bearing heavy fruits are planted above parking spaces, roads or sidewalks, damaging parked cars underneath and creating dangerous situations because of slippery fallen fruit.
- Trees sensitive for salt are planted next to roads which are applied with salt in the winter, causing harm to the tree.
- Trees known to heave asphalt with their roots, are planted close to pavements, creating dangerous or costly situations when the pavement is heaved.
- Trees planted too close to buildings, street lights, sewer systems or other trees, creating damage to the tree itself or its surroundings.
- Too many trees within the same area from the same species, making them susceptible for pests and diseases. Therefore, trees could be less healthy and well rooted resulting in falling branches which damages the tree and may damage the surroundings or people underneath.

Selecting suitable trees

Because of the problems trees can cause, it is important to make informed decisions, based on spatial information and tree species characteristics, when planting a tree. Tree species characteristics and spatial information regarding the public environment are abundant on the internet. However, the problem is that humans have difficulty in handling large amounts of complex information in a consistent way (Department for Communities and Local Government: London, 2009). Decision-makers have to analyze the environment in the proximity of the tree to make informed decisions regarding suitable tree species. This information is stored in soil maps created for the Dutch government and PDOK owned by the Dutch government. PDOK is a centralized, open, online environment where municipalities store their spatial data. To analyze all information, the decision-maker has to gather different maps and calculate distances to all objects surrounding the tree.

When all objects in the tree's proximity are analyzed, a choice can be made from more than 1200 trees species and cultivars. So, to know if a tree is suitable, the decision-maker has to compare all tree characteristics against the objects found in the analyzed environment which is, because of the many parameters, extremely complicated.

Another problem is stated in a research article, published in "Boomzorg 2014 – number 5", presenting a survey for people involved with urban foresting. More than half of the participants stated that they barely receive information from growers (Raats, 2014), while all necessary information regarding tree species is presented on the growers' websites.

1.2. Sweco

Because it is a long and complicated process for decision-makers in municipalities to retrieve all the right information, Sweco, the commissioning party, wants to automate the process to aid decision makers in their work.

Sweco's goal is to help customers keeping the environment livable and workable. Experts develop software allowing governments and businesses to have constant access to correct, up to date information about the environment. Information about the layout of the country and information to manage the public spaces, as well as information to address social issues or to work more efficiently on building projects. One of their products is the management system for the living and work environment; Obsurv. Obsurv is the first integrated management system to help municipalities with their planning and budgeting in one process with a user friendly, interactive interface. Besides managing, planning and budgeting, Sweco wants to include the design of the public space within their system.

1.3. Objective

It is now clear which problems trees can cause in an urban environment and which problems decision-makers run into trying to decide suitable trees for a location. The objective of this report, commissioned by Sweco, is to develop a tool which will assist decision-makers in making the right choices regarding the plant of new tree in an urban environment.

To be a successful tool for the decision-makers, it should include the following aspects. The tool has to prevent trees from being planted in places where they cause nuisance to their surroundings so unnecessary costs and problems to municipalities will be prevented. The tool has to contain the possibility to involve citizens in the process of planting new trees in public streets and it has to be integrable with Sweco's current management system, Obsurv.

To achieve the objective, this report addresses the following research question;

How can the choice for a new tree be automated and citizen participation encouraged within Obsurv?

To answer the research question, the following sub questions will be addressed;

1. *What are the current practices of selecting tree species for a location?*
2. *Which criteria determine the suitability of a tree for a specific location?*
3. *What is the necessary data input?*
4. *How to encourage citizen participation?*
5. *How to automate a process?*

These questions have been formulated to monitor the entire process. After the factors which influence trees and the problems caused by trees are identified, criteria solving or minimizing these problems can be determined. When the criteria are established, necessary input can be defined to meet these criteria. Corresponding spatial data from the factors influencing trees are necessary, but also tree species characteristics, to select favorable species regarding the influencing factors. When all input data is defined, the process can be automated, so the best options for a new tree will be given. Ways to improve citizen participation will be explored and the requirements and general operations of the system will be defined.

1.4. Contribution to sustainability

A technique that helps municipalities planting the right tree species in a specific location contributes to sustainability in both the economic, ecological and social sense of the word. Economical because the tool must minimize damage to the public space caused by trees, preventing costs for municipalities. Ecological, because there will be a threshold of the number of same species within the species composition in one area of jurisdiction. Furthermore, the suitable species will be sorted on their effect on the environment. Social, because the technique is automated and usable for everyone, citizens could make decisions on which tree they favor out of the possibilities provided by the tool, which could lead to a higher citizen participation. This is important because the relationship between citizens and the government is changing, with citizens taking more initiative and the government taking a more facilitating position (Overzicht trends en ontwikkelingen, 2015). To be ready for future changes, the technique will be unlimitedly expandable and adaptable.

1.5. Reading guide

The report is divided in multiple chapters. Chapter two describes the methodology used to answer the research question described in the objective. Chapter three handles the results from the methodology mentioned in chapter two and answers the sub-questions. In chapter three, literature covers all factors influencing a trees growth and how to solve corresponding problems. Furthermore, all steps taken to automate the process are covered. The conclusion in chapter four answers the research question based on the sub questions, which are answered in chapter three. Chapter five discusses the conclusion and the work approach. In chapter six, recommendations are given to further improve the created technique.

2. Methodology

To answer the research questions, multiple sources and methods were used. In this chapter, the methodology of answering the sub questions will be discussed.

2.1. What are the current practices

To determine the current practice of selecting suitable tree species for an urban location, interviews with decision-makers Brian van Straalen (Sweco) and urban forester Jeroen Glissenaar (municipality of Arnhem) were held. Furthermore, a literature study was conducted on the relevant legislations and the work approach for different municipalities is reviewed and compared, to identify the most common current practices.

2.2. Which criteria determine the suitability of a tree for a specific location

A literature study was conducted to identify all factors influencing or influenced by the growth of a tree, in an urban environment. Trees are affected by their environment and vice versa, so it was important to have a clear overview from the factors influencing a tree or its surroundings. When the factors were identified, corresponding criteria were identified, minimizing or solving the problems. When possible, criteria determining a tree's suitability were retrieved from *Handboek bomen 2018*. If not possible, other sources were consulted.

Handboek bomen, which means handbook of trees in English, has been substantively validated by specialists from the green sector. In addition to the participation of clients, contractors and educational institutions, external specialists are intensively involved in the validation. Norminstituut Bomen, creator of *Handboek bomen*, attaches great value to this extensive validation: the established quality requirements, guidelines and standards are technically standardized and there is a broad support base (Norminstituut bomen, 2018). Furthermore, in the ground/road/hydraulic engineering sector, it is general practice to refer to *Handboek bomen* (Goudzwaard, 2017).

Meetings with decision-makers Brian van Straalen (Sweco) and urban forester Jeroen Glissenaar (municipality of Arnhem) were conducted to discuss what they take into consideration when selecting a new tree and to see how the decision-making is done in practice, which could differ from theory. Furthermore, an interview with Guide Ebben (Vitens) was held to discuss the effects a tree has on sewer pipes. Vitens is the largest drinking water company in the Netherlands, delivering drinking water to 5,6 million people (Vitens, 2018).

When all factors influencing the growth of a tree were identified, they were transformed into filters, filtering the list of tree species for suitable tree species for a specific location. Tree species passing all filters were suitable for the location and were not expected to cause any kind of problems.

2.3. What is the necessary input

When criteria, minimizing the factors influencing the growth of a tree in an urban environment were established, corresponding spatial data was searched for. Spatial data regarding the public space was imported from the BGT, which is Dutch for “basic registration large-scale topography”. The BGT contains the design of the physical environment like roads, buildings, waterways, railways, and surface water (Ministerie van binnenlandse zaken, 2018). Additional spatial data regarding soil information was derived from soil maps created for the Dutch government. Information about underground infrastructures, like sewers and cables, were imported from Obsurv. When spatial data was not available, the corresponding factor could not be included in the technique.

Tree species characteristics were imported from tree grower Ebben. Ebben is one of the biggest tree nurseries in Europe, producing over 450.000 trees a year (Boomkwekerij Ebben B.V, 2018). They collect tree species information from their own experience and from other experts in the field and makes it publicly available as open source data.

To assure the quality of the tree species characteristics and spatial data regarding the public environment were accurate, only literature from scientific- and government sources were consulted.

2.4. How to encourage citizen participation

To identify efficient ways to involve citizens in the process of making decisions related to their living environment, a literature study was conducted. The results have been taken into consideration when framing the system requirements.

2.5. How to automate a process

System requirements and general operation

To determine the system requirements, the following information was necessary;

- Problems trees can cause and how to limit those problems
- Necessary input data
- Efficient ways to encourage citizen participation
- Stakeholders
- Stakeholders objectives

When the system requirements were clear, the general product operation could be established.

Feature manipulation engine (FME)

To learn how to automate a process and how to translate the earlier determined criteria into filters, to select suitable tree species, basic and advanced courses of Feature manipulation engine (FME) were followed. FME is used to automate the process and to enable the integration of the tool with Obsurv.

Multi objective decision-making technique

A literature study was conducted to search for a detailed process description stating how to solve a problem covering multiple objectives. This process was applied to the problems covered in this research and used as guideline in the development of the tool.

Creating

The FME model aims to deliver a list with suitable tree species for a given location, from a list with all tree species grown in the Netherlands. Tree species suitability is based on objectives derived from objects surrounding the new tree location. Favorable tree species characteristics have been determined for all objects. These form the criteria to pass a filter when an object is found near the tree. The process to achieve the desired output is visualized in figure 1.

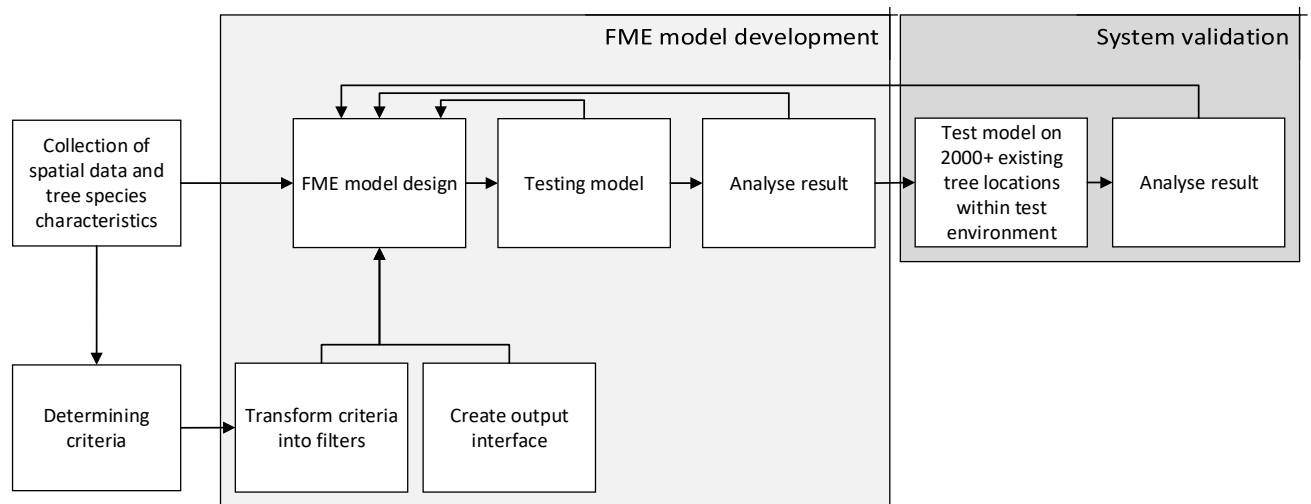


Figure 1. Model development process

The development of the model started with importing spatial data and tree species characteristics into the workspace. The input data was used to filter suitable tree species, from a list containing all tree species, based on the established criteria. To do this, criteria, derived from literature, were transformed into filters using FME. A user-friendly interface was created to present the output to the end users.

System validation

When creating the filters, continuous testing was necessary to ensure only tree species with suitable characteristics were able to pass the filter. When the model was built, the system validation could begin to ensure the end result was a valid representation of the real world and only suitable species would be present. This was done by running the model on 2377 tree locations in Oostburg, the Netherlands, in a test environment. The number of suitable locations per species and the number of suitable species per location were calculated.

3. Results

In this chapter, the sub questions will be answered. When all sub questions are answered, the research question will be discussed. First, the current practice of selecting suitable tree species for an urban location is analyzed. The second question will cover the criteria determining suitable tree species for a location. When all criteria are clear, corresponding tree species characteristics and spatial information will be searched for. After the necessary input is specified, possibilities for citizen participation will be explored. Finally, the system automation will be discussed, covering the system requirements and general operation.

3.1. Current practices

An annually recurring activity for municipalities is the planting of trees. Considerations have to be made which are summarized by municipalities by the phrase 'the right tree in the right place'. Frameworks and guidelines are indicated in various national government policy documents. The Nature Conservation Act is the Dutch law that regulates the protection of nature reserves, species and forest. The law is effective since the first of January 2017. This law includes three older laws: the 1998 nature conservation act, the forest act and the flora and fauna act. These policy documents have an effect on municipal plans. This chapter discusses the relevant laws and the current practice of municipalities when designing a new tree location.

3.1.1. Legislation

Both the forest act and flora and fauna act affect the way municipalities can work with and around trees. The nature conservation act only affects Natura 2000 areas and is therefore not covered in this chapter.

Flora and fauna act

The flora and fauna act protect the survival of endangered plant and animal species. Therefore, actions that threaten the existence of these species are forbidden. If work must be carried out in or around these tree species, an exemption is required. A plan of approach can be drafted, based up on the basis of a flora and fauna check prior to the work.

A part of the flora and fauna law is the "duty of care - trees". The tree owner has received a general duty of care. The law says that the tree owner is in principle not liable for any damage, if the duty of care is met. To comply with the duty of care, all risk trees (danger trees) must be visually inspected once a year. The remaining trees must be visually inspected for defects once every three years.

Forest act

The aim of the Forest Act is to preserve the acreage of forests in the Netherlands. In short, the forest act says: what forest is, must remain. A forest that is cut must be replanted. If that is not possible in the same place, then elsewhere (compensation). The Forest Act does not have a licensing system, but a notification obligation. The responsibility lies with the Ministry of Economic Affairs. The province carries out the actual assessment of the requests and supervises the replanting. Protected under the Forest Act are all plantings of trees larger than 0.1 hectare or row plantings that consist of more than 20 trees. The following tree species are not covered by the forest law; lime, horse chestnut, Italian poplar and weeping willow. Single-row plantings of poplar and willow along agricultural grounds are also not covered by the Forest Act, just like orchards and nurseries from Christmas trees or forest plants.

3.1.2. Current design process

When designing the public space, municipalities take into account the spatial choices and different areas in the city, which are usually also recorded on a green structure map. When choosing a tree for a specific location, the consideration determines what is important or gets priority. If, for example, the cultural-historical value is leading, this may result in a different choice for a tree species than in the pursuit of more ecological value. Most municipalities or decision-makers use their own guidelines when selecting new tree species to be planted, but “Handboek bomen” is frequently used or referred to by municipalities (Straalen van, 2018). Furthermore, in the ground/road/hydraulic engineering sector, it is also general practice to refer to Handboek bomen (Goudzwaard, 2017).

Table 1 shows an overview of 24 municipalities and the guidelines they use when designing a new tree location.

Table 1. Guidelines used by municipalities and provinces

Municipality/province	Guidelines	Source
Amersfoort	Both	(Municipality of Amersfoort, 2017)
Amsterdam	Own guidelines	(Municipality of Amsterdam, 2009)
Bussum	Own guidelines	(Municipality of Bussum, 2014)
De ronde venen	Own guidelines	(Municipality of Ronde Venen, 2017)
Deventer	Handboek bomen	(Norminstituut bomen, 2014)
Emmen	Handboek bomen	(Norminstituut bomen, 2018)
Gelderland	Handboek bomen	(Norminstituut bomen, 2018)
Haaren	Handboek bomen	(Norminstituut bomen, 2018)
Haarlem	Own guidelines	(Esterik van, et al., 2015)
Hollands kroon	Handboek bomen	(Municipality of Hollands Kroon, 2018)
Leiden	Own guidelines	(Municipality of Leiden, 2017)
Leidschendam-voorborg	Own guidelines	(Municipality of Leidschendam-Voorburg, 2016)
Lisse	Both	(Bomenwacht Nederland B.V., 2015)
Meerijstad	Handboek bomen	(Norminstituut bomen, 2018)
Meppel	Handboek bomen	(Norminstituut bomen, 2018)
Neder-betuwe	Own guidelines	(Municipality of Neder-Betuwe, 2017)
Oestgeest	Handboek bomen	(Management and maintenance team, 2018)
Oldebroek	Handboek bomen	(Norminstituut bomen, 2018)
Papendrecht	Both	(Municipality of Papendrecht, 2017)
South West-Friesland	Own guidelines	(Municipality of South-West Friesland, 2012)
Uden	Own guidelines	(Dijk van, 2017)
Utrecht	Handboek bomen	(Municipality of Utrecht, 2017)
Wijdmeren	Own guidelines	(Municipality of Wijdmeren, 2012)
Woudrichem	Own guidelines	(Municipality of Woudrichem, 2015)

58.3% of the investigated municipalities make use of Handboek bomen, other municipalities use their own guidelines. Therefore, Handboek bomen will be referred to when identifying criteria determining a trees suitability.

The level of design varies per municipality, some have strict and extensive rules where other municipalities only have a few guidelines. On the basis of the sources mentioned in table 1, it can be concluded that the following guidelines are the most important, according to municipalities;

- Available space (distance to above ground and to underground infrastructures)
- Tolerance to stand in pavement or concrete
- Tolerance to soil moisture
- Preferable soil type
- Suitable soil fertility
- Ecological, social, cultural or historical value

In the majority of the documents it is mentioned that if a location is unsuitable for a tree, the location must be adjusted if possible. This means adjusting soil type, structure, moisture and fertility as well as creating space for the tree to grow. For this reason, soil type and fertility are excluded first, when no suitable trees are found. Soil moisture is not excluded because increasing soil moisture may be possible, yet reducing soil moisture is difficult and not desirable. Furthermore, trees planted in too wet or too dry soils, can cause dangerous situations since a tree cannot secure itself if the groundwater level is too high. Ecological, social, cultural or historical value of certain trees is not included in the technique because this can vary per municipality.

3.2. Criteria determining tree suitability

Interviews and literature indicated fourteen different factors that influenced the growth of a tree in an urban environment. Most important were the distances to infrastructure, sewers and pipes, street lights, buildings, playgrounds and parking spaces. Other factors were soil type and fertility, species composition and planting location. In addition, the effect a tree has on its environment should also be taken into account since climate change and air pollution is a current issue.

Tree species are grouped together, based on specific characteristics in the database, forming the attributes. Species groups are used to achieve objectives with multiple attributes, like parking spaces and playgrounds. These groups are filtered against specific conditions, derived by the spatial data. For example, for parking spaces, all tree species heaving one of the following characteristics are unsuitable;

- Species bearing big, heavy or poisonous fruits
- Species sensitive for wind
- Aphid sensitive lime trees
- Species with thorny branches
- Species attractive for birds

In the example for parking spaces, if a tree species does not have one of the characteristics mentioned above, it is suitable to grow near a parking space. If it does have one or more of the characteristics, the species is not suitable to grow near parking spaces. This was done for all objectives with multiple attributes, for more information about objectives and their attributes, see figure 5.

3.2.1. Distance to buildings

An important aspect when planting a new tree is the distance to the nearest building. Trees can damage buildings with their branches when they become too big for their location, hence the importance of knowing the maximum crown width and the space available for tree growth. When these factors are known, it is possible to calculate the minimum distance of the trunk with respect to the surrounding buildings by the following calculation (Norminstituut bomen, 2018);

$$\text{Maximum crown diameter} * \text{factor } 0,6 = \text{suitable planting distance}$$

For example, “*Acer campestre*” has an expected crown diameter of 8m, $8 * 0,6 = 4,8m$. The minimum distance an *Acer campestre* should be planted away from the nearest building is 4,8m.

3.2.2. Distance to pavement

Pavement includes roads, sidewalks and concrete. Distance to pavement is important because trees growing near pavement can cause disturbances when fruits or branches are falling out of the tree or roots heave the surrounding pavement. Therefore, the distance to pavement is measured, which is the distance a tree can grow without causing disturbances related to the pavement. The calculation used for buildings is also used for pavement.

$$\text{Maximum crown diameter} * \text{factor } 0,6 = \text{suitable planting distance}$$

However, species suitable for parking spaces are also suitable to grow near roads, because they are not expected to cause any harm. Therefore, parking space species, that are also unknown for heaving up paving with their roots, are acceptable to plant above roads. For information about suitable tree species near parking spaces, see chapter 3.2.7.

In theory, every tree species is able to heave paving with their roots, when the available rooting space is insufficient. A tree will not grow in its natural way if this is not possible, causing deep rooting species to root superficial (Iperen van, 2012). But according to literature from multiple government sources, tree species with superficial rooting system or root suckers are responsible for most pavement damage caused by roots (Stolk & Hoffman, 2000 & Gemeente Terneuzen, 2011). For this reason, tree species with superficial rooting system or root suckers are classified as paving lifting species.

For sidewalks the criteria are a bit different. Only tree species having one of the following characteristics are unsuitable to grow above sidewalks;

- Wind sensitive species
- species bearing heavy, big or poisonous fruits
- Aphid sensitive Lime trees (*Tilia spec.*)
- host plant for birds
- Species having thorny twigs
- species that are known to heave pavement

All tree species with crowns not reaching the pavement, are suitable as well.

3.2.3. Distance to other trees

The distance to the nearest tree can also be important to avoid complications between tree crowns. First, the closest tree is analyzed and the maximum crown diameter is derived from the tree species database. Second, the available left-over space is calculated by subtracting the crown radius from the distance between the tree bases. The same calculation used for buildings or pavement is used to calculate suitable species for the available left-over space;

$$0,6 * \text{Maximum crown diameter} = \text{minimum amount of necessary space}$$

This filter entirely depends on spatial tree data delivered by municipalities and assumes every tree reaches its maximum diameter. This is usually not the case in urban environments, where trees are often limited in their space. Therefore, this filter is sensitive for errors and limits the technique too much. Hence, this variable will not be included in this technique but will be recommended for further work.

3.2.4. Distance to Sewers and cables

The distance from the base of a tree, to underground works like sewers and cables, is an important aspect when planting a tree. Tree roots can infiltrate underground infrastructures in search of water and nutrients and thereby cause significant damage. According to a recent geostatistical study conducted in Bogotá, Colombia, large trees are prone to cause more pipe damage. Therefore, tree-pipe distance is a relevant parameter control for reducing potential deterioration (Torres, Rodríguez, & Leitão, 2017). This is also the reason why “Handboek bomen 2018” increases the minimal obstacle-free underground with bigger trees.

Table 2. Obstacle-free underground according to “Handboek bomen 2018”.

In Handboek bomen, a certain minimum obstacle-free underground space is used, based on tree height. Table 2 presents a summary of the tree height and the corresponding obstacle-free underground space. A factor is calculated to apply on a dynamic scale without the need to group the tree species into classes. The following equation will be used to calculate the minimum obstacle-free underground space per tree species (Norminstituut bomen, 2018);

Tree height (m)	Obstacle-free underground (m)	Factor (/)
20	2,5	0,13
15	2	0,13
10	1,5	0,15
5	1,25	0,25
3	1	0,33
Average		0,20

*Maximum Tree height * 0,20 = minimum obstacle-free underground space.*

For example, “Acer campestre” has an expected maximum height of 12m, $12 * 0,20 = 2,4$ m. The minimum distance an Acer campestre should be planted away from underground infrastructures is 2,4m.

3.2.5. Distance to Street lights

Distance to street lights should be considered to avoid blocked street lights or the necessity of frequent tree pruning. To determine which tree species are suitable for the available space, the tree – lamppost distance is calculated. The same calculation as with other above ground structures is used;

*0,6 * Maximum crown diameter = minimum amount of necessary space*

3.2.6. Planting strip, pavement or park

An important factor to consider when planting a new tree, is the location. The question is whether the tree is going to be planted in a planting strip, paved surface or a park. Certain tree species are much more resistant to grow in pavement than others. This information is collected by tree grower Ebben and grouped together into classes; open and closed pavement. The technique takes tree species suitable for closed-pavement in consideration when the tree is not planted in a park or planting strip. Based on interviews, planting strips with a width of more than 4m are considered planting strips. Therefore, planting strips smaller than 4m are considered as pavement, since trees need more space to grow. Species able to grow in pavement are also suitable to grow inside a planting strip or park.

3.2.7. Parking space and playgrounds

To limit the inconvenience of trees growing above parking spaces and playgrounds, selection of suitable tree species must be carried out carefully. When a parking space or playground is in the proximity of a tree, certain tree characteristics are not preferred. The following characteristics are not preferable when looking for a suitable tree species for a parking space or playground;

- Sensitivity for wind is important as wind sensitive trees are more likely to have branches falling out of the crown, creating dangerous situations.
- Trees bearing big or heavy fruits are not preferred. Big sized or heavy fruit can damage cars parked underneath the tree, causing unnecessary costs for municipalities or citizens.
- Trees bearing many fruits are also unfavorable because they can ruin parking spaces, playgrounds or parked cars underneath. These places are then avoided by citizens, while there already is a limited amount of available parking spaces within the city (Nederlandse overheid, 2008).
- Trees bearing poisonous fruits are also not preferred, in case of children eating the fruits.
- Thorny twigs, because the tree is growing near parked cars or playgrounds.
- Aphid sensitive lime trees (*Tilia spec.*), according to a research article released in “Boomzorg 2014 – number 5”, between 0 and 40% of all lime trees in the Netherlands are affected by honeydew. Honeydew, which is a sticky deposit, is caused by aphids and can be potentially troublesome and hazardous when dripping on cars or sidewalks. In urban areas, honeydew can lead to pressure on tree managers to remove lime trees or to exclude them from planting programs (Carter, 1992). This is unnecessary because there are lime tree species available which aren’t affected by aphids.
- Host plant for birds. Because some tree species are host trees for birds, it is better to avoid planting them in the proximity of parking spaces and playgrounds. When a tree is favorable for birds, birds are likely to be found within their crowns. This can cause disturbance underneath the tree because bird droppings pollute the parking spaces, parked cars and playgrounds underneath.

3.2.8. Residential area

According to the World Allergy Organization, allergic rhinitis, like hay fever and asthma, affects between 10% and 30 % of the population worldwide (Pawankar, Canonica, Holgate, & Lockey, 2011). These allergic-rhinitis are associated with a group of symptoms affecting the nose. These symptoms occur when you breathe in something you are allergic to, such as dust or pollen (MedlinePlus, 2018). To limit the airborne pollen, pollen-free tree species are preferred when planting in a residential area. Tree species triggering allergic reactions by citizens are unsuitable when the tree is planted in a residential area. The following species can cause allergic reactions according to studied literature; Birch, Cypress, Pine, Oak, Alder, Hornbeam, Elm, Chestnut, Poplar, Fir, Yew, Hazel, Sycamore and Willow (Kinder allergie centrum Amsterdam, 2017 & Nederlandse Vereniging voor Allergologie, 2014 & Leef.nl, 2017).

3.2.9. Soil type

Although soil type is important in a natural environment, it is less important in an urban environment. Most cities are incremented with sand before they are built, especially larger cities (Straalen van, 2018). This minimizes the soils effect on a plant because it consists mostly out of sand. Soil maps do not include the soil underneath bigger cities but assign the label “buildings”. This is the reason soil types are the first to be excluded from the tool when no suitable species are found the first time. The BRO soil map, used in this technique to analyze the soil, stands in Dutch for “Basic registration subsurface” and is retrieved from PDOK, the open source spatial data hosting environment, provided by the Dutch government (PDOK, 2017).

Heavy clay is a limiting soil. When found, only species suitable for heavy clay pass the filter. Light clay is a less limiting for a plant, species that are suitable for heavy clay are also suitable for light clay. When peat soils are found underneath a city, only species suitable for peat soils pass the filter.

3.2.10. Soil moisture

The maximum permeable space within a groundwater profile is primarily related to the groundwater level. Places where a high groundwater level is found, root-through depth is limited (Norminstituut bomen, 2018). This inhibits the growth and the final image of a tree and can lead to dangerous situations if the tree is not properly anchored. According to Rijkswaterstaat (2018), the executive organization of the Ministry of Infrastructure and Water Management, hydrological systems in urban areas are strongly influenced by human action. The natural system is determined by:

- Seepage or infiltration.
- The presence of extensive surface water (lakes, ponds, rivers) that feed the groundwater or dehydrate it.

The influence of man on the natural hydrological system is the result of:

- Extensive groundwater extractions.
- Level management of surface water.
- Dewatering the city via drainage systems and leaking sewers.
- Temporary dewatering.
- Underground obstacles such as tunnels, parking garages and deep sheet piling.
- Increased paving and concretion through which rainwater no longer infiltrates into the soil (Rijkswaterstaat, 2018).

When a location has a groundwater level with an average higher than 60 cm below ground level (third level of the water table in figure 2), suitable tree species must be carefully selected. When a tree is planted in paving in this situation, it will probably imprint the paving. It is possible to alter the environment by artificially raising the ground, but not preferable. A better solution would be to plant moisture tolerant trees. For all steps of the water table, see figure 2, where GHG stands for mean highest groundwater level and GLG, for mean lowest groundwater level.

Because 1 meter of underground rooting space is preferred (Norminstituut bomen, 2018), the fourth level of the water table in figure 2 is suitable for all trees. If water level three is found, tree species suitable for wet and very wet soils can pass the filter. When water level one or two is found, only tree species suitable for very wet soils can pass the filter.

When the average groundwater level is too low, drought tolerant species have an advantage, especially when located in an urban environment, where the water supply can be limited. When the average highest groundwater level is lower than 80cm below ground level (water level seven), the soil is classified as dry, very dry and dry tolerant species can pass the filter. When water level eight is found, only tree species suitable for very dry soils can pass the filter.

Water table		
cm - ground level		
I		GLG < 50
IIa	GHG < 25	GLG 50-80
IIb	GHG 25-80	GLG 50-80
IIIa	GHG < 25	GLG 80-120
IIIb	GHG 25-40	GLG 80-120
IV	GHG 40-120	GLG 80-120
Va	GHG < 25	GLG > 120
Vb	GHG 25-40	GLG > 120
VI	GHG 40-80	GLG > 120
VII	GHG 80-140	GLG > 120
VIII	GHG > 140	GLG > 120

Figure 2. Water table

3.2.11. Soil fertility

According to Schils (2013), organic matter is one of the most important indicators of soil fertility. It is essential for chemical, biological and physical soil fertility. Organic matter in the soil is formed by dead plant material and contributes to the soil structure. It also retains soil moisture and is food for soil life. Many nutrients are released during the breakdown of organic matter (Schils, 2012). The soil acidity is also important because this determines how much nutrients become available. However, the lack of a reliable pH map of the Netherlands means that soil pH is not included in the technique and organic matter is used as an indicator for soil fertility. The soil map used is called BOFEK2012 and was commissioned by the Dutch ministry of economic affairs and made by Alterra, Wageningen university (Wösten, et al., 2013).

A minimum organic matter value making the difference between poor and rich sandy soil is unknown. However, several minimum percentages are mentioned in the literature on which a plant could still grow well. A research conducted by Römken & Oenema used a minimum organic matter content of 2% for a fertile soil (Römken & Oenema, 2004). According to Smit, van Beek & Hoogland the minimum threshold value is 2% organic matter which is also used by Geesje Rotgers (Smit, van Beek, & Hoogland, 2007 & Rotgers, 2008). In conclusion, sandy soils with an organic matter content of less than 2% are classified as poor soils, > 2 % as normal.

The difference in organic matter content in clay soil is large when peat is found in the soil structure compared to soils without peat. Clay soils, without a peat horizon, have a maximum mean organic matter content of 4,75% while clay soils with peat have a minimum mean organic matter content of 13,12%. Therefore, clay soils with peat are classified as rich soils and the remaining clay soils are classified as normal.

There are three different kinds of peat; oligotrophic, mesotrophic and eutrophic. Oligotrophic means the peat soil is infertile, mesotrophic means the peat soil is moderately fertile and eutrophic means fertile peat (de Vries, Hendriks, Kemmers, & Wolleswinkel, 2008).

The remaining soils are harder to classify on the organic matter content only, which is the reason they are all classified as “everything”, enabling all species to pass the filter. For a complete overview of the classified soil types refer to Appendix II “2.14 Organic matter filter”.

3.2.12. Water

When surface water is found in the tree’s proximity, the soil is likely to be saturated with water (Hoffman & Hop, 2012). Therefore, tree species growing well on very moist soils can pass the filter when surface water is found within 25 meters of the tree’s location. When no surface water is found, all species can pass.

3.2.13. Species composition

A research done by the U.S. department of agriculture (2002) concluded that a broader diversity of trees is needed in our urban landscapes to protect them against the possibility of large-scale devastation. Urban foresters and municipal arborists should use the following guidelines for tree diversity within their areas of jurisdiction (Santamour, 2002):

- Plant no more than 10% of any species
- No more than 20% of every genus
- No more than 30% of any family

However, according to more recent research, the 10-20-30% rule was not sufficient enough to stop large-scale devastation when pests occurred. Safer guidelines would be a 5-10-20% rule (Zuring & Grootens, 2015);

- Plant no more than 5% of any species
- No more than 10% of every genus
- No more than 20% of any family

Because the database does not contain the family, only species is included in the analysis. When the total amount of trees within a municipality contains more than 5% of the same species, this species is excluded from the technique. Due to a limited time frame, genus is not included in the technique, this will be recommended for further work.

3.2.14. Salt sensitivity

Although almost no tree species are completely insensitive for salt, certain tree species are able to handle salt exposure better than others. Salt is most frequently applied to the main roads in the winter, tree species tolerating salt can pass the filter when planted next to main roads. When planted near smaller roads, salt sensitive species can also pass the filter.

3.2.15. Urban heat island and air pollution

Urban heat island

According to a recent study by Karl, Melillo and Peterson, “The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. These emissions come mainly from the burning of fossil fuels like coal, oil, and gas. Other important contributions are coming from the clearing of forests, agricultural practices, and other human activities” (Karl, Melillo, Peterson, & (eds.), 2009).

A direct result from global warming is the process called ‘urban heat island’. Several studies (Van Hove, et al., 2011; Kim, 1992) included that rapidly heating urban surfaces consisting of buildings, asphalt and bare soil absorb heat, causing cities to be 0.5°C to 10°C degrees warmer than the surrounding countryside (Hove van, et al., 2011) (Kim, 1992). The heat differential between cities and countryside depends on how much of the ground is covered with trees (Carlowicz, 2009). Trees provide shade, preventing sunlight from reaching the ground, evaporate water to stay cool, increasing air humidity and lowering surrounding temperatures (Kuypers, de Vries, & Peeters, 2008).

Air pollution

According to the world health organization (WHO), air pollution is a major environmental risk to health. By reducing air pollution levels, countries can reduce the burden of strokes, lung cancer, and both chronic and acute respiratory diseases. The WHO estimated that around the world, 4.2 million people prematurely die because of air pollution (World health organization, 2018). To comply with European standards regarding maximum concentrations of particulate matter (a common form of air pollution) in the open air, measures must be implemented in the Netherlands. One way to filter particulate matter from the air is the use of trees. Due to their dimensions, trees are the most effective in capturing air pollutants such as particulate matter (Hoffman, 2009).

According to studies conducted by Hoffman (2009) and Tonneijck & Kuypers (2006), certain plant properties and structures play an important role in the removal of particulate matter from the air. Coniferous trees are more efficient in trapping air pollutants than deciduous trees because of the fine needle structure. This is reinforced by the fact that many pine trees remain green in the winter and therefore continue to work as a filter, while most deciduous trees lose their leaves. From

deciduous trees, species with rough or hairy leaves can catch the most particulate matter. Furthermore, the volume and crown structure of the tree has a major influence on the quantity of particulates filtered from the air, since more leaf surface means more uptake. Crown structure is important because a semi-open structure means that the wind can blow through the crown and comes into contact with the leaves. A closed crown structure stops the wind and can work like a wind tunnel, while an open crown structure does not stop the wind sufficiently and the particulate matter blows completely through the crown (Hoffman, Planten en luchtkwaliteit, 2009 & Tonneijck & Kuypers, 2006).

Therefore, the following criteria is established to rank the trees efficiency in capturing particulates from the air;

- Trees > 15m = 1 point, trees 8 - 15m = 0.5 point and trees < 8m = 0 points.
- Open crown structure = 0 points, closed crown structure = 0.5 points and semi-open crown structure = 1 point.
- Wide crown shape = 1 point, semi-wide = 0.5 points and small = 0 points.
- Evergreen = +1 point.
- Pine trees and conifers = +1 point.
- Hairy leaves = +1 point.

Points are awarded based on the above criteria and the sum is calculated. Because characteristics can be suitable, unsuitable and moderate suitable, scores between 0-1 are assigned. 1 for suitable characteristics, 0.5 for moderate suitable and 0 for unsuitable. Suitable species in the output will be sorted from high to low, based on these numbers. Crown structures are classified into three classes, based on their shape and adjective, presented in figure 3.

Because of the points awarded to tree size, crown width and crown structure, trees efficient in filtering particulate matter from the air are also efficient in countering the urban heat island effect.

3.3. What is the necessary data input?

After identifying all criteria which determine the tree suitability, the necessary data input will be determined. The tree species characteristics and spatial information, as mentioned before, are of highest importance and will be treated in this chapter.

3.3.1 Tree species characteristics

The information stored in the database will be used to filter suitable tree species by using specific characteristics of each tree species. Additional information, like leaf color and shape, is presented in the output to help decision-makers in their choice. The database used as input in the technique is derived from the website Ebben.nl. The database includes 1142 tree species and cultivars, with 37 attributes. The attributes contain all plant information and are used to group them together based on certain characteristics, more information about plant groups is given in chapter 3.2. For a detailed example and link to the database, see appendix IV.

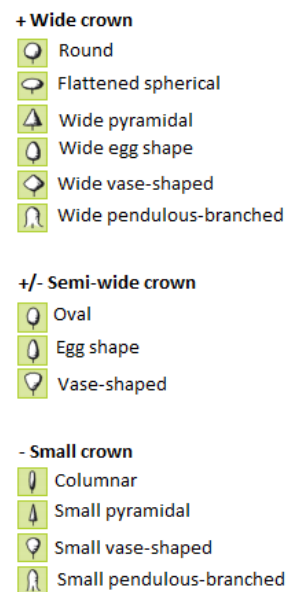


Figure 3. Crown forms grouped into classes according to Van den Berk

The database contains information shown in table 3, the left column is information used to retrieve suitable tree species and the right column is additional information for the decision-maker.

Table 3. Tree species database information

Information used to retrieve suitable tree species	Additional information for the decision-maker
Scientific name; scientific Latin plant names	Pictures; plant pictures
Suitable locations; street, cemetery, park, garden, etcetera	Other information; sensitivity to drought or floods and air or salt pollution
Suitable for pavement; if the plant is suitable for closed- or open pavement	Dutch name; Dutch plant names
Height; minimum and maximum tree height	Winter hardiness zone; a plants ability to tolerate cold weather.
Width; minimum and maximum crown width	Light preference; amount of light preferred
Wind; if a tree is sensitive to wind top branches might break, causing dangerous situations	PH range; optimal pH range
Soil type; preferable soil type per species	Flower; flower information
Soil fertility; preferable soil fertility per species	Flower color; flower color
Soil moisture; preferable soil moisture per species	Flowering time; time of flowering
Host plant: for insects, birds or mammals	Leaves; leaf information
Fruits; fruit information	Leaf color; leaf color
Twigs; twig information	Fall color; the color a plant has in fall
Root system; root system information	Fruit color; the color of the fruits
Tree information; type and shape of tree	Planting concepts; shade, climate, etcetera
Crown structure; the density of the tree crown	Bark; bark information
Crown shape; the shape of the tree crown	Bark color; the color of the bark
	Twig color; the color of the twigs
	Self-pollinator; if a plant is able to self-pollinate

3.3.2. Spatial data

The second source of necessary input is the spatial data. After the database is established with characteristics of each tree species, corresponding spatial data can be searched for. When all spatial data is gathered, it is analyzed to identify the key attributes which are necessary to meet the established criteria.

When no spatial data is found regarding certain factors, it is excluded from the technique. When spatial data is too general (i.e. not specific enough), it is also excluded from the technique. For example, when spatial data regarding roads is found, but without details concerning the specific roads, it is not possible to classify different road types and select tree species based on this.

Spatial data is not uniform for every place within the Netherlands, not all municipalities record their spatial data in the same format. The technique is mainly based on the BGT and the accuracy of the analysis depends on the accuracy and completeness of the spatial data provided by the municipalities. Obsurv automatically integrates the BGT within the system, which ensures the technique will be up-to-date. The completeness of the spatial data will be checked if a municipality acquires the technique. Because of the lack of a soil pH map, pH is not included in the technique. See table 4 for all types of spatial input data and their source.

Table 4. Input data and source

Spatial data	Source
Roads (roads, sidewalks, bicycle lanes, parking spaces, pedestrian areas)	BGT
Green elements (growing strips, grass, trees)	BGT
Underground infrastructures (sewers, cables, pipes)	Obsurv
Buildings*	BGT
Street lights	BGT
Playgrounds	BGT
Surface water	BGT
Administrative boundaries	BGT
Soil type	Soil map of the Netherlands 2006. Alterra, Wageningen (WUR-Alterra)
Soil moisture	Soil map of the Netherlands 2006. Alterra, Wageningen (WUR-Alterra)
Soil fertility	BOFEK 2012. Commissioned by the Dutch ministry of economic affairs and made by Alterra, Wageningen university (Wösten, et al., 2013).

* All buildings are spatially buffered with 2 meters because balustrades and other objects above ground level are not included in the BGT. This means that in the technique, buildings seem two meters wider on every side of the building on ground level.

3.4. How to encourage citizen participation?

Almost thirty years ago, citizens expressed their discontent about the limited possibilities to participate. In municipal elections in 1990, 39% of the citizens stayed away. Started by municipalities, local experiments started in which citizens were given 'real opportunities to participate' in order to actually influence decision-making. The experiments yielded interesting insights. One of these insights is that citizens accept interactive policy only if their contribution is actually reflected in the policy. Another insight is that the policy can be of better quality if citizens are involved in its production (Schram, van Twist, & van der Steen, 2018). Nowadays, the roles are reversed, it is no longer about citizens who respond to the government, but the government is asked to adapt to the wishes and initiatives of citizens. This is increasingly common at municipal level (Stipdonk van, 2017).

There are multiple strategies to involve citizens in processes executed by municipalities. In a research, conducted by Mannarini, Fedi and Trippetti (2009), they conclude that researchers, institutions and social workers aim to improve citizen participation. They suggest that they should design and manage their consulting platforms in a way to make it more:

- Accessible for citizens.
- Sustainable (in terms of interpersonal relationships to prevent conflicts among participants).
- Transparent (making publicly clear what participants are expected to do and what use will be made of the outcomes of the discussion).
- Effective (in term of impact on the community, i.e. transforming suggestions and recommendations into concrete interventions). (Mannarini, Fedi, & Trippetti, 2009)

According to the website Government technology (2013), the first steps are to

- provide an easy-to-use platform for innovation and engagement. Citizens should be able to quickly retrieve data, submit forms and find the information they are searching for.
- empower citizens, give some authority and power in the decision-making process to citizens closest to the issue.
- Develop a communication strategy. (Government technology, 2013)

Francis Pisani stated that to encourage citizen participation, technology should be simplified to make it more understandable and has to start with the specific, what affects the life of citizens (Pisani, 2015).

The steps mentioned above are all included in the created technique. The technique acts as an effective communication strategy because it is easy to use and transparent in why trees are suitable for which location. The technique shows a factual realistic view of the outside world. The interactive map is easy to use for decision makers in Sweco's current system and easy to extent for citizens on a HTML page outside of the system. Because the system is automated and easy to use, citizens can participate in making decisions related to their own living environment. Therefore, the technique could empower citizens, which can help to encourage citizens participation. This technique can only offer a platform to contribute to citizens participation, but more should be done by municipalities themselves to achieve it.

3.5. How to automate a process?

When problems from trees are clear, criteria established, a database created, spatial data gathered and ways to improve citizen participation are outlined, the automation process can start. To enable the integration of the system within Sweco's current management system, FME is used. Before creating the system, requirements are drafted. After the requirements are clear, the general system operation can be outlined. Once both the system requirements and the general product operation are clear, a tool covering multiple objectives can be established.

3.5.1. System requirements

To get a clear understanding of what is needed, system requirements are drafted. The first requirement is that the technique must limit problems caused by trees. To do this, a literature study is conducted to identify all factors influencing trees or influenced by trees. The second requirement stated that all available tree species characteristics must be stored in an Oracle format database and the technique is developed using FME, to enable integration with Sweco's current system. The third requirement is that all available spatial data regarding the public space is taken in consideration. The fourth requirement is the possibility to encourage citizen participation. The last requirement is that the technique is accessible on an interactive spatial map, with the only input required being the new location for which the new tree species is selected.

3.5.2. General operation

The general operation of the technique will incorporate all spatial data and information about tree species to form the input of the technique. All objects in the proximity of the tree are collected and analyzed. Trees species not expected to cause problems in the analyzed area, can pass the filter, tree species passing all filters are suitable for the location. The suitable tree species are presented on a HTML page with all relevant tree species characteristics and pictures. To encourage urban foresters in choosing species to counter air pollution, the suitable tree species will be sorted on their efficiency of filtering particulates from the air.

To encourage citizens to participate in the selection of new tree species, the decision-maker can send the list of suitable tree species to the citizens. Citizens can send back their choice and the decision-maker can include this in the final decision. The course of operation is monitored to ensure the entire process is valid. Every filter is tested throughout the creation of the system, ensuring only suitable species pass the filter and the possibility for all species to pass the filter when no limiting factors are found. When the system is ready, it will be tested on 2000+ tree locations within a municipality.

3.5.3. FME

FME is used to automate the process because Sweco's current management system is also created with FME. This enables the integration between the two systems.

According to Safe software, the developer of FME (Feature Manipulation Engine), FME was designed to overcome many of the problems associated with traditional translation methods. The software used to translate data to a different format had limited capabilities. Most of the data would be forced through a limited data model causing much of the meaning to be lost in translation. FME was the first tool designed to be a spatial ETL (*Extract, Transform and Load*) application, focusing on translation of geographic data. Today, FME's ETL capabilities cover many kinds of data, both spatial and non-spatial. ETL can be described as a data warehousing tool that extracts data from a source, transforms it to fit the users' needs, and then loads it into a destination or data warehouse. Data can be read from any format and written to any other. (FME, 2018)

3.5.4. Obsurv

Obsurv is a user-friendly web-based management system, developed by Sweco. It is an integral management system with planning and budgeting in one place featuring an attractive interface which is simple and intuitive to operate. It can be used anytime and anywhere and meets the latest (open) ICT standards.

Municipalities can use Obsurv to manage their assets like roads, grass, trees, sewers, bridges, etcetera. Obsurv includes the planning of inspections, budgets and measures. The modules and functional characteristics of Obsurv are based on nationally established and widely used standards and norms while supporting all relevant open standards such as GML, IMGeo, Open GIS, WMS and WFS. For more information about Obsurv, see appendix V.

3.5.5. Multi objective decision-making technique (MDMT)

To determine suitable species for a specific location, a technique analyzing the spatial environment and comparing it against tree species characteristics is necessary. The technique used to achieve this is called a multi objective decision-making technique (MDMT), which can solve a problem with multiple objectives. The technique takes all spatial data and tree species characteristics in consideration.

This chapter explains and discusses the meaning of a MDMT and how it relates to the technique created in this research. First, a description is given in chapter 3.5.5.1, cited from “Multi objective decision making” by Vira Chankong and Yacov Y Haimes. The different steps in the process of MDMT development are explained. The first step, the initiation step, is the recognition of the need of change (chapter 1). Second, is the problem formulation step (chapter 3.2). The overall objective is to limit damage and problems caused by- and to trees, the problems and the corresponding objectives are further worked out in the hierarchical tree, presented in figure 5. The third step is the system modeling step (chapter 3.5.5.2), which is the creation of the system. The last step is the analysis evaluation step (chapter 3.5.6), where the system will be tested on existing tree locations.

3.5.5.1. What is a MDMT?

According to Vira Chankong and Yacov Y Haimes (2008), the term Multi objective decision-making refers to the entire process of problem solving, consisting out of five steps covered in figure 4. The process begins when the decision-maker feels the need to alter the course of the system of which he is concerned. The situation is then diagnosed, and general statements of overall objectives are stated. The problem formulation step begins then. Tasks involved in this step include translating vaguely stated overall objectives into a more operational set of specific objectives.

When the system and the set of objectives are defined, an appropriate model is constructed. By a model is meant a collection of key variables and their logical or physical relationship which together facilitate an effective analysis returning suitable alternatives. Normally, the alternative having the highest rank according to the decision rule is then chosen for implementation. However, all tree species present in the output are suitable for the selected location, but to facilitate urban foresters better, the output is sorted on the tree's efficiency in filtering particulates from the air. Although the suitable tree species are sorted, the final decision is to be made by the decision maker.

A MDMT must have objectives. Essentially, an objective is a statement about the desired state of the system. A well-defined set of objectives often exhibits a hierarchical structure, as illustrated in figure 5. The highest level of this structure (orange box in figure 5), represents the broad overall objective, this objective is however often vaguely stated and hence, un-operational. As we go down the hierarchical tree, objectives at the lower level are more specific and operational. An objective is operational if there is a practical way to assess the possibility of achieving the objective. A set of attributes (green in figure 5) is assigned to each objective in the lowest level (blue in figure 5). For each objective in the lowest level there should exist an attribute or a set of attributes, whose value is a direct measurement of the level of achieving that objective. A good description of the decision situation should clearly specify the type and amount of inputs needed and those which are available; the set of decision variables and the set of attributes. (Chankong & Haimes, 2008)

For an overview of the types of input needed refer to chapter 3.3, for an overview of the objectives and attributes see chapter 3.2 and figure 5.

The Multiobjective Decision Problem

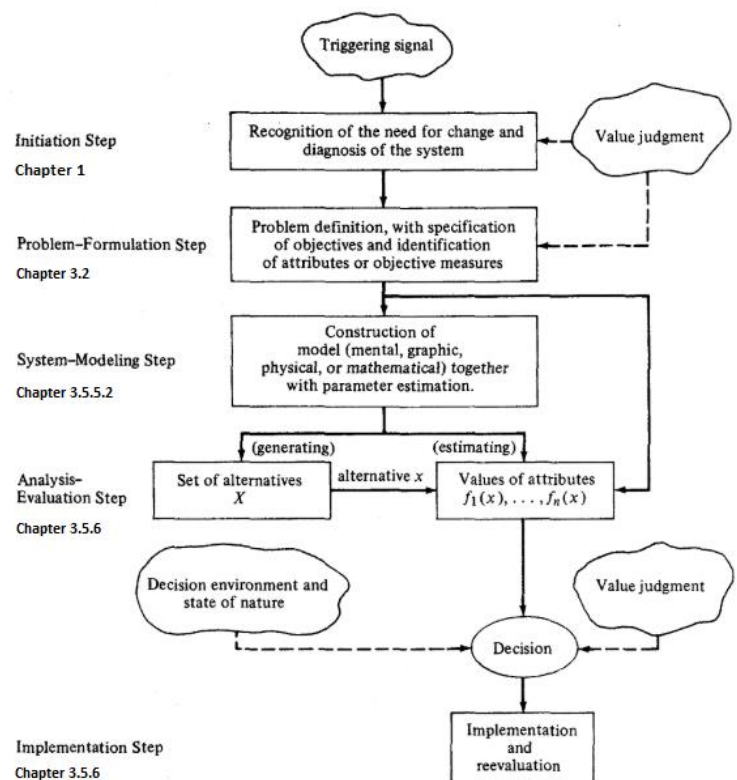


Figure 4. Typical multi objective decision-making process

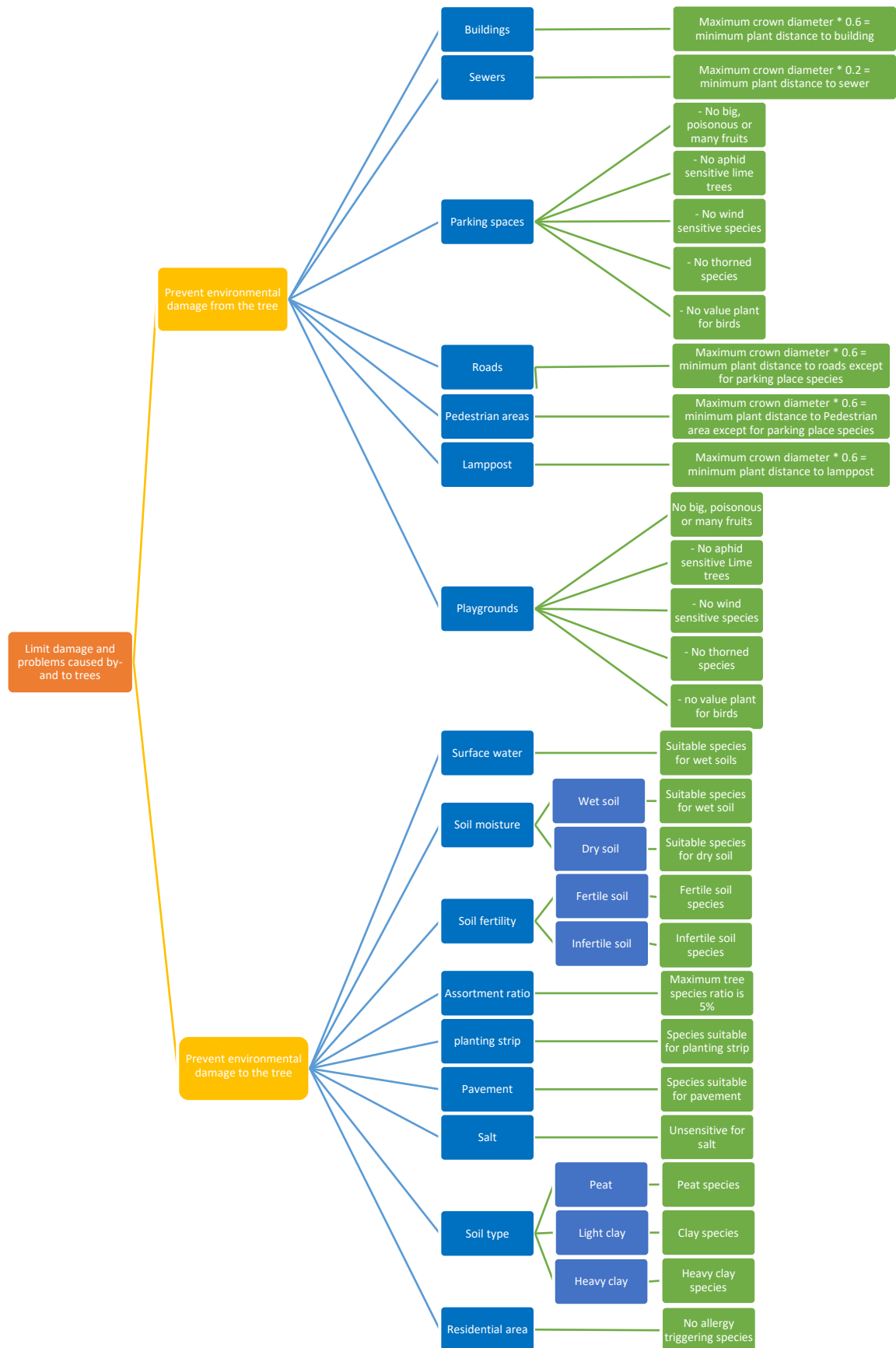


Figure 5. Hierarchical structure of objectives with corresponding attributes

3.5.5.2. Detailed MDMT description

Figure 6 shows a schematic overview of the MDMT. In step 1, all spatial data and tree species characteristics are read into the workspace. First, a tree location is generated, used as test location while creating the system. Later on, the tree location generator will be replaced with coordinates specified by decision makers on a spatial map. Second, the location is spatially buffered with 25 meters. The location is spatially buffered with 25 meters because the maximum tree crown width is less than 50m, hence the maximum distance a tree will influence his environment significantly is 25 meters or less. Only spatial data intersecting the tree buffer is read into the workspace, because reading in all spatial data would slow down the technique too much. For detailed information about the input data, see chapter 3.3, for a detailed overview from the steps within step 1 in the workspace, see appendix I.

Step 2, is analyzing the incoming spatial data. The determined objectives form the criteria covered in chapter 3.2. Every objective has a corresponding filter, 17 filters in total. All tree species read into the workspace are now compared against the spatial data found within the tree's proximity. When objectives limiting the growth of a tree are found, only species having favorable characteristics can pass the filter. When no limiting objectives are found, all tree species can pass the filter in question. Tree species able to pass every filter are suitable for the chosen location. For a complete overview of the different filters refer to chapter 3.2, figure 6 and appendix II.

As shown in figure 6, and more detailed in appendix III, step 3 analyzes the output. First, the technique looks for species that passed every filter, which are the suitable species (blue in figure 6 step 3). When no suitable species are found, the technique will look again, but this time excluding soil type and fertility from the technique (red in figure 6 step 3). When still no suitable species are found, the technique will look again, this time also excluding the residential area filter (green in figure 6 step 3). The reason this filter is excluded is because a lot of tree species can trigger allergic reactions from citizens and it is not always possible to take this in consideration.

When suitable species are found, the technique continues to the HTML-output-builder in step 3.4 (pink in figure 6 step 3). Unnecessary attributes are removed, photos in step 3.5 (yellow in figure 6 step 3) are merged with the corresponding suitable species and a HTML page is build. The last step is the spatial logger in step 3.6 (grey in figure 6 step 3), logging all spatial aspect influencing the suitable species. This enables urban foresters to verify why the species are suitable and what is found in the proximity of the new location. When in the first step no suitable species are found, but only after the second or third step, a message will be shown to the urban forester, explaining what is excluded from the analysis and why. The suitable species list is sorted on the species efficiency on filtering particulate matter from the air. For a detailed description of step 3, see Appendix III.

The user interface created in step 3 shows a list of the suitable tree species on a HTML page. The list contains a map showing the specific location, photos and the following tree species characteristics; scientific name, Dutch name, height, width, location, pavement tolerance, crown structure, crown shape, leaf, flower, fruit, twigs, bark, flowering time, soil type, pH-range, pH value, soil moisture, soil fertility, root structure, light requirement, wind sensitivity, efficiency in filtering particulates from the air, value / food plant for animals, tree information, other information and percentage of every species of the total species composition. The interface is clear and easy to use so citizens are encouraged to participate, if that is preferred by the municipality. For an example of the output interface, see figure 7, where an existing tree location in the city Oostburg is analyzed for suitable tree species and the output presented two pages.

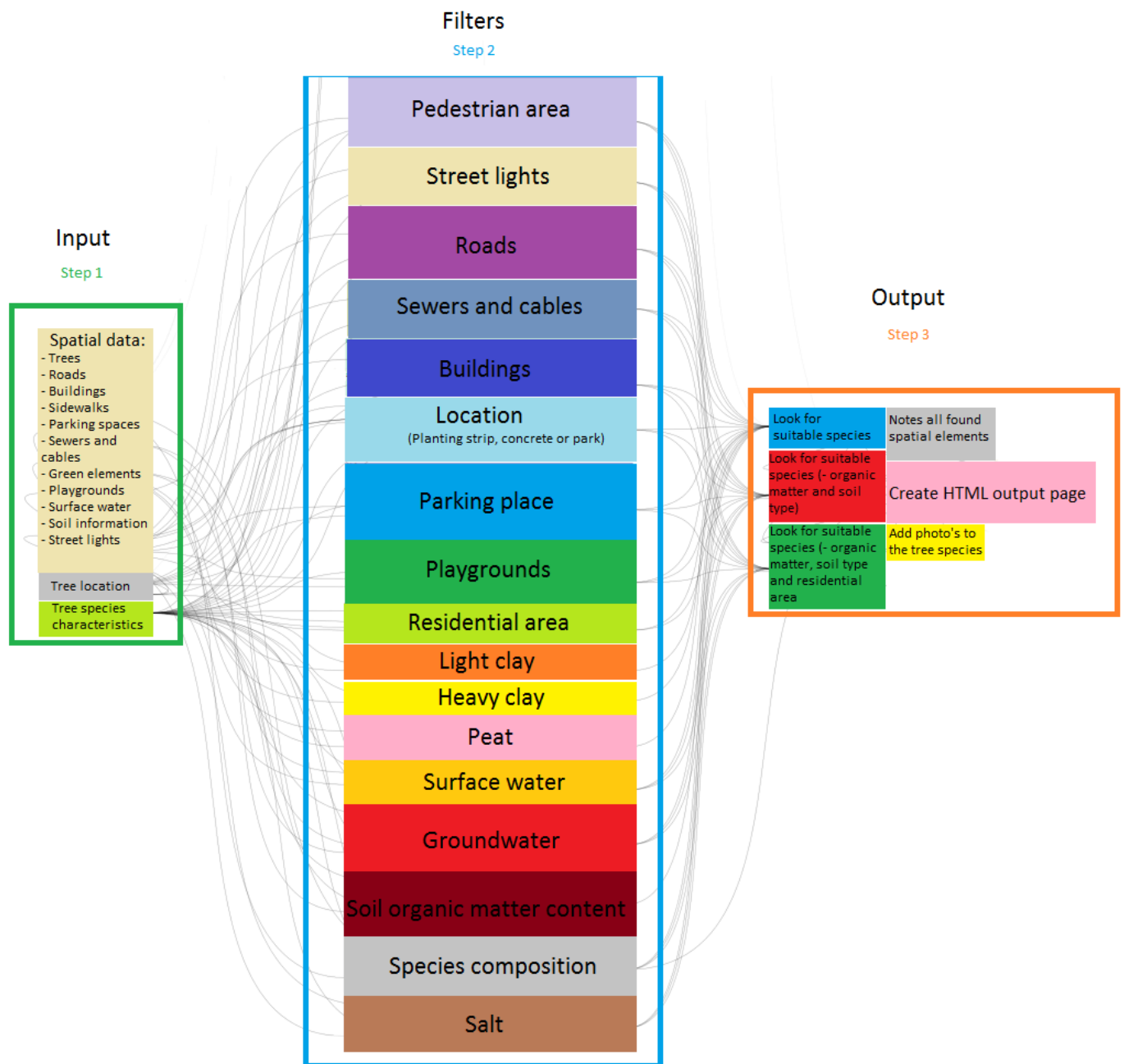


Figure 6. Schematic MDMT overview



Gevonden ruimtelijke objecten

- De boom staat binnen de bebouwde kom, hierdoor zijn soorten die allergische reacties opwekken bij mensen uitgesloten van de analyse
- De bodemschicht is: Niet indeelbaar
- De coördinaten zijn: 20196.365507, 379462.914496
- De gevonden bodem is niet voedselarm of rijk
- De gemiddelde afstand tot het dichtstbijzijnde wegdek is: 18.47 m
- De gemiddelde afstand tot het dichtstbijzijnde riool is: 3.57 m
- De gemiddelde afstand tot het dichtstbijzijnde gebouw is: 13.16 m
- Populus nigra is uitgesloten van de analyse omdat de soortpercentage van het totale areaal groter is dan 5%, namelijk: 7.98 %
- Salix alba is uitgesloten van de analyse omdat de soortpercentage van het totale areaal groter is dan 5%, namelijk: 9.94 %

Geschikte soorten:

Wetenschappelijke naam	Nederlandse naam	Hoogte	Breedte	Locatie	verharding	Kroonstructuur	Kroonvorm	blad
Zeikova carpinifolia	Kaukasische schijniep, Kaukasische zeikova	20-25	15-20	straat/laan/plein/park/groenstrook/bakken/containers/daktuin/grote tuin/begraafplaats/verkeer, industrie	geen/open/dicht	halfopen	breed eirond	bladverliezend/eirond/ovaal/klein/
Pyrus nivalis		6-10	5-7	straat/plein/park/grote tuin/kustgebied	geen/open/dicht	halfopen	rond	bladverliezend/ovaal/behaard/get
Tilia platyphyllos	Zomerlinde, Grootbladige linde	25-30	20-25	straat/laan/plein/park/keerplaats/park/groenstrook/grote tuin/begraafplaats/landschap/ecologische zone/windsingel	geen/open/dicht	gesloten	breed eirond	bladverliezend/hartvormig/onderz
Celtis australis	Europese netelboom, Zwepenboom	15-20	10-15	straat/laan/plein/park/groenstrook/grote tuin/begraafplaats/verkeer, Industrie/ecologische zone	geen/open/dicht	halfopen	rond	bladverliezend/eirond/lancetvormig
Celtis julianae	Chinees zwepenboom	15-20	12-15	laan/park/groenstrook/grote tuin/begraafplaats/verkeer, industrie	geen/open/dicht	halfopen	vaas	bladverliezend/eirond/omgekeerd
Pyrus salicifolia	Wijgbladige treurpeer	5-7	5-7	park/grote tuin/kleine tuin/begraafplaats/verkeer, industrie/kustgebied	geen/open/dicht	halfopen	breed treur	bladverliezend/lancetvormig/smal

Figure 7. HTML output example

- Tilia platyphyllos - Foto's en informatie

Zomerlinde, Grootbladige linde

Wetenschappelijke naam	Nederlandse naam	Hoogte	Breedte	Locatie	verharding	Kroonstructuur	Kroonvorm	blad	bloem	Vrucht	Twijgen	bast	bl
Tilia platyphyllos	Zomerlinde, Grootbladige linde	25-30	20-25	straat/laan/plein/parkerplaats/park/groenstrook/grate tuin/begraafplaats/landschap/ecologische zone/windsingel	geen/open/dicht	gesloten	breed eirond	bladverliezend/hartvormig/onderzijde behaard/gezaagd	tuiten/opvallend/hangend/geurend	onopvallend/steenvrucht	donzig behaard	gegroeft	jur



Foto 1.



Foto 2.

- Celtis australis - Foto's en informatie

Europese netelboom, Zwepenboom

Wetenschappelijke naam	Nederlandse naam	Hoogte	Breedte	Locatie	verharding	Kroonstructuur	Kroonvorm	blad	bloem	Vrucht	Twijgen

3.5.6. System validation

The system validation test showed that on average, almost fifteen percent (14%) of the locations appear to be suitable per tree species, meaning there will be about 338 suitable locations per species on average, as shown in table 5. However, the median of six percent (6%) indicates that a greater number of tree species has about 147 suitable locations. This only concludes that 1132 tree species have suitable locations in Oostburg (from the example in figure 7), but not how many species will be returned on average in the output. Therefore, the number of suitable species per location is calculated in table 6. The results of the system validation tests are summarized in table 5 and 6 and visualized in figure 8.

Table 5. Suitable locations (n=2377) per tree species (n=1132)

Average percentage of suitable locations per species	14% (338)
Range of percentages of suitable locations per species	1% - 96% (26 – 2277)
Median of percentages of suitable locations per species	6% (147)

A third (35%) of the locations returns one to ten suitable species, these locations are mainly positioned near roads within the city center. Eleven to one hundred suitable species are found in less than a third (30%) of the locations, these locations are mainly positioned within the city center and more towards the edges. Therefore, the total number of trees to choose from is reduced with at least 91% in 65% of the cases (1-100 suitable tree species for 825 locations).

More than a quarter (27%) of the locations are suitable for 100 to 499 species, these locations are positioned close to each other in a more natural habitat within the city, like parks and the country side near the city edge. Nine percent of the locations return more than 500 suitable species, these locations are all positioned close to each other and barely face any interference from their surroundings. Locations with more than 500 suitable species are found on the edge of the city.

Table 6. Number of suitable tree species(n=1132) per location (n=2377)

Average number of suitable species per location	14% (160)
Range of suitable species per location	0,01%-100% (1-1132)
Median of suitable species per location	3% (32)
Number of locations without suitable species	0% (0)
Number of locations with only one suitable species	18% (418)
Number of locations with 2 to 10 suitable species	17% (407)
Number of locations with 11 to 99 suitable species	30% (704)
Number of locations with 100 to 499 suitable species	27% (633)
Number of locations with 500 to 999 suitable species	4% (98)
Number of locations with 1000 to 1132 suitable species	5% (117)

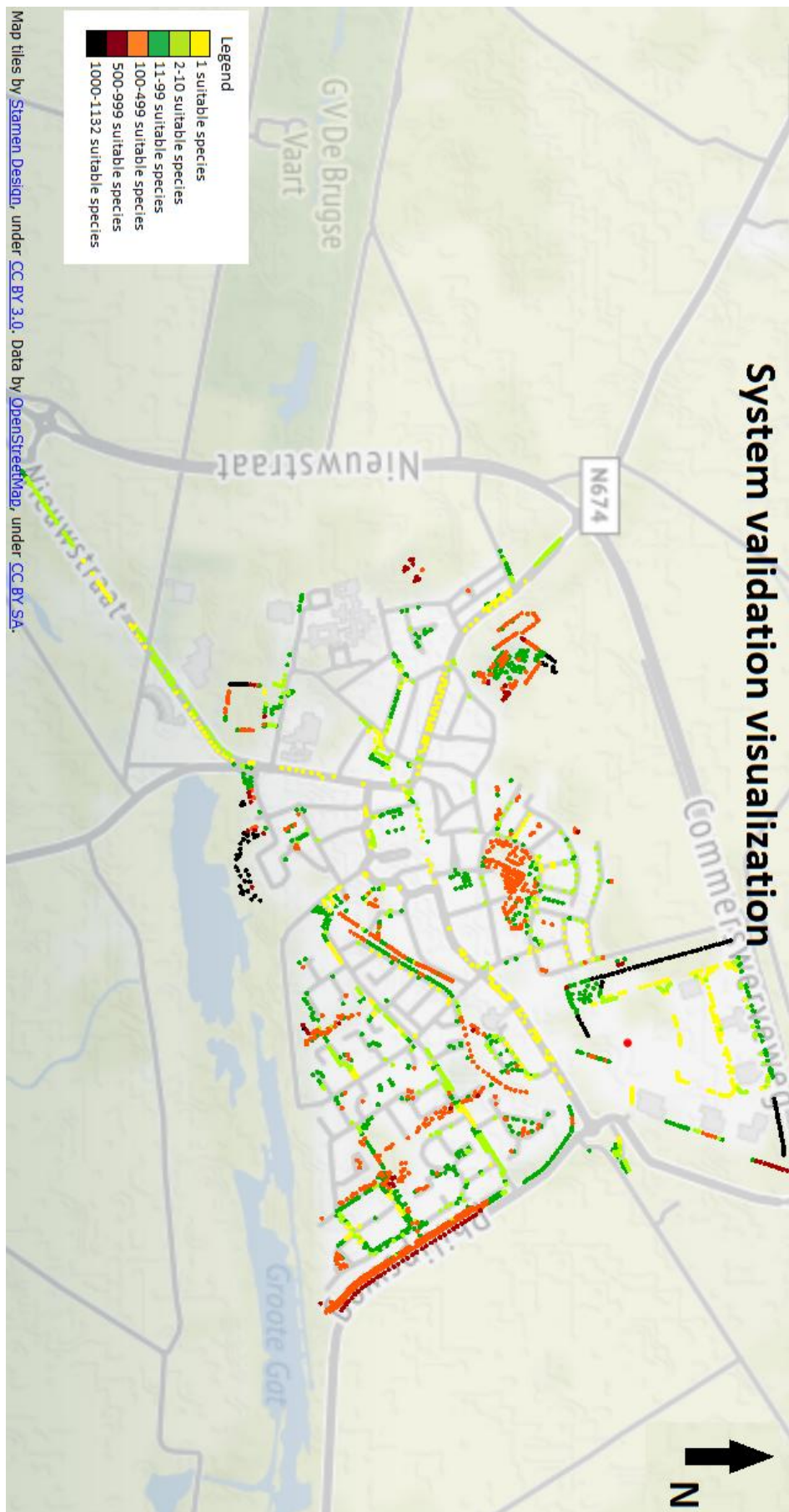


Figure 8. System validation visualization of Oostburg

4. Conclusion

In conclusion, how can the choice for a new tree be automated and citizen participation encouraged within Obsurv? By using FME, all tree species characteristics and available spatial data regarding the public space. However, the decision is still in hands of the decision-maker. The technique returns a list with suitable tree species for most locations within the city, for the city edge and countryside a lot of species are returned. This can be explained since trees face barely to no limitations from the environment on the country side, while they do in the city. Almost two thirds (65%) of the locations is suitable for 1 to 100 species. Therefore, the total amount of trees to choose from is reduced with at least 91% in 65% of the cases.

The technique is developed with FME and the tree species characteristics are stored in an Oracle format database, this makes integration with Sweco's current management system possible. Because the tree species characteristics and almost all relevant spatial data are available, the choice for a new tree can be automated. Criteria are established, based on what people already use, determining suitable tree species characteristics for all objects surrounding trees in an urban environment.

The technique contributes to sustainability in an economic, ecologic and social way.

Economic

Because the technique prevents problems caused by trees in the public space, municipalities have less work to counteract the problems and thus lower costs. Furthermore, because the tree automatically generates a list with suitable tree species for a location, the time of the existing process of selecting suitable tree species is heavily reduced, also lowering the costs for municipalities.

Ecologic

Because this technique uses a maximum number of 5% of the same species within a municipality, the biodiversity between trees planted is guaranteed. When there already are tree species with too many individuals within a municipality, the species is automatically excluded from the technique. Furthermore, because the location is analyzed and only suitable trees are present in the output, trees have less disturbance from the urban environment and vice versa. Therefore, it is more likely that the tree can grow without the need for it to be extensively pruned or even removed. Since the technique only return suitable species, all species present on the output list can be planted. This offers the possibility to experiment with planting other tree species than municipalities used to do, which could lead to increasing the biodiversity. Furthermore, the technique does not use tree-height classes, but maximum crown diameter of each individual tree. Therefore, trees planted after using this tool will be better suited for the available space.

Social

A technique that enables citizens to be involved in the process of planting new trees in their streets is valuable in the social aspect of sustainability. Citizen participation is getting more important for municipalities and this technique gives them a tool to communicate with the citizens and to involve them in the process of choosing a new tree to be planted in their own streets. Because the tool is easy to use and also easy to extend to a HTML page, citizens can be empowered to use the tool themselves, if preferred by the municipality.

5. Discussion

In chapter one, multiple problems are stated. The main problem, trees being planted at unsuitable location, is solved, based on spatial data representing the public environment and a database containing tree species characteristics.

To enable the selection of suitable tree species, based on the identified objectives in the proximity of the tree location, suitable tree species characteristics were identified for every objective. 17 different spatial elements are analyzed and compared against 1142 different tree species. If a human has to process the same amount of information for every tree to be planted by a municipality, the process would take much longer. With the created technique, suitable tree species for thousands of locations can be identified within a couple of hours.

35,6% of the analyzed locations return more than 100 suitable species per location. More filters can be established to reduce these numbers to a more preferable outcome. Two thirds (64,4%) of the locations is suitable for 1 to 100 species, which is a desirable outcome.

The filter analyzing the closest tree entirely depends on spatial tree data delivered by municipalities and it assumes that the new tree as well as the old tree reaches its maximum diameter. Therefore, the filter is sensitive for errors and limits the technique too much, because trees in an urban environment usually do not reach their maximum diameter. Hence, this variable is not included in this technique but will be recommended for further work when more research is conducted on urban tree growth.

The technique depends on the validity of spatial data delivered by municipalities, tree species characteristics from Ebben and the tree species groups the species are classified in. When the spatial data or tree species characteristics are invalid, the results are not representing the real-world situation. The spatial data is provided by the municipalities and the official soil maps are provided by the Dutch government. The municipalities are responsible for the spatial data in their own area of jurisdiction, they update the BGT which is automatically updated in Obsurv.

Soil types can be classified into more depth when time allows it. Soil pH can be included as soon as a soil pH map of the Netherlands is available. Furthermore, when a pH map of the Netherlands becomes available, it should be included in the soil fertility calculation as well. Pests and diseases are not included in this technique because they can be location dependent and vary in their intensity.

Criteria used to identify suitable tree species are based on literature. Although Handboek bomen is a widely used standard in the industry, the information is not guaranteed to be correct. Furthermore, criteria determining suitable species to grow near parking spaces and playgrounds are based on interviews, literature and personal experience, this could be different per municipality. The minimum width of a planting strip used in this research is 4 meters, 2 meters on every side of the tree, no literature was found to confirm this.

The technique analyzes a radius of 25 meters around the tree, this could be insufficient in regard to surface water and the effect of surface water on trees. No distinction has been made to classify allergy triggering tree species further. Further research needs to be carried out to classify allergy triggering species more in-depth, on their effect on citizens.

Because the technique will be integrated with Obsurv, it will always be up-to-date. If criteria need to be changed, it has to be done manually.

6. Recommendations

To further improve the existing technique, the following factors can be included;

- Include half-open pavement in the analysis.
- When a valid pH map of the Netherlands is available it should be included in the technique.
- A new spatial object can be created in the form of a polygon, representing the North Sea. This enables the technique to include the effect the North Sea has on the coastal vegetation.
- Evapotranspiration per tree species can be included in the technique when further research is conducted.
- Some municipalities have a spatial referenced file, explaining the intensity in which salt is applied to roads in the winter, this can be included in the technique when municipalities are interested.
- Include volatile organic compounds (VOCs) in the analysis. This can only be done when more research is conducted on the VOC per tree species.
- Include tree control measures and costs performed by the municipalities within their area of jurisdiction, to be able to see estimated future costs for a municipality, regarding different tree species.
- To include pests and diseases in the technique, more research should be conducted to clearly identify the severity for pest and disease per species, per location and preferable, per cultivar.
- Include the nearest tree filter with preferably an altered maximum crown diameter, more suitable for urban trees.
- Calculate obstacle-free underground per tree height class
- More filters can be created to filter the tree species more intensively when too many suitable tree species are identified.
- Include species genus within the technique

To update and improve the technique in the future, multiple expansions can be made. These improvements will be included in future versions of the technique. The following improvements are already identified while creating the technique, some are occasionally worked on already;

- To really be able to support municipalities by the design of public space, the technique will be adjustable per municipality in the future.
- Public parameters can be determined to enable landscape architects to slightly change the desired technique. When, for example, roots heaving up pavement are acceptable, landscape architects will be able to “tell” this to FME using private parameters, which will exclude the filter from the technique.
- Expand the technique with the possibility to design the public space regarding all assets managed by municipalities, like roads, bushes, sewers, bridges, street lanterns, etc.
- Include the possibility to find new places within a city, suitable for the planting of trees. This could be used to calculate the best suitable species per location to achieve the highest possible tree cover within a city.
- Another new function could be the possibility to let the technique calculate what the most efficient public space design would be within a street, for example, making certain factors like buildings the base feature, designing the remaining assets around it.
- Create the possibility for a dynamic output, enabling decision makers to change which tree characteristics are displayed in the output.
- To achieve more citizen participation, a second HTML page should be established which is accessible by the citizens themselves.

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Appendices

Appendix I. Overview step 1

Appendix II. Overview step 2

Appendix III. Overview step 3

Appendix IV. Database overview

Appendix V. Obsurv website Information

Appendix VI. Technique validation; number of suitable locations per species

Appendix VII. Technique validation; number of suitable species per location

Appendix I. Overview step 1

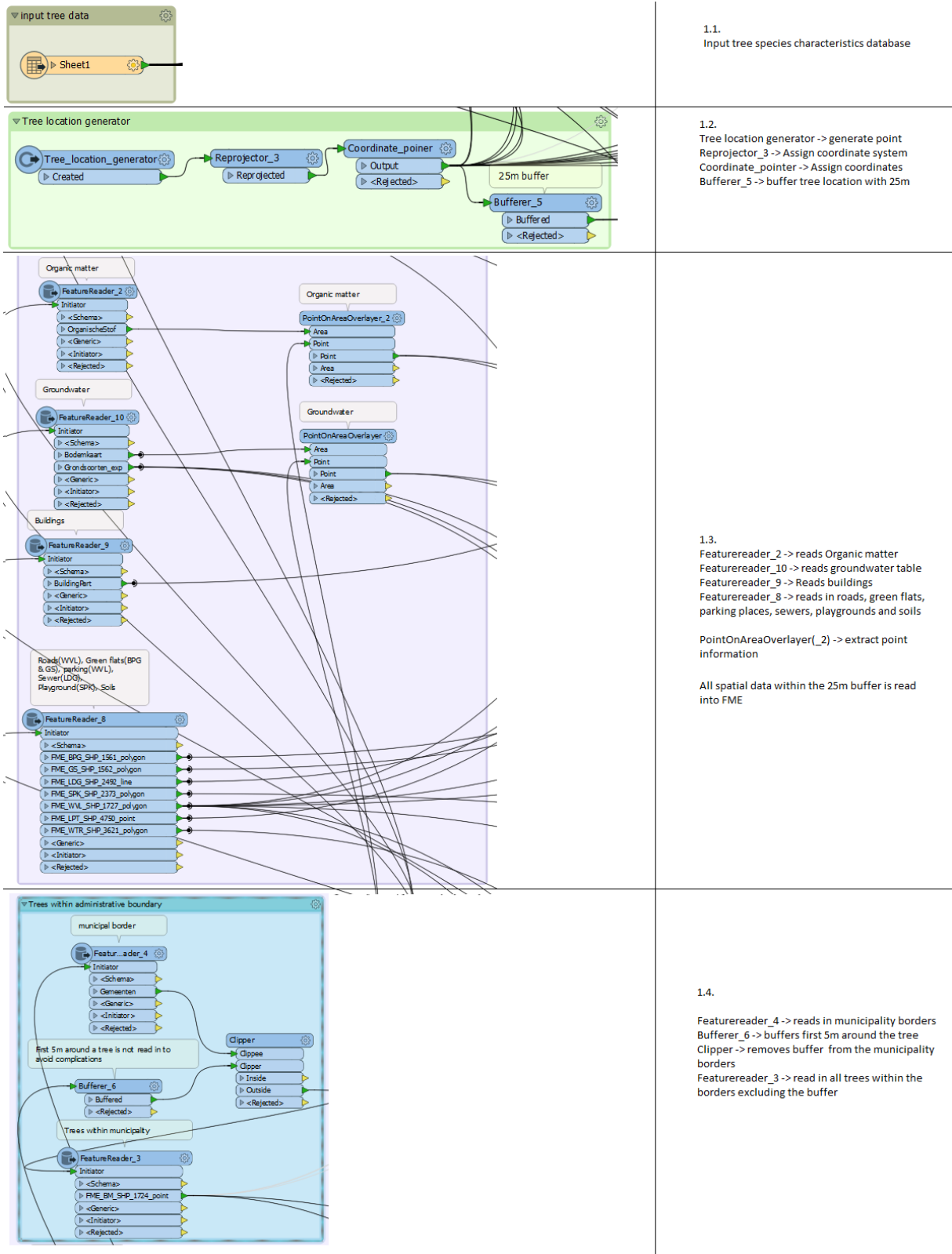


Figure A 1. Step 1 detailed

Appendix II. Overview step 2

2.1 Pedestrian filter.

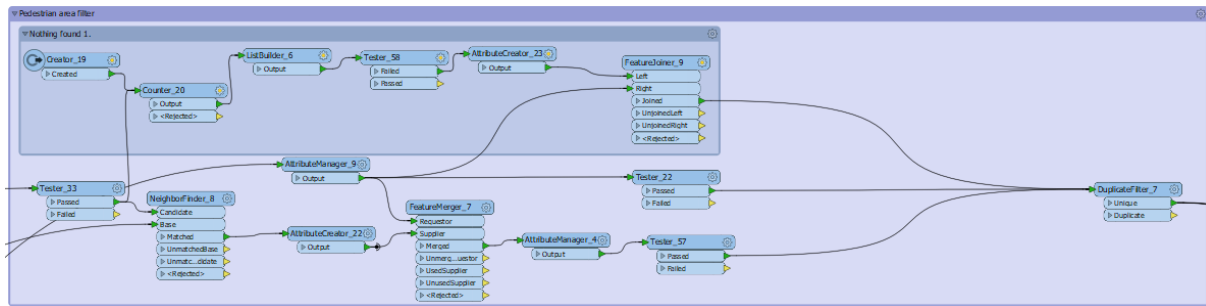


Figure A 2. Pedestrian filter

Bookmark “Nothing found 1” counts the incoming attributes and enables all tree species to go through when no pedestrian areas are found, when there is a pedestrian area found, no species go through. Creator_19 creates one feature, counter_20 counts all incoming features, when it is more than one, the featureJoiner_9 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_19, so no pedestrian areas are found. When more than 1 feature is counted, the analysis continues in the other part of the pedestrian filter.

Tester_33: only let pedestrian area features pass.

NeighborFinder_8: finds the closest distance from the tree base to the pedestrian area

AttributeCreator_22: enables merge

FeatureMerger_7: merge the found tree-pedestrian area distance to the tree species

AttributeManager_4: Only let tree species with a crown radius smaller than the measured distance keep their attribute value.

Tester_57: Only let species with a value pass

AttributeManager_9: supplies tree species to the filter

Tester_22: Only let tree species pass which are able to grow above a parking space and do not have a superficial rooting system.

DuplicateFilter_7: Makes sure that no duplicate tree species pass the filter.

2.2 Lamppost filter

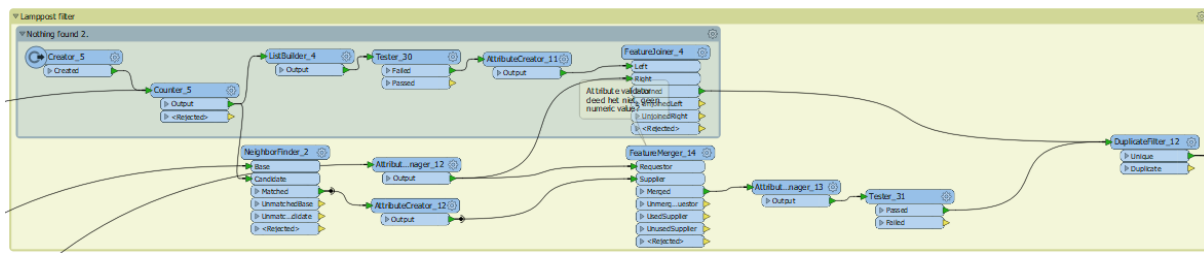


Figure A 3. Lamppost filter

Bookmark “Nothing found 2” counts the incoming attributes and enables all tree species to go through when no lampposts are found, when there is a lamppost found, no species go through. Creator_5 creates one feature, counter_5 counts all incoming features, when it is more than one, the featureJoiner_4 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_5, so no lampposts are found. When more than 1 feature is counted, the analysis continues in the other part of the lamppost filter.

NeighborFinder_2: finds the closest distance from the tree base to the nearest lamppost

AttributeCreator_12: enables merge

FeatureMerger_14: merge the measured tree-lamppost distance to the tree species

AttributeManager_13: Only let tree species with a crown radius smaller than the measured distance keep their attribute value.

Tester_31: Only let species pass with a value

AttributeManager_12: supplies the filter with tree species

DuplicateFilter_12: Makes sure that no duplicate tree species pass the filter.

2.3 Roads filter

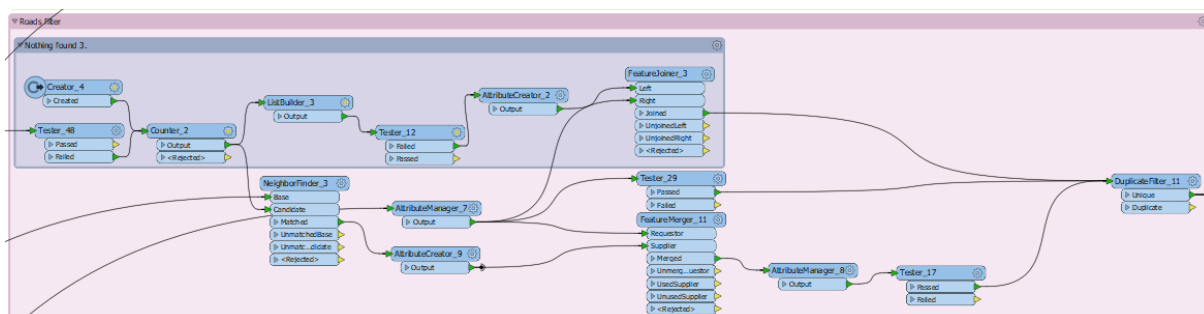


Figure A 4. Roads filter

Bookmark “Nothing found 3” counts the incoming attributes and enables all tree species to go through when no streets are found, when there is a street found, no species go through. Creator_4 creates one feature, counter_2 counts all incoming features, when it is more than one, the featureJoiner_3 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_4, so no streets are found. When more than 1 feature is counted, the analysis continues in the other part of the street filter.

NeighborFinder_3: finds the closest distance from the tree base to the closest street

AttributeCreator_9: enables merge

FeatureMerger_11: merge the found tree-street distance to the tree species

AttributeManager_8: Only let tree species with a crown radius smaller than the found distance keep their attribute value.

Tester_17: Only let species pass with a value

AttributeManager_7: supplies tree species

DuplicateFilter_11: Makes sure that no duplicate tree species pass the filter.

Tester_21: Always let species pass which are able to grow above parking spaces and do not have a superficial rooting system.

2.4 Sewer filter

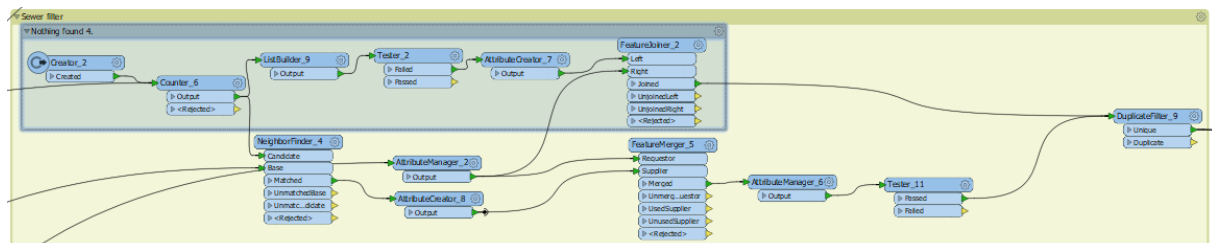


Figure A 5. Sewers filter

Bookmark “Nothing found 4” counts the incoming attributes and enables all tree species to go through when no sewers are found, when there are sewers found, no species go through. Creator_2 creates one feature, counter_6 counts all incoming features, when it is more than one, the featureJoiner_2 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_2, so no sewers are found. When more than 1 feature is counted, the analysis continues in the other part of the sewer filter.

NeighborFinder_4: finds the closest distance from the tree base to the closest sewer

AttributeCreator_8: enables merge

FeatureMerger_5: merge the found tree-sewer distance to the tree species

AttributeManager_6: Only let tree species with a crown radius smaller than the found distance keep their attribute value.

Tester_11: Only let species pass with a value

DuplicateFilter_11: Makes sure that no duplicate tree species pass the filter.

AttributeManager_2: supplies tree species

2.5 Building filter

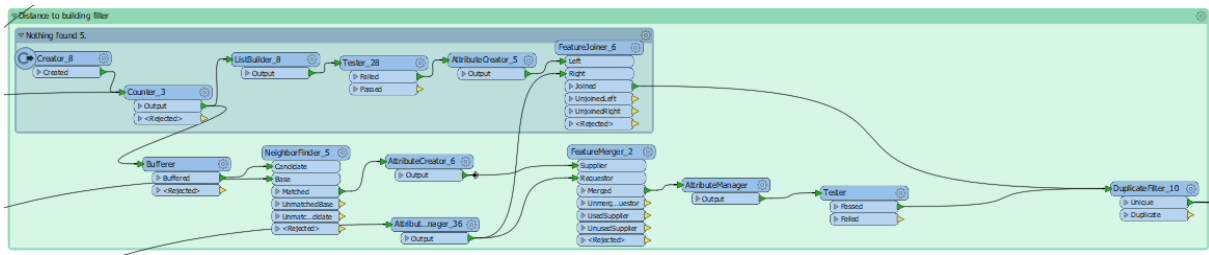


Figure A 6. Building filter

Bookmark “Nothing found 5” counts the incoming attributes and enables all tree species to go through when no buildings are found, when there are buildings found, no species go through. Creator_8 creates one feature, counter_3 counts all incoming features, when it is more than one, the featureJoiner_6 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_8, so no buildings are found. When more than 1 feature is counted, the analysis continues in the other part of the building filter.

Bufferer: give the buildings a spatial buffer of 2m to account for protruding object like balconies.

NeighborFinder_5: finds the closest distance from the tree base to the closest building

AttributeCreator_6: enables merge

FeatureMerger_2: merge the found tree-building distance to the tree species

AttributeManager: Only let tree species with a crown radius smaller than the found distance keep their attribute value.

Tester: Only let species pass with a value

DuplicateFilter_10: Makes sure that no duplicate tree species pass the filter.

AttributeManager_36: supplies tree species

2.6 Planting strip, pavement or park filter

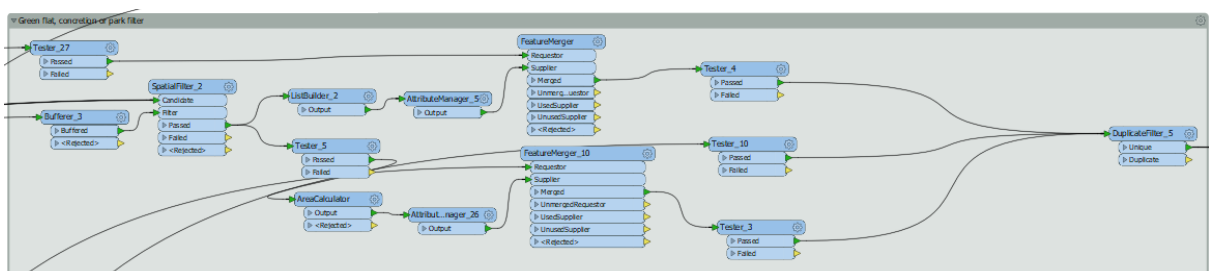


Figure A 7. Planting strip, pavement or park filter

Tester_27: Only let species pass which are able to grow in a planting strip

FeatureMerger: merge features when only planting strips are found in the proximity of the tree, if also pavement is found, the merge will not be able.

Tester_4: ensures only tree species able to grow on a planting strip are able to pass the filter this way.

Bufferer_3: spatially buffers the tree location with 2m

SpatialFilter_2: analyze every feature coming in

ListBuilder_2: put all features in a list

AttributeManager_5: Scans entire list if only planting strips are present, if pavement is also present, the feature merger will not be able to merge and so the planting strip features will be blocked.

Tester_5: only let planting strips pass

AreaCalculator: Calculates the area of the planting strip in square meters

AttributeManager_26: makes merge possible if the area is bigger than 500m², if the area is smaller, the merge will not be possible and no species will pass this part of the filter.

FeatureMerger_10: merge features if the planting strip area is bigger than 500m².

Tester_3: only let species able to grow in a park pass the filter.

Tester_10: always let species able to grow in pavement pass the filter

2.6 Parking space filter

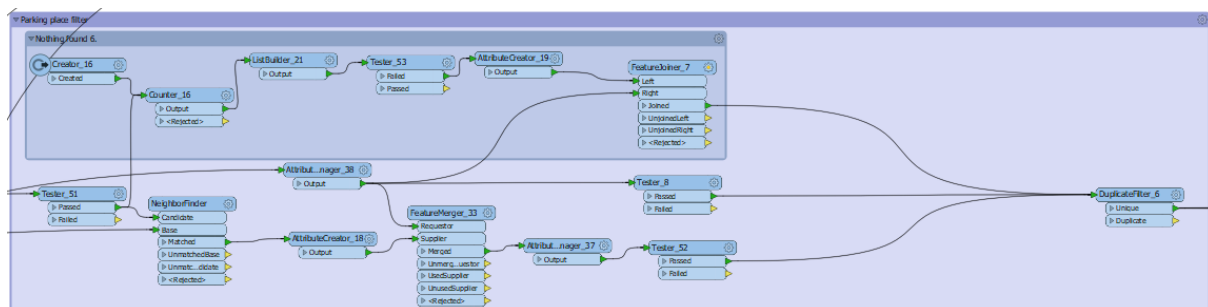


Figure A 8. Parking space filter

Bookmark “Nothing found 6” counts the incoming attributes and enables all tree species to go through when no parking spaces are found, when there is a parking space found, no species go through. Creator_16 creates one feature, counter_16 counts all incoming features, when it is more than one, the featureJoiner_7 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_16, so no parking spaces are found. When more than 1 feature is counted, the analysis continues in the other part of the parking space filter.

Tester_51: only let parking space features pass

NeighborFinder: finds the closest distance from the tree base to the closest parking space

AttributeCreator_18: enables merge

FeatureMerger_13: merge the found tree-parking space distance to the tree species

AttributeManager_33: Only let tree species with a crown radius smaller than the found distance keep their attribute value.

Tester_52: Only let species pass with a value

AttributeManager_38: supplies tree species

DuplicateFilter_6: Makes sure that no duplicate tree species pass the filter.

Tester_8: Always let species pass which are able to grow above parking spaces.

2.7 Playground filter

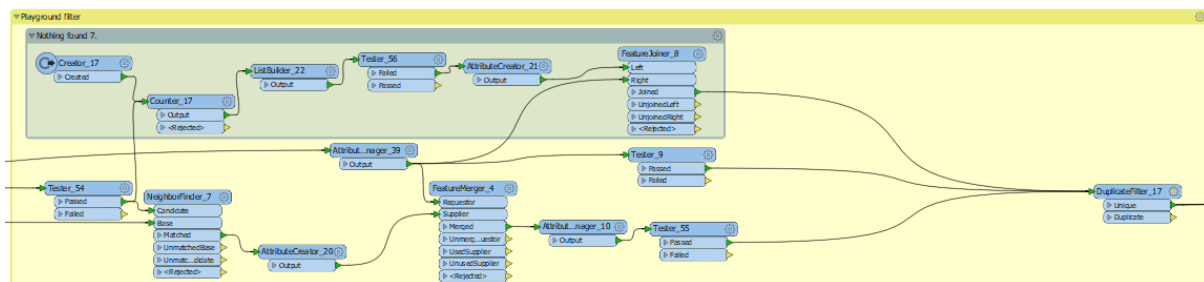


Figure A 9. Playground filter

Bookmark “Nothing found 7” counts the incoming attributes and enables all tree species to go through when no playground is found, when there is a playground found, no species go through. Creator_17 creates one feature, counter_17 counts all incoming features, when it is more than one, the featureJoiner_8 is not able to let the tree species pass the filter. When only one feature is counted, it is the feature created by Creator_17, so no playground is found. When more than 1 feature is counted, the analysis continues in the other part of the playground filter.

Tester_54: only let playground features pass

NeighborFinder_7: finds the closest distance from the tree base to the closest playground

AttributeCreator_20: enables merge

FeatureMerger_4: merge the found tree-playground distance to the tree species

AttributeManager_10: Only let tree species with a crown radius smaller than the found distance keep their attribute value.

Tester_55: Only let species pass with a value

AttributeManager_39: supplies tree species

DuplicateFilter_17: Makes sure that no duplicate tree species pass the filter.

Tester_9: Always let species pass which are able to grow above parking spaces (which have the same criteria as playground species)

2.8 Residential area filter

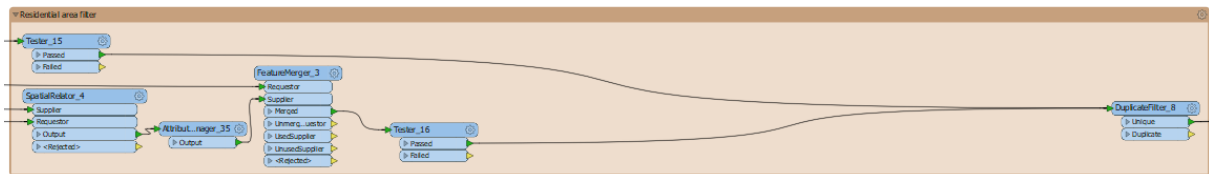


Figure A 10. Residential area filter

Tester_15: always let species, which do not trigger allergic reactions at citizens, pass.

SpatialRelator_4: looks if the location is in a residential area

AttributeManager_35: looks if the location is in a residential area

FeatureMerger_3: merge species if no residential area is found

Tester_16: only let species pass which are not able to grow in a residential area

2.9 Light clay filter

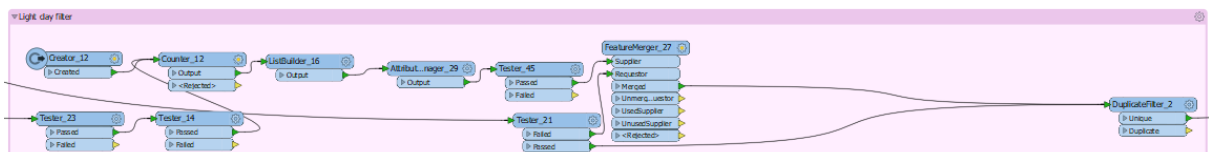


Figure A 11. Light clay filter

Tester_23: only let spatial clay features pass

Tester_14: only let spatial light clay and sea clay features pass

Creator_12: create one feature

Counter_12: Counts features

ListBuilder_16: make a list of all found features

AttributeManager_29: If the second feature in the list has a value, light clay is found, and the attribute is assigned the value "Yes"

Tester_45: features are only able to pass this filter if AttributeManager_29 assigned the value "Yes"

FeatureMerger_27: merge features if no spatial light clay features are found, enabling all species to pass the filter, if spatial light clay features are found, the featureMeger_27 will not merge the tree species, blocking them from passing through the filter

DuplicateFilter_2: makes sure no duplicate species leave this filter

Tester_21: always let light clay species pass

2.10 Heavy clay filter

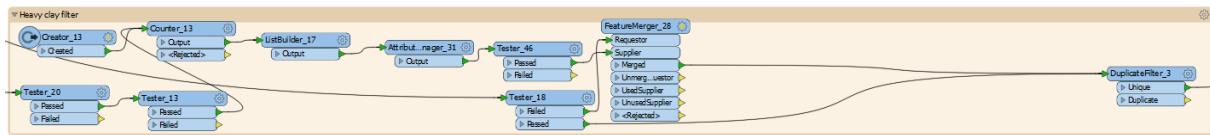


Figure A 12. Heavy clay filter

Tester_20: only let spatial clay features pass

Tester_13: only let spatial heavy clay features pass

Creator_13: create one feature

Counter_13: Counts features

ListBuilder_17: make a list of all found features

AttributeManager_31: If the second feature in the list has a value, the attribute is assigned the value "Yes"

Tester_46: features are only able to pass this filter if AttributeManager_29 assigned the value "Yes"

FeatureMerger_28: merge features if no spatial heavy clay features are found, enabling all species to pass the filter, if spatial heavy clay features are found, the featureMeger_28 will not merge the tree species, blocking them from passing through the filter

DuplicateFilter_3: makes sure no duplicate species leave this filter

Tester_18: always let heavy clay species pass

2.11 Peat filter

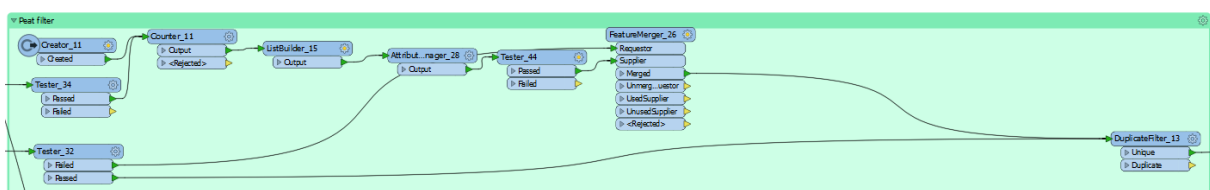


Figure A 13. Peat filter

Tester_34: only let spatial peat features pass

Tester_32: always let tree species able to grow on peat pass, sent the species unable to grow on peat to the featureMerger, when no spatial peat features are found, all species leave the featureMerger

Creator_11: create one feature

Counter_11: Counts features

ListBuilder_15: make a list of all found features

AttributeManager_28: If the second feature in the list has a value, the attribute is assigned the value "Yes"

Tester_44: features are only able to pass this filter if AttributeManager_29 assigned the value “Yes”

FeatureMerger_26: merge features if no spatial light clay features are found, enabling all species to pass the filter, if spatial peat features are found, the featureMeger_26 will not merge the tree species, blocking them from passing through the filter.

DuplicateFilter_13: makes sure no duplicate species leave this filter

2.12 Surface water filter

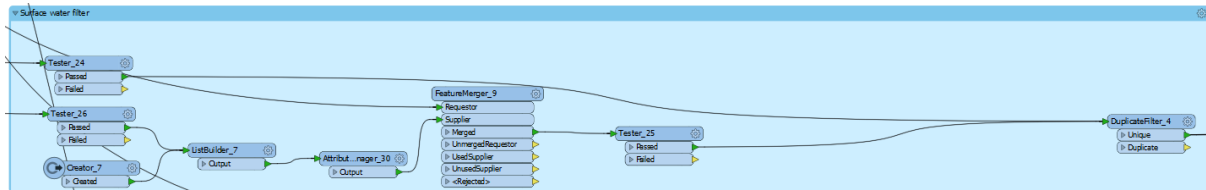


Figure A 14. Surface water filter

Tester_24: always let species pass which are able to grow in very wet soils

Tester_26: only let spatial surface water features pass

Creator_7: creates a point feature

ListBuilder_7: Builds a list of incoming features

AttributeManager_30: creates new attribute, if the list from listbuilder_7 contains a surface water feature, the new attribute is assigned the value “Yes” and no merge is possible. If no surface water features are found, the attribute is assigned the value “No”, and a merge is possible, letting a tree species pass

FeatureMerger_9: merges tree species and letting them pass if no surface water is found, if there is surface water found, no merge is possible.

Tester_25: only let tree species pass that are not able to grow in wet soils

DuplicateFilter_4: makes sure no duplicate species leave this filter

2.13 Groundwater filter

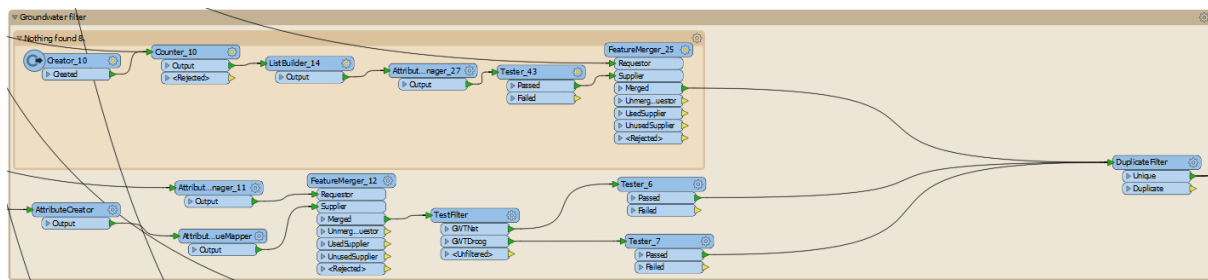


Figure A 15. Groundwater filter

Bookmark “Nothing found 8” counts the incoming attributes and enables all tree species to go through when no groundwater step is found, when there is a groundwater step found, no species go through. Creator_10 creates one feature, counter_10 counts all incoming features, when it is more than one, the featuremerger_25 is not able to let the tree species pass the filter. When only a single feature is counted, it is the feature created by Creator_10, so no groundwater step is found. When more than 1 feature is counted, the analysis continues in the other part of the groundwater step filter.

AttributeCreator: Create new attribute to enable merge.

AttributeValueMapper: Renames the groundwater steps from roman alphabet to numeric values.

AttributeManager_11: Creates two new attributes, one named “GWTWetRange” is assign values to tree species based on the sensitivity for soil moisture. Tree species suitable for very wet soils and unsensitive for flooding, are assigned a value of 0.5. Tree species suitable for wet soils get a value of 2 and all other species are assigned a value of 3. The second attribute created is called “GWTDryRange” and is assigned values based on tree species sensitivity for dry soils. When a tree species is suitable for very dry soils, it is assigned the value 9, when the species is suitable for dry soils, it is assigned the value 8, all other tree species get the value 7.

FeatureMerger_12: Merges the groundwater step to the tree species.

TestFilter: When a groundwater step lower than 6 is found the tree species go to the “wet” output port, when groundwater step 6 or higher is found, the species are sent to the “dry” output port.

When arriving in the “wet” output port, all tree species with a value lower than the groundwater step are suitable. For example: when a groundwater step 1 is found, only tree species with a value of 0.5 are able to pass the filter. When groundwater step 3 is found, all tree species with value 0.5 and 2 are able to pass the filter. When groundwater step 4 is found, all tree species are able to pass the filter. When arriving in the “dry” output port, all tree species with a value higher than the groundwater step are suitable. For example: When groundwater step 8 is found, only tree species with value 9 are able to pass the filter. When groundwater step 7 is found, tree species with value 8 or 9 are able to pass the filter. When groundwater step 6 is found, all tree species are able to pass the filter.

Tester_6: Only let tree species pass if their “GWTWetRange” value is lower than the groundwater step and Tester_7: Only let tree species pass if their “GWTDryRange” value is higher than the groundwater step.

DuplicateFilter: Makes sure no duplicate species leave this filter.

2.14 Organic matter filter

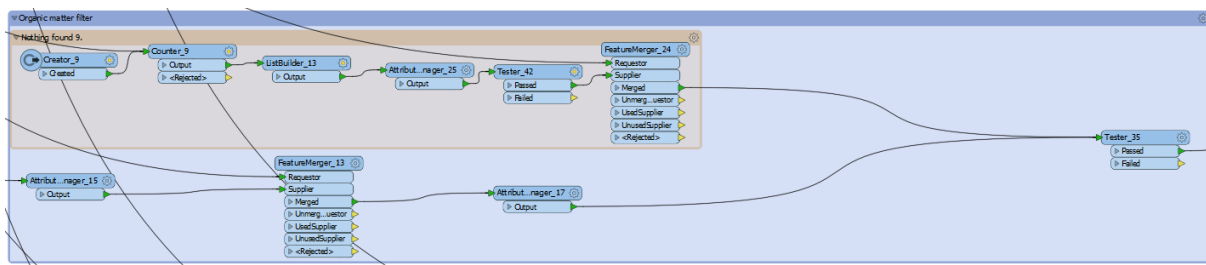


Figure A 16. Organic matter filter

Bookmark “Nothing found 9” counts the incoming attributes and enables all tree species to go through when no organic matter value is found, when there is an organic matter value found, no species go through. Creator_9 creates one feature, counter_9 counts all incoming features, when it is more than one, the featuremerger_24 is not able to let the tree species pass the filter. When only a single feature is counted, it is the feature created by Creator_9, so no organic matter value is found and all species are able to pass the filter. When more than 1 feature is counted, the analysis continues in the other part of the organic matter filter.

AttributeManager_15: Classifies the incoming soil types from the BOFEK2012 map as fertile, unfertile and everything. Everything, means no clear classification could be made and all tree species are able to pass the filter. Soil type number 301, 303, 304, 307, 308, 309, 310, 311, 312, 313, 315, 316, 317, 318, 319, 320, 321, 322, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 102, 103, 104, 106, 108, 109, 201, 202, 203, 204, 205, 206, 501, 502, 503, 504, 505, 506, 507 are classified as everything. Soil type number: 302, 305, 306, 314, 323, 324, 325, 326, 327, 105, 107 and 110 are classified as unfertile and soil type number 402, 403, 404, 405, 406, 407 and 101 as fertile. Soil type number 999 and 998 are classified as everything because it implies water or urban area and further analysis in the real world is required.

FeatureMerger_13: Merge the found soil fertility value to the tree species

AttributeManager_17: To determine which tree species are suitable, the tree species attribute “soil fertility” has to contain the found soil fertility value. Tree species suitable for the analyzed soil fertility are assigned the value “Yes”, other species the value “No”.

Tester_35: Only let tree species pass with the value “Yes”

2.15 Tree assortment filter

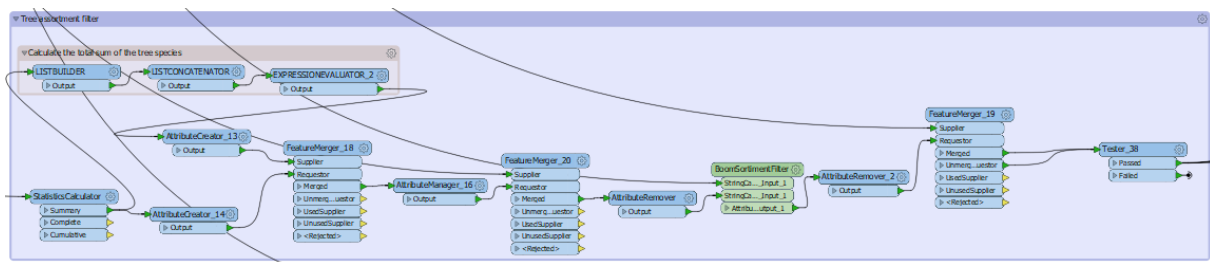


Figure A 17. Tree assortment filter

Bookmark “Calculate the total sum of the tree species in comparison to the total stand” calculates the total sum of tree species

AttributeCreator_13: Create new attribute to enable merge.

StatisticsCalculator: Counts the number of trees per tree species

Attributecreator_14: Create new attribute to enable merge.

FeatureMerger_18: Merge number of tree species with the sum of tree species

AttributeManager_16: Calculates the percentage per tree species compared to the total sum.

FeatureMerger_20: Merges the calculated percentages with the tree database within the municipality.

AttributeRemover: Removes unnecessary attributes.

BoomSortimentFilter: Trim all special characters from both databases to enable merge

AttributeRemover_2: Removes unnecessary attributes.

FeatureMerger_19: Merge the municipality tree database with the tree species database

Tester_38: Only let species pass with a calculated percentage lower than 5%.

2.16 Salt filter

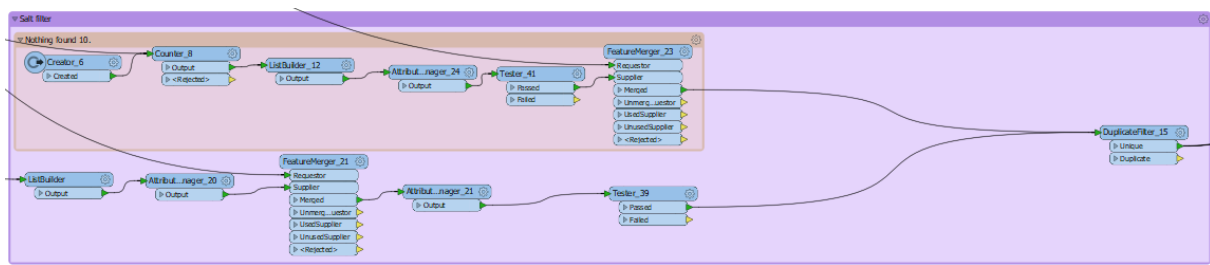


Figure A 18. Salt filter

Bookmark “Nothing found 10” counts the incoming attributes and enables all tree species to go through when no heavily used roads are found, when there are heavily used roads found, no species go through. Creator_6 creates one feature, counter_8 counts all incoming features, when it is more than one, the featuremerger_23 is not able to let the tree species pass the filter. When only a single feature is counted, it is the feature created by Creator_9, so no heavily used roads are found and all species are able to pass the filter. When more than 1 feature is counted, the analysis continues in the other part of the heavily used roads filter.

ListBuilder: Builds list of incoming road features

AttributeManager_20: Create new attribute and scan list if it contains heavily used roads, if found, the new attributes are assigned the value “Yes”, otherwise “No”

FeatureMerger_21: Merges tree species if the assigned value is “Yes”, enabling to pass through. If not merged, tree species will not be able to pass the filter.

AttributeManager_21: Creates new attribute, if heavily used roads are found, the attribute is assigned the value “strooizout” (salt).

Tester_39: Only let species unsensitive for salt pass the filter.

DuplicateFilter_15: Makes sure no duplicate species leave this filter.

Appendix III. Overview step 3

3.1 Output 1

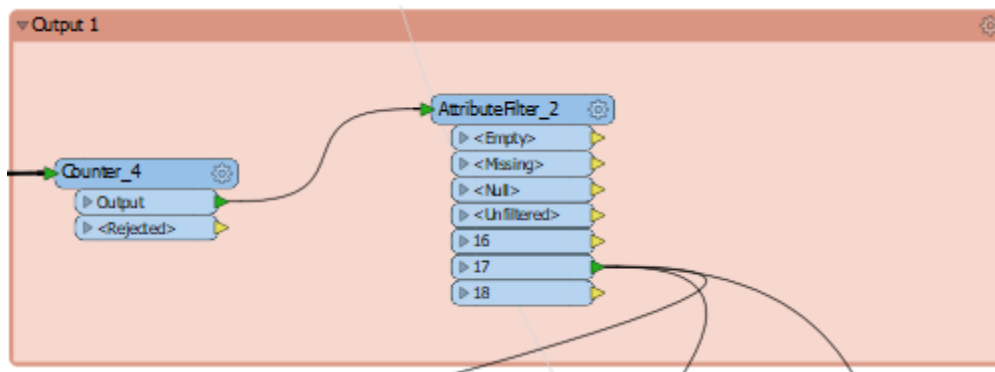


Figure A 19. output 1

Counter_4: Counts how many times a specific tree species is passing the filter

Attribute filter_2: Filters the number of times a tree species is counted. If a tree species is counted 17 times, the analysis moves on to step 3.4 with all species which are counter 17 times. If no species are counted 17 times, the analysis moves on to step 3.2.

3.2 Output 2

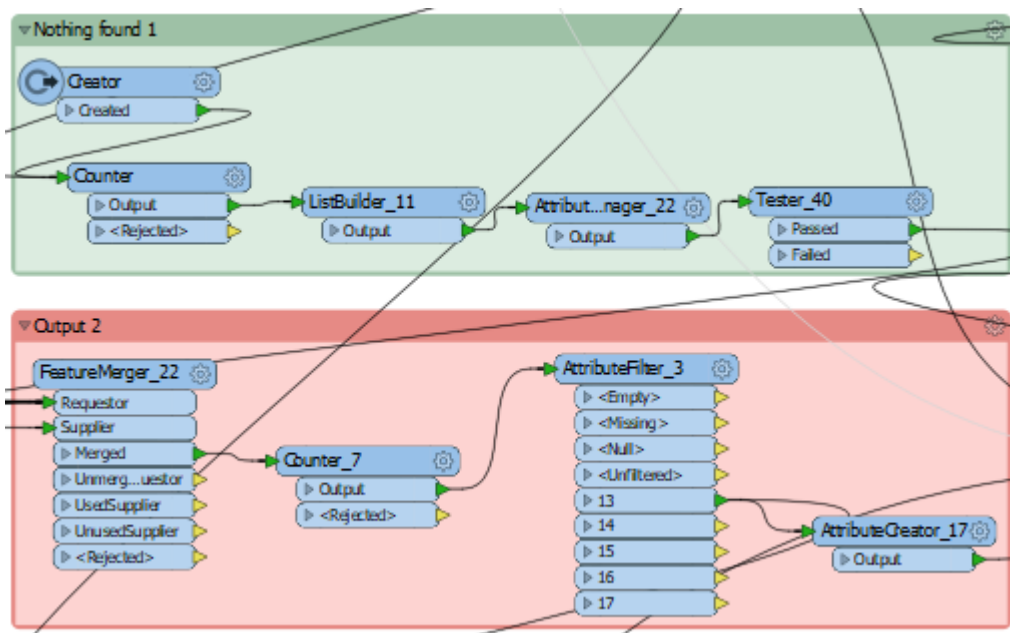


Figure A 20. Output 2

Bookmark "Nothing found 1"

Creator: Creates one feature.

Counter: Counts incoming features.

ListBuilder_11: Build list of incoming features.

AttributeManager_22: Creates two new attributes. Attribute 1 enables the merge. Attribute 2 is assigned the value "No" if no second feature is found, meaning no suitable species passed the "Output 1" filter and the analysis will continue with step 2. If there are multiple features counted, the attribute is assigned the value "Yes", meaning there are already suitable species found and the analysis will continue with step 3.4.

Tester_40: Blocks features if suitable species are already found. Let features pass through if no suitable species have been found.

Bookmark "Output 2"

FeatureMerger_22: Merge attribute from "Nothing found 1" to the new species. If there were already suitable species found, the merge will not be possible and this filter stops. If no suitable species have been found in step 3.1, the merge will be possible.

Counter_7: Counts all incoming tree species excluding the soil type filters and the soil fertility filter.

AttributeFilter_3: Filters the number of times a tree species is counted. If a tree species is counted 13 times, the analysis moves on to step 3.4 with all species counted 13 times. If no species are counted 13 times, the analysis moves on to step 3.3.

AttributeCreator_17: Enables merge if suitable species are found.

3.3 Output 3

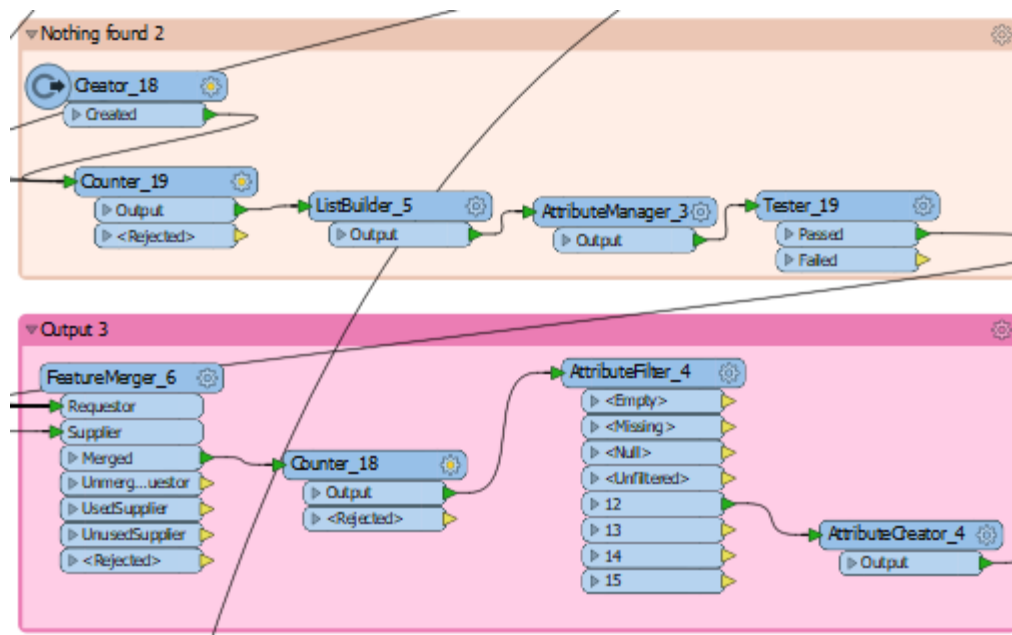


Figure A 21. Output 3

Bookmark "Nothing found 2"

Creator_18: Creates one feature.

Counter_19: Counts incoming features.

ListBuilder_5: Build list of incoming features.

AttributeManager_3: Creates two new attributes. Attribute 1 enables the merge. Attribute 2 is assigned the value "No" if no second feature is found, meaning no suitable species passed the "Output 1" filter and the analysis will continue with step 2. If there are multiple features counted, the attribute is assigned the value "Yes", meaning there are already suitable species found and the analysis will continue with step 3.4.

Tester_19: Blocks features if suitable species are already found. Let features pass through if no suitable species have been found.

Bookmark "Output 2"

FeatureMerger_6: Merge attribute from "Nothing found 1" to the new species. If there were already suitable species found, the merge will not be possible and this filter stops. If no suitable species have been found in step 3.2, the merge will be possible.

Counter_18: Counts all incoming tree species excluding the soil type filters, soil fertility filter and residential area filter.

AttributeFilter_4: Filters the number of times a tree species is counted. If a tree species is counted 12 times, the analysis moves on to step 3.4 with all species counted 12 times. If no species are counted 12 times, the MDMT will not return any suitable species for the location.

AttributeCreator_4: Enables merge if suitable species are found.

3.4 HTML creator

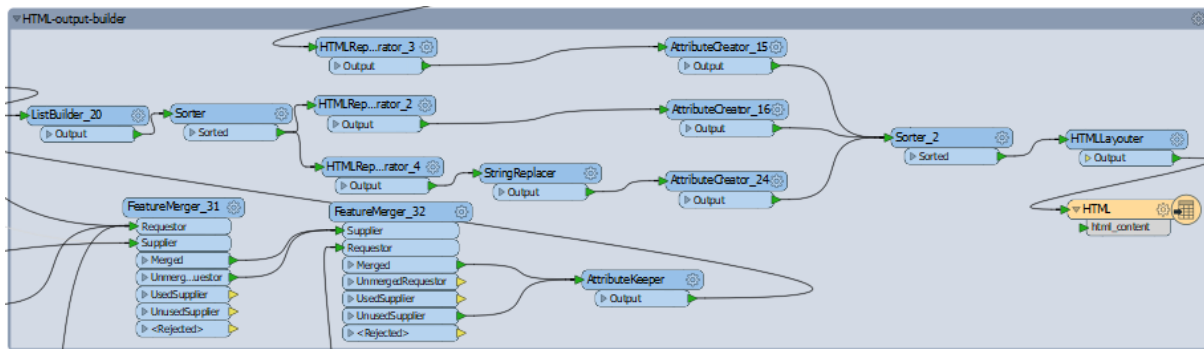


Figure A 22. Output 4

FeatureMerger_31: Merge assortment percentage to the suitable tree species found in step 3.1, 3.2 or 3.3.

FeatureMerger_32: Merge photos with the suitable plant species

AttributeKeeper: Only keeps the necessary attributes used as information for the urban foresters and citizens.

ListBuilder_20: Build a list of all attributes per tree species.

Sorter: Sort tree species on their effect on filtering particulates from the air.

HTMLReportGenerator_4: Generates an overview per suitable species, displaying all attributes and 5 photos. If there a not 5 photos available, the text "No pictures available" will appear.

StringReplacer: Removes the alternative text "No pictures available"

AttributeCreator_24: gives the value 3, meaning it will be the third to be displayed.

HTMLReportGenerator_2: Generates an overview of all suitable tree species, storing them into one database displayed before the individual tree species information.

AttributeCreator_16: gives the value 2, meaning it will be the second to be displayed.

HTMLReportGenerator_3: Generates an overview of all spatial data found surrounding the tree, derived from step 3.6.

AttributeCreator_15: gives the value 1, meaning it will be the first to be displayed.

Sorter_2: Sorts the generated HTML pages into the sequence appointed by the AttributeCreators.

HTMLLayouter: Generate page title and horizontal layout.

HTML: HTML is the final output writer. A pop-up HTML page will appear when the analysis is ready.

3.5 Photo merge

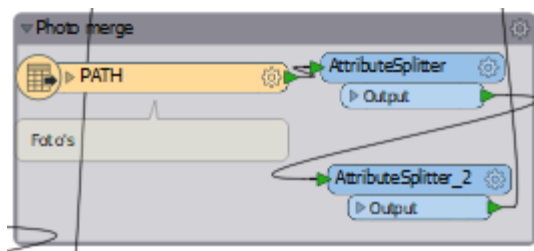


Figure A 23. Photo merge

PATH: Reads in all photos

AttributeSplitter: Split the photo path name to derive the scientific plant name.

AttributeSplitter_2: Split the photo path name to derive the scientific plant name.

3.6 Spatial logger

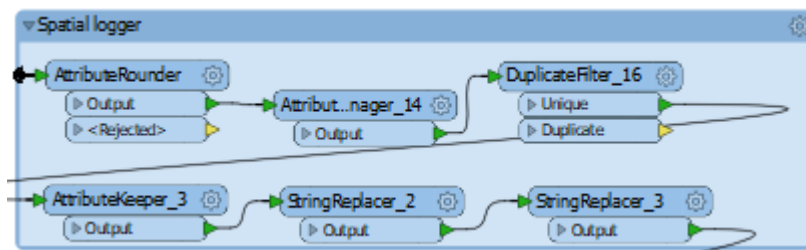


Figure A 24. Spatial logger

AttributeRounder: Round the incoming attributes. The attributes to round of are distance to building, sewer, lamppost, roads, sidewalks and the calculated tree species percentages of the total stand.

AttributeManager_14: Collect all spatial attributes surrounding the tree and writes them into a list

DuplicateFilter_16: Removes duplicates from the list.

AttributeKeeper_3: Only keeps the created list in AttributeManager_14.

StringReplacer_2: Removes the character: (, surrounding the imported values.

StringReplacer_3: Removes the character:) surrounding the imported values.

Appendix IV. Database overview

Link to database: <https://1drv.ms/f/s!AoDeprBCnhyFbN6EEyuC5ehME2g>

Vetenschappelijke naam	NederlandseNaam	Locatie
<i>Cornus officinalis</i> 'Robin's Pride'	Chinese vuurjaarskonroel 'Robin's Pride'	park/groenstrook/grote tuin/klieve tuin/patio/tuin
<i>Crataegus coccinea</i>	Meidoorn	straat/landelijk/grote tuin/klieve tuin
<i>Crataegus pubescens</i> f. <i>stipulacea</i>	Meidoorn	park/groenstrook/grote tuin/klieve tuin/begrasplaats/ecologische zone
<i>Crataegus</i> » <i>laevifolia</i> 'Lanierer'	Meidoorn	straat/park/groenstrook/grote tuin/klieve tuin/veekeer, industrie/uitgebied
<i>Elaeagnus umbellata</i>	Oliefijg	park/groenstrook/grote tuin/klieve tuin/begrasplaats/veekeer, industrie
<i>Ilex</i> » <i>koehorniana</i>		park/grote tuin/uitgebied
<i>Magdolia</i> » <i>bedfordii</i>		park/groenstrook/grote tuin/klieve tuin
<i>Picea abies</i> 'Pendula'		park/grote tuin
<i>Pinus sylvestris</i> 'Glaucia'		park/groenstrook/grote tuin/klieve tuin/veekeer, industrie/uitgebied
<i>Prunus padus</i> 'Nana'		straat/park/groenstrook/klieve tuin
<i>Prunus padus</i> 'Tiefurt'	Vogelkers 'Tiefurt'	straat/landelijk/park/groenstrook
<i>Pseudotsuga menziesii</i> var. <i>glauca</i>		park/grote tuin
<i>Pterocarya staneyana</i>	Chinese vleugelhout	straat/landelijk/park/viad
<i>Quercus palustris</i> 'Green Dwarf'		grote tuin/klieve tuin
<i>Salix alba</i> 'Biarlo'		land/park/groenstrook/grote tuin/begrasplaats/landschap/ecologische zone/viad
<i>Salix babingtonii</i> 'Tortuosa'		klein/park/groenstrook/grote tuin/klieve tuin/ecologische zone/viad
<i>Sequoia dendenron giganteum</i> 'Glaucum'		park/grote tuin/begrasplaats
<i>Sorbus aucuparia</i> 'Fastigiata'	Zukomige kriebes	straat/park/groenstrook/grote tuin/klieve tuin/begrasplaats
<i>Abies procera</i>	Nobilis con. edelhout	park/groenstrook/grote tuin/begrasplaats/veekeer, industrie
<i>Arucaria araucana</i>	Slangenden, sparboom	park/grote tuin/begrasplaats
<i>Abutilon undedo</i>	Asterboom	park/daunt/grote tuin/klieve tuin/veekeer, industrie/uitgebied
<i>Chamaecyparis pisifera</i> 'Aurea'		grote tuin/klieve tuin/begrasplaats
<i>Firmiana simplex</i>		park/groenstrook/grote tuin/klieve tuin
<i>Juniperus communis</i> 'Suecica'	Zur-jeneverbes	park/groenstrook/grote tuin/klieve tuin/patio/tuin/begrasplaats
<i>Kalanchoe septemlobus</i> var. <i>maximowiczii</i>		park
<i>Larix decidua</i> 'Pendula'		park/groenstrook/grote tuin/klieve tuin
<i>Malus domestica</i> 'Golden Pearmain'	Nagarsappel 'Golden Pearmain'	park/groenstrook/balken/containers/edeltuin/grote tuin/klieve tuin/patio/tuin/landschap
<i>Nerium oleander</i>		park/balken/containers/grote tuin/patio/tuin
<i>Picea abies</i>	Finpaar	park/groenstrook/grote tuin/begrasplaats/landschap/uitgebied
<i>Picea engelmannii</i>		park/grote tuin/klieve tuin
<i>Picea omorika</i>	Servische spar	park/groenstrook/grote tuin/begrasplaats/veekeer, industrie
<i>Pinus densiflora</i>	Japane roden den	park/groenstrook/grote tuin/klieve tuin
<i>Pinus heldreichii</i>		park/grote tuin
<i>Pinus mugo</i> 'Montana'		park/groenstrook/balken/containers/edeltuin/grote tuin/klieve tuin/patio/tuin/begrasplaats/uitgebied
<i>Pinus peuce</i>		park/grote tuin/veekeer, industrie
<i>Pinus sylvestris</i> 'Norska'	Pirnbom 'Norska', Grove den 'Norska'	park/groenstrook/balken/containers/edeltuin/grote tuin/begrasplaats/veekeer, industrie/landschap/vindingsgelukgebied
<i>Pinus vallichiana</i>		park/grote tuin/begrasplaats
<i>Pseudolarix amabilis</i>		park/grote tuin
<i>Pyrus communis</i> subsp. <i>caucasica</i>	Kalkastische peer	land/park/groenstrook/balken/containers/edeltuin/grote tuin/veekeer, industrie/landschap/vindingsgelukgebied
<i>Quercus suber</i>	Kuriek	park/groenstrook/grote tuin/veekeer, industrie/uitgebied
<i>Robinia pseudoacacia</i> 'Bessoniata'		straat/landelijk/park/veeplaats/park/groenstrook/balken/containers/grote tuin/begrasplaats/veekeer, industrie
<i>Robinia pseudoacacia</i> 'Sandaulga'	Schnjapacide 'Sandaulga'	straat/landelijk/park/groenstrook/edeltuin/grote tuin/begrasplaats/veekeer, industrie

Figure A 25. Database part 1.

Verharding	Hoogte Breechi Vinter/ Vind	Grondsoort	Voedselrijkdom	Bodemvochtigheid	Lichtbehoefte	pH-waarde	Ph-Ran	Vaardplant/voeds	
geen	5-6	3-4	5A-5B	verdaagt matige vind/verdaagt vind	zavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	5-7	4-5	5A-5B	verdaagt matige vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	4-8	4-8	7A-7B	verdaagt vind	zavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen/lopendicht	5-7	4-5	5A-7B	verdaagt geen vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog	zon	zavelneutraal/basisch
geen/lopendicht	3-4	2-3	4A-5B	verdaagt vind/verdaagt zeevind	loetzandflemige grond	matigvoedselijk	droog	zon	zavelneutraal/basisch
geen	4-6	2-3	6A-5B	verdaagt vind	alle grondsoorten	matigvoedselijk	droog	zon	
geen	5-8	3-5	5A-5B	verdaagt geen vind	zavel/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen/lopendicht	3-4	2-3	3A-5B	verdaagt geen vind	zavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen/lopendicht	5-8	5-8	3A-5B	verdaagt vind/verdaagt zeevind	loetzavelveerlichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen/lopendicht	3-4	2-3	3A-5B	verdaagt geen vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	12-18	4-5	5A-7B	verdaagt vind	zavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen/lopendicht	12-18	14-20	6A-8B	verdaagt matige vind	zavel/alle klei/zandflemige grond	matigvoedselijk	vochtig/nat	zon	zavelneutraal/basisch
geen	3-4	1-2	5A-5B	verdaagt vind	alle grondsoorten	matigvoedselijk	droog	zon	zavelneutraal
geen/lopendicht	20-25	10-12	4A-5B	verdaagt vind	alle grondsoorten	matigvoedselijk	vochtig/nat	zon	zavelneutraal
geen	15-30	6-7	7A-5B	verdaagt matige vind/verdaagt vind	zavel/alle klei/lothe klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	7-8	2-4	4A-5B	verdaagt vind	rand/alle grondsoorten	matigvoedselijk	droog	zon	zavelneutraal
geen	20-25	6-8	5A-5B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	20-30	15-25	6B-5B	verdaagt vind	loetzavel/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal
geen/lopendicht	5-8	6-8	7B-5B	verdaagt vind/verdaagt zeevind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	3-5	1-2	5A-7B	verdaagt vind	zavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig/nat	zon	zavelneutraal/basisch
geen	3-12	6-9	7A-5B	verdaagt matige vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal/basisch
geen	3-5	1-2	3A-7A	verdaagt vind	loetzavelveer/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	4-7	4-7	4A-7B	verdaagt vind	zavelveer/lothe klei/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal
geen	3-4	2-3	4A-7B	verdaagt geen vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen/lopendicht	4-6	2-4	4A-8B	verdaagt matige vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	3-6	1-3	8A-7B	verdaagt vind/verdaagt zeevind	zavellichte klei/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal
geen	30-35	9-12	3B-8B	verdaagt vind/verdaagt matige zeevind	loetzave alle klei/lothe klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen	15-20	3-6	2B-7B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen	15-25	2-4	4A-5B	verdaagt geen vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	10-15	10-15	6B-7B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen	6-10	3-6	6A-5B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	2-4	1,5-3,5	4A-7B	verdaagt vind/verdaagt zeevind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog	zon	zavelneutraal
geen	10-15	4-6	5A-8B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	8-10	6-8	2A-5B	verdaagt vind/verdaagt zeevind	loetzavelveer/zandflemige klei/lothe klei/zandflemige grond/alle grondsoorten	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen	15-30	20-40	5A-7B	verdaagt geen vind	loetzavelveer/zandflemige grond	matigvoedselijk	droog	zon	zavelneutraal
geen/lopendicht	12-18	7-10	4A-5B	verdaagt vind/verdaagt zeevind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen	10-18	10-18	8A-11A	verdaagt vind/verdaagt zeevind	zavel/alle klei/lothe klei/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal
geen/lopendicht	15-20	10-15	5A-5B	verdaagt matige vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen/lopendicht	15-20	10-15	5A-5B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	6-8	4-6	5A-5B	verdaagt vind	zavellichte klei/zandflemige grond	matigvoedselijk	vochtig/nat	zon	zavelneutraal/basisch
geen	7-10	5-9	5B-7B	verdaagt matige vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal
geen	6-10	5-9	5B-7B	verdaagt vind/verdaagt zeevind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	25-30	10-12	5A-5B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen	12-15	6-8	5B-5B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen	25-30	6-8	5A-5B	verdaagt vind	loetzavellichte klei/zandflemige grond	matigvoedselijk	droog/vochtig	zon	zavelneutraal
geen/lopendicht	6-10	6-8	6B-5A	verdaagt matige vind/verdaagt matige zeevind	loetzavellichte klei/zandflemige grond	matigvoedselijk	vochtig	zon	zavelneutraal/basisch
geen/lopendicht	3-5	3-5	5A-5A	verdaagt vind/verdaagt zeevind	loetzavelveer/zandflemige klei/lothe klei/zandflemige grond/alle grondsoorten	matigvoedselijk	droog/vochtig	zon	zavelneutraal/basisch
geen/lopendicht	10-12	7-8	5A-5B	verdaagt vind/verdaagt zeevind	loetzavellichte klei/zandflemige grond	matigvoedselijk	nat	zon	zavelneutraal/basisch

Figure A 26. Database part 2.

Figure A 27. Database part 3.

Figure A 28. Database part 4.

Beplantingsconcepten	Overige beplanting	Zelfbestuiver	Overig	Maatloos	Maatloos	Parkplaats	Voorwijk	Verharding2	Vuist opduik	ZwaartKie	LichteKie	Groenstrook	ZeeNet	Park	Breedte	Aangepas	V
				6	4	Ja	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		2,4	8
				7	6	Nee	Ja	Nee	Nee	Nee	Ja	Nee	Nee	Ja		3,6	8
				8	6	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		4,8	8
				7	6	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		3,6	8
			verdaag: doogtelverdaag: lichtevoering	4	3	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		1,8	8
			verdaag: stroozoufverdaag: doogtelverdaag: lichtevoering	6	3	Nee	Ja	Nee	Nee	Ja	Nee	Nee	Nee	Ja		1,8	8
			verdaag: doogte	8	8	Nee	Ja	Ja	Nee	Nee	Nee	Ja	Nee	Ja		4,8	8
			verdaag: lichtevoering	5	5	Nee	Nee	Ja	Nee	Nee	Ja	Nee	Nee	Ja		3	8
				15	8	Nee	Nee	Nee	Nee	Nee	Ja	Ja	Nee	Ja		4,8	8
				4	3	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		1,8	8
			verdaag: doogte	12	8	Nee	Ja	Ja	Nee	Nee	Nee	Ja	Nee	Ja		4,8	8
			verdaag: stroozouf	18	8	Nee	Ja	Nee	Nee	Nee	Ja	Nee	Nee	Ja		4,8	8
			verdaag: kortstondige overstroming	18	20	Nee	Ja	Ja	Nee	Ja	Nee	Nee	Nee	Ja		12	8
			verdaag: stroozouf	4	2	Nee	Nee	Nee	Nee	Ja	Nee	Nee	Nee	Ja		1,2	8
			verdaag: doogtelverdaag: lichtevoering/verdaag: kortstondige overstroming	25	20	Nee	Nee	Nee	Nee	Ja	Nee	Ja	Ja	Ja		12	8
			verdaag: kortstondige overstroming	12	8	Nee	Nee	Nee	Nee	Ja	Ja	Ja	Ja	Ja		4,8	8
			verdaag: doogte	30	7	Nee	Ja	Nee	Nee	Nee	Ja	Nee	Nee	Ja		4,2	8
			verdaag: lichtevoering	8	4	Nee	Ja	Nee	Nee	Ja	Nee	Ja	Nee	Ja		2,4	8
			verdaag: lichtevoering	25	8	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		4,8	8
			verdaag: doogtelverdaag: lichtevoering	30	25	Nee	Ja	Nee	Nee	Nee	Nee	Nee	Nee	Ja		15	8
				8	8	Nee	Nee	Nee	Ja	Nee	Ja	Nee	Nee	Ja		4,8	8
				5	2	Nee	Ja	Ja	Nee	Nee	Ja	Nee	Nee	Ja		1,2	8
				12	8	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		5,4	8
				5	2	Ja	Nee	Nee	Nee	Nee	Nee	Ja	Nee	Ja		1,2	8
				7	7	Nee	Ja	Ja	Nee	Nee	Ja	Nee	Nee	Ja		4,2	8
				4	3	Nee	Ja	Ja	Nee	Nee	Ja	Ja	Nee	Ja		1,8	8
			ja	6	4	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		2,4	8
				35	12	Nee	Nee	Nee	Nee	Nee	Ja	Nee	Nee	Ja		1,8	8
			verdaag: doogtelverdaag: lichtevoering	20	6	Nee	Nee	Ja	Nee	Nee	Ja	Nee	Nee	Ja		3,6	8
			verdaag: doogtelverdaag: lichtevoering	25	4	Nee	Nee	Nee	Nee	Nee	Ja	Ja	Nee	Ja		2,4	8
			verdaag: doogte	15	15	Nee	Nee	Nee	Nee	Nee	Ja	Ja	Nee	Ja		9	8
			verdaag: doogte	10	6	Nee	Nee	Ja	Nee	Nee	Ja	Nee	Nee	Ja		3,6	8
				4	3,5	Nee	Nee	Nee	Nee	Nee	Ja	Ja	Nee	Ja		2,1	8
			verdaag: doogtelverdaag: lichtevoering	15	6	Nee	Nee	Nee	Nee	Nee	Ja	Nee	Nee	Ja		3,6	8
			verdaag: doogtelverdaag: lichtevoering/verdaag: hite	12	8	Nee	Nee	Nee	Ja	Ja	Ja	Ja	Nee	Ja		4,8	8
			verdaag: doogte	30	40	Nee	Nee	Ja	Nee	Nee	Nee	Nee	Nee	Ja		10,8	8
				12	8	Nee	Ja	Ja	Nee	Nee	Nee	Nee	Nee	Ja		4,8	8
			verdaag: lichtevoering	18	10	Nee	Ja	Ja	Nee	Ja	Ja	Ja	Nee	Ja		6	8
			verdaag: stroozoufverdaag: lichtevoering	18	18	Nee	Nee	Nee	Nee	Ja	Ja	Ja	Nee	Ja		10,8	8
			verdaag: stroozoufverdaag: doogtelverdaag: lichtevoering	20	15	Nee	Nee	Nee	Ja	Nee	Ja	Ja	Nee	Ja		9	8
			verdaag: stroozoufverdaag: doogtelverdaag: lichtevoering/verdaag: hite	20	15	Nee	Nee	Nee	Ja	Nee	Ja	Ja	Nee	Ja		9	8
			verdaag: kortstondige overstroming	6	6	Nee	Nee	Nee	Nee	Ja	Ja	Nee	Nee	Ja		3,6	8
			verdaag: lichtevoering	10	6	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		3,6	8
			verdaag: doogte	10	9	Nee	Ja	Nee	Nee	Nee	Ja	Nee	Nee	Ja		5,4	8
			verdaag: doogte	10	9	Nee	Ja	Nee	Nee	Nee	Ja	Nee	Nee	Ja		5,4	8
			verdaag: lichtevoering	30	12	Nee	Nee	Nee	Ja	Nee	Ja	Ja	Nee	Ja		7,2	8
				15	6	Nee	Nee	Nee	Ja	Nee	Ja	Nee	Nee	Ja		4,8	8
			verdaag: lichtevoering	30	8	Nee	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		4,8	8
			verdaag: doogtelverdaag: lichtevoering/verdaag: hite	10	8	Nee	Nee	Nee	Ja	Nee	Ja	Ja	Nee	Ja		4,8	8
			verdaag: stroozoufverdaag: doogtelverdaag: lichtevoering/verdaag: hite	5	5	Ja	Nee	Nee	Ja	Ja	Ja	Ja	Nee	Ja		3	8
			verdaag: stroozoufverdaag: lichtevoering	12	6	Ja	Ja	Nee	Nee	Nee	Ja	Ja	Nee	Ja		4,8	8

Figure A 29. Database part 5.

Veen	Breedte	Ondergrond	ID	Voetpad	KroonVorm	KroonStructuur	Fijnstof	Schaduw
Nee	1,2	317	Ja	breed ovaal	halfopen	gesloten	2	1,5
Nee	1,4	874	Nee	rond	gesloten	gesloten	1,5	2
Nee	1,6	948	Nee				0,5	0
Nee	1,4	875	Nee	rond	gesloten	gesloten	2	2
Nee	0,8	1143	Nee	rond	halfopen	halfopen	2	1,5
Nee	1,2	1046	Ja	smal piramidaal	gesloten	gesloten	1,5	1
Nee	1,6	742	Nee	breed vaas	halfopen	halfopen	2	1,5
Nee	1	1095	Nee	treur	halfopen	halfopen	2,5	1
Ja	3	493	Nee	piramidaal	gesloten	gesloten	2,5	2
Nee	0,8	1171	Nee	rond	gesloten	gesloten	1,5	2
Nee	2,4	555	Ja	breed eirond	gesloten	gesloten	2	2,5
Nee	3,6	387	Ja				2	1
Nee	3,6	335	Ja	breed ovaal	gesloten	gesloten	2,5	3
Nee	0,8	1183	Ja	afgeplat rond	gesloten	gesloten	1,5	2
Nee	5	78	Ja	breed ovaal	halfopen	halfopen	3,5	2,5
Nee	2,4	495	Ja	eirond	halfopen	halfopen	3	1,5
Nee	6	313	Ja	smal piramidaal	gesloten	gesloten	2,5	2
Nee	1,6	678	Nee	piramidaal			0,5	0,5
Nee	5	131	Nee	smal piramidaal	gesloten	gesloten	2,5	2
Ja	6	40	Ja	breed eirond	open	open	3	2
Nee	1,6	854	Nee	eirond			1,5	0,5
Nee	1	1181	Ja	breed piramidaal	halfopen	halfopen	3	1,5
Nee	2,4	554	Ja	ovaal	halfopen	halfopen	2	1,5
Ja	1	1178	Ja	zuil	gesloten	gesloten	1,5	1
Ja	1,4	960	Ja				0,5	0
Nee	0,8	1164	Nee	treur	halfopen	halfopen	1,5	1
Nee	1,2	1025	Nee	ovaal	halfopen	halfopen	1,5	1
Nee	1,2	1168	Nee				1	0
Nee	7	2	Ja	smal piramidaal	gesloten	gesloten	2,5	2
Nee	4	318	Ja	smal piramidaal	gesloten	gesloten	3,5	2
Nee	5	143	Nee	smal piramidaal	gesloten	gesloten	2,5	2
Nee	3	411	Nee	piramidaal	halfopen	halfopen	3	1,5
Nee	2	789	Nee	piramidaal	open	open	2	1
Nee	0,8	1231	Ja	eirond	gesloten	gesloten	2	1,5
Nee	3	519	Nee	smal piramidaal	gesloten	gesloten	2	1,5
Ja	2,4	608	Nee	breed piramidaal	gesloten	gesloten	3	2,5
Ja	6	155	Nee	breed piramidaal	open	open	3	2
Nee	2,4	620	Nee	piramidaal	open	open	1	1
Nee	3,6	368	Nee				2	1
Nee	3,6	409	Ja	rond	halfopen	halfopen	5,5	2,5
Nee	4	236	Nee	breed eirond	halfopen	halfopen	3	2,5
Nee	4	195	Nee	breed eirond	halfopen	halfopen	3	2,5
Nee	1,6	790	Ja	eirond			0,5	0,5
Nee	2	669	Nee	piramidaal	gesloten	gesloten	2,5	2
Nee	2	716	Ja	rond	open	open	1,5	1,5
Nee	2	721	Ja				0,5	0,5
Nee	6	29	Nee	smal piramidaal	gesloten	gesloten	2,5	2
Ja	3	383	Nee	piramidaal	gesloten	gesloten	2,5	2
Nee	6	30	Nee	smal piramidaal	gesloten	gesloten	2,5	2
Nee	2	616	Ja	rond	halfopen	halfopen	2,5	2
Ja	1	1074	Ja	rond	gesloten	gesloten	1,5	2
Nee	2,4	480	Ja	eirond	gesloten	gesloten	1,5	2

Figure A 30. Database part 6

Appendix V. Obsurv website information

What can you do with Obsurv?

It is a challenge to manage our living and working environment. As an administrator you want to know: which assets do I have? What is the quality? What costs do we have to make in the coming years to maintain it? Obsurv answers these questions and supports the work processes that come with it.

INVENTORY AND INSPECT

Obsurv has various (online) drawing functions that support the employee outside in the field when entering new or modified objects. These drawing functions are limited to what is actually required, nothing more and nothing less. Without complex import and export operations.

Smart planning and budgeting

You do not only want to know where things are, you also want to calculate where more or less can be spent. You always want to keep the quality at an acceptable level. Obsurv offers you the possibility to record different quality levels with the help of the scale bars of the CROW.

With Obsurv you can plan and budget management on a tactical and strategic level. It is easy to draw up a multi-year maintenance plan. It is truly an integral management system: planning and budgeting in one process.

DEALING DAILY MAINTENANCE

With Obsurv you can record the process for handling the daily maintenance. This process consists of capturing, approving, executing and deregistering notifications. Because this is all done online, everyone always has access to the right, up-to-date information.

OBSURV MAKES MANAGEMENT EASIER

STRATEGIC:

Choices based on ambition level and image quality

Integral overview of assets and maintenance plans

Quick insight through dashboards

TACTICAL:

Drafting long-term maintenance plans

Calculating maintenance scenarios

OPERATIONAL:

Daily maintenance

Inspections

Data management

Modules

The modules and functional characteristics of Obsurv are based on nationally established and widely used standards and systematics. Such as NEN 2767-4, CROW 146, CROW 288, NPR 3220, NPR 3398 and NEN 3399.

OBSURV OFFERS THE FOLLOWING MODULES:

- Roads
- Green
- Trees
- Sewerage
- Road signs
- Bridges and other structures
- Public lighting
- Traffic installations
- Playgrounds
- Cables and pipes
- WION Exchange
- Inventory and Inspection
- IBOR
- Integral programming and project planning
- Message traffic BGT
- Daily maintenance