Navigating the Future of Metropolitan Trees
Improving the Urban Forest Resilience and Longevity

Master thesis landscape architecture
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How should we want to plant, maintain and manage our trees in metropolitan city centres to create pleasant atmospheres for the future generation?

Fig. 1, Bonsai garden of master Seji Morimae at Daitoku-ji Temple, Japan (2023)

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Fig 2, Oude haven Rotterdam (n.b.)
Photo: M. van der Stelt

1 Introduction

Project aim | 1.01

This graduation project aims to rethink the way the urban forest is designed, maintained and strategically managed in order to sustain and improve the liveability of future city centres for the next generation. Due to numerous challenges that trees in the urban environment need to face the potential benefits that trees can provide are rarely fully exploited. By observing these urban forestry challenges from a bonsai perspective alternative methods for management and design of trees within the urban landscape are being explored.

Landscape architecture internships Japan | 1.02

As I started to comprehend the significance of trees in tackling a range of urban livability challenges, I delved deeper into the possibilities of applying bonsai techniques to address various urban forestry issues.

Within my first graduation presentation, I introduced bonsai-inspired (Fig. 3) solutions to various urban forestry challenges. With gratitude towards the advice and guidance of prof. Erik de Jong I embraced the special opportunity to validate my hypothesis during a foreign excursion to Japan. Over the coarse of 5 weeks I attended an intern ship at Teijyuen Co. ltd in Osaka and at Ueyakato landscape Co, Ltd in Kyoto. In between these unique learning experiences I had the opportunity to interview bonsai master Kunio Kobayashi. The insights from these interviews, internships and gathered literature during this trip are elaborated upon and illustrated in my report titled “The Role of Trees in Japan.”

Being an integral part of this graduation thesis several concepts discussed in this graduation report are draw upon knowledge and insights gained in Japan. Within this thesis report there will be referred to the transcribed interviews and insights illustrated within the ‘the role of trees in Japan’ This report can be found in the appendix of this thesis report.

Fig. 3, Bonsai garden by Seji Morimae at Daitoku-ji Temple, Japan (2023)

Prototype development
Project: 'bos op poten' | 1.03

Another integral part of thesis resolves around the close participation within the transplantation of the climate arboretum that have been situated in front of the faculty of architecture in delft between 2020 and 2023. During this master thesis under supervision of Rene van der Velde, Jaap smit en Michiel poulderooi I excecuted various designed explorations for the prototype that is created for the transplantation of the 36 trees to Rotterdam handelsplein. Together we transported the trees to Rotterdam by truck. (Fig 4). Both the prototype creation, transplantation and installation of the arboretum in Rotterdam have been documented and included within this thesis report. By participating in this project I have significantly increased my knowledge about both the technical design and maintenance of trees.

In line with the bonsai-inspired knowledge gained in Japan and the practical knowledge gained from participating within the transplantation project this thesis aims to continue the exploration and creation of adaptive forestry methods on a larger scale for the city of Rotterdam.

Fig 4, Bos op poten, Handelsplein Rotterdam, Photo: Evy Hachmang, (2023)

2 Problem statement

Abstract | 2.01

Urban populations are rising all over the world. According to the United Nations 60% of global populations is projected to live in urban area's by 2030. The formation of the urban heat island effect (UHI) and it's impact on human health and well-being by the increase of heat stress in hard surfaced urban area's has been described and measured by a multitude of studies. (Oke, 1989) The cooling ability of urban green infrastructures (Pauleit et al., 2020) with trees in particular is currently widely acknowledged. (Rahman et al., 2020).

However, planting trees in city centres where they are most needed for a healthy and sustainable living environment still remains a challenge due to extreme growth conditions (Sjöman et al., 2018). Densely populated urban area's are constantly developing and due to the limited above and underground space new planted trees rarely reach maturity. In addition the underground utilities with frequent maintenance, soil compression and the lack of nutrients further complicate healthy and consistent growth of tree canopies. (Ferrini et al., 2019)

If we want our trees in the hardscaped ever-changing urban environments of city centres to provide many of its benefits for the next generation, the technical design for planting, maintaining and strategically locating trees in urban area's should be reassessed now. The complexity of the urban forest is multifaceted and knows site specific challenges therfore implementing new methods in real life projects is essential for creating new knowledge within the urban forest discipline

Research question | 2.02

Over the coarse of this graduation thesis my research question has continue to evolve. Being intrigued by the various challenges that the urban forest needs to face, the implementation of bonsai-inspired techniques from Japan in combination with close participation in the transplantable arboretum has led to explore the concept of transplanting trees in the urban environment.

Although it is widely known that trees have the ability to improve the liveability in hardscaped city centres the potential of adaptive forestry implementations in that regards have not yet been investigated. The combination of the above aspacts result into the following research question:

What are the potentials and constrains of transplanting trees in hardscaped city centres for improve the urban forest resilience and longevity?

What are the potentials and constrains of transplanting trees in hardscaped city centres like rotterdam for improve the urban forest resilience and longevity?

Fig 5. Schouwburgplein(n.b.), Photo:Claire Droppert

3 Urban forestry research methodology

Methodology & Research Question | 3.01

The rapid transformation of urban landscapes and the absence of long-term urban forestry visions have led to a common issue: trees in hardscaped city centers seldom reach maturity. Given that trees begin to significantly contribute to ecosystem services as their canopies grow, it becomes imperative to engage in discussions about long-term strategies for establishing a sustainable urban forest.

If we aspire to foster healthy and liveable urban environments, particularly in light of the inevitable challenges posed by climate change and urban densification, proactive planning and tree planting are essential. The groundwork for creating these future urban green spaces must begin now.

To comprehend the multifaceted and constantly evolving nature of the urban forest, I have developed a methodology that delves into various domains of urban forestry. This methodology serves as a framework for analysing and designing urban forests. Each of these domains can be seen as sub-questions to support the main research question.

Fig 6, Granary square, London (2023)

Methodology Implementation | 3.02

To analyse the current urban forestry challenges, I have developed an extensive methodology that serves as a valuable framework for comprehending the diverse issues across different scales, time frames, and long-term urban development goals. Throughout this master's thesis, this methodology is utilized to analyse, design, and reflect upon various aspects, ultimately addressing the research question.

Each domain within this methodology corresponds to a dedicated chapter within the research project, laying the groundwork for understanding the prototype design and the large scale implementation for Rotterdam. These three domains encompass the Detailed **Technical Design**, **Maintenance** Management, and **Long-Term Strategies**.

In each chapter, a thorough exploration is conducted, drawing upon various reference projects, interviews, and literature studies. At the conclusion of each chapter, a summary page outlines the specific challenges faced in urban forestry within that domain. Subsequently, an alternative solution to these problems is presented, focusing on Adaptive forestry alternatives. Importantly, both the urban forestry and adaptive forestry aspects within each domain are discussed on the same page, ensuring a clear and comprehensive understanding of the challenges and potential solutions.

Following the in-depth exploration of each domain, the prototype development for the transplantable arboretum in Rotterdam is critically examined, utilizing insights from the three domains. The knowledge gleaned from this reflection is then consolidated in a scale-up exploration that delves into the potential applications of adaptive forestry for challenging locations in Rotterdam.

Lastly, employing the framework of the three domains, this large-scale design exploration for the city of Rotterdam undergoes another round of reflection. The goal of this iterative process is to ultimately provide a comprehensive and well-informed answer to the research question, drawing upon the insights and experiences gained from the entire research journey.

There are two methodologies, one for Urban forestry and one for Adaptive forestry. Although there is a slight difference within both methodologies they will be used throughout the master thesis to provide clarity and sharpness.

Fig 7, Prototype design (2023)

Urban forestry methodology | 3.03

Inorder to make a long term strategic plan for sustainable urban forestry methods within this thesis I created a methodology (Fig. 8) that can be used for both the analysis, design and management of urban forests. A good interaction between the 3 domains described in the illustration should stimulate long term strategic urban forestry practices

When all domains are effectively addressed, aspects related to time, growth, urban densification, climate change, site-specific challenges, budget, strategic goals, and the long-term maintenance of the complex green infrastructure known as the urban forest, a well-rounded and sustainable approach can be achieved.

The establishment of these three domains or perspectives on the urban forest not only aids in analysing existing urban forestry practices but can also be integrated into the design and management of future urban forests. This approach ensures that urban forests evolve and thrive in a manner that aligns with broader urban development goals and environmental considerations.
The technical design domain primarily concerns the small-scale design of individual trees, with a focus on the annual cycle. This domain covers a wide range of aspects, including specimen selection, allocation of both above and below-ground space, soil selection, and the development of innovative tree pit designs. It also encompasses considerations for containerized trees and designs that integrate trees into rooftops.
The maintenance domain centres on the well-being of individual trees and the urban forest as a whole over time, with a focus on the decadian cycle. Within this domain, topics such as growth regulation, canopy pruning, and soil management are discussed to ensure the health and vitality of the urban forest. Lastly, the long-term strategies domain delves into the spatial planning of urban forestry on a larger scale, with a time frame that can extend well beyond half a century into the future. This domain explores aspects such as canopy coverage policies, street typologies, and the longevity of tree lifespan to shape the future of urban greenery and its impact on the cityscape..

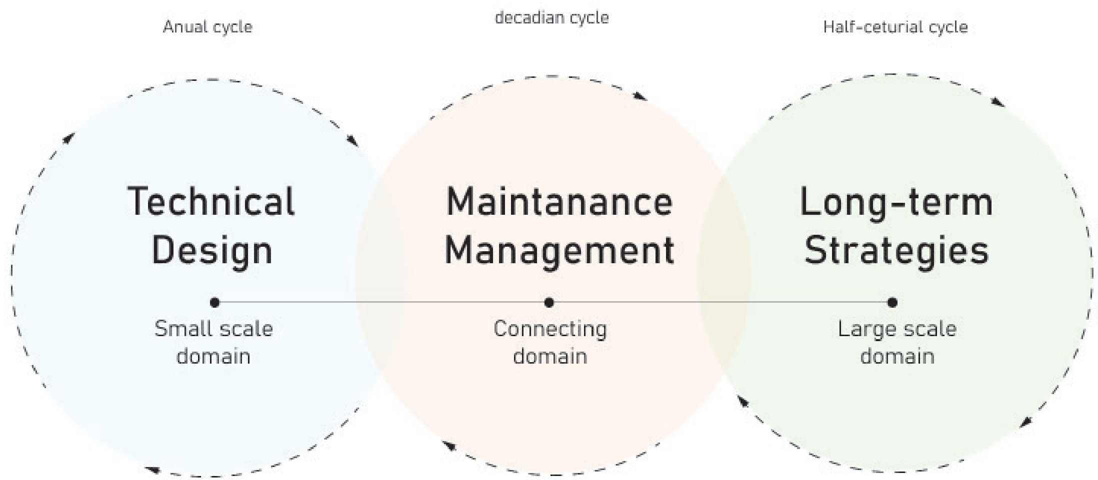

Fig 8, Urban Forestry Methodology

Adaptive forestry methodology | 3.04

Given the dynamic nature of the adaptive forest concept, the timeframes for each domain have been adjusted in the Mobile forestry Methodology (Fig. 9). As the management of a adaptive forest requires more frequent maintenance, a data-driven management domain has been incorporated into this adaptive forestry methodology framework.

All three domains are in continuous interaction through the connecting data-driven management domain, which operates across all scales, from individual trees in a promenade to the adaptive forest as a whole.

Because the spatial arrangement of the adaptive forest can be altered at any time, all domains within the adaptive forestry methodology function within various timeframes. While the technical domain in traditional urban forestry methodologies typically operates on an annual cycle, in the context of adaptive forestry methodology, the technical domain for individual trees is now linked to the entire lifespan of the tree. This shift in perspective necessitates for a well organised data-driven dynamic and adaptable approach to managing the adaptive forest.

The data-driven management practices are actively employed at every level, promoting the health and sustainability of the adaptive forest concept.

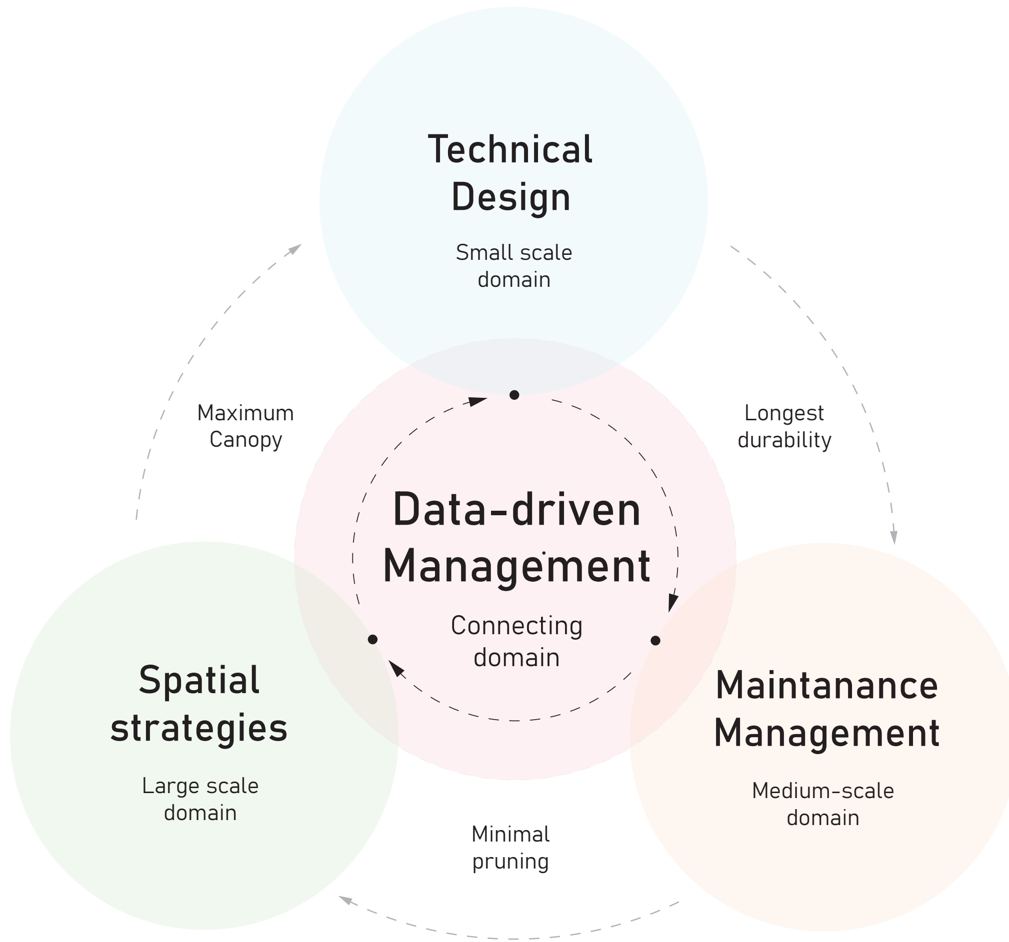

Fig 9, Mobile forestry Methodology

4 Theoretical background

Trees in the urban landscape can have many benefits for all life forms. They can cool down cities, enhance biodiversity but also increase mental health and well being. (Rahman et al., 2020)

In most cases, it can be asserted that the larger the canopy proportions of urban trees, the greater their value and contributions to ecosystem services and other benefits within the urban landscape .However, due to numerous challenges related to urban densification, climate change, and the ever-evolving nature of both trees and their urban surroundings, trees rarely reach maturity. (Copijn, 1977)

This introductory section of the thesis is focused on explaining the importance of trees and detailing the inevitable challenges trees and designers must overcome in densely paved city centres to make trees fulfil their potential roles. (Ferrini et al., 2017)

Fig 10, Monumental tree, Imperial palace Kyoto, 2023

The value of trees | 4.01

The significance of trees in an urban setting encompasses a diverse range of elements. They offer not only technical and cost-effective benefits but also contribute significantly to the social and cultural aspects, enhancing the mental health and overall well-being of individuals who interact with the spaces where trees are present.
(De Roo, 2011)

Trees inhabit both private and public domains, with municipal authorities being responsible for their management in public spaces. Unfortunately, in many metropolitan areas, municipalities are not fully aware of the diverse benefits that urban forests can provide. They often view trees as expenses rather than assets. In response, researchers are now attempting to quantify the benefits, such as cooling effects and biodiversity enhancements, to enable municipalities to establish sustainable financial budgets.
(Butler, 2021)

While the technical quantification of trees is an effective way to persuade municipalities to see trees in urban environments as assets rather than costs, the social and cultural value of trees should not be overlooked.
(Fig. 10)

The collective impact of for instance blossoming trees all over the world fosters a sense of community that has the potential to address climate change issues. Especially in heavily paved, urbanized areas, the social role of trees can have a transformative effect on how we perceive and wish to experience public spaces (Interview Kunio-Kobayashi, 2023)

While it may be more logical to expect some of the following tree benefits in rural settings, the role of trees is multifaceted and can contribute to various aspects.
It’s worth noting that the significance of the benefits listed below is often directly related to the size of the tree canopy. Trees can fulfill the following roles and purposes:
(Ferrini et al., 2017)

Temperature Regulation: Shade provided by trees reduces the urban heat island effect, keeping temperatures cooler in hot weather and reducing energy consumption for cooling.

Air Quality Improvement: Trees help filter and purify the air by absorbing pollutants and emitting oxygen, leading to cleaner and healthier urban environments.

Noise Reduction: Trees can act as a natural sound barrier, absorbing and deflecting noise pollution, creating quieter and more peaceful urban spaces.

Wind Speed Reduction: Trees can help mitigate high wind speeds in areas prone to strong winds, particularly around buildings

Aesthetic Enhancement: Trees contribute to the beauty and aesthetics of city streets and parks, making urban areas more visually appealing.

Psychological Well-being: Greenery and natural elements have been linked to reduced stress, improved mental health, and overall well-being for urban residents.

Biodiversity Support: Urban trees provide habitat and food for various wildlife species, promoting urban biodiversity and ecological balance.

Stormwater Management: Tree roots help absorb rainwater, reducing surface runoff and the risk of flooding in urban areas.

Energy Conservation: Properly placed trees can provide shade to buildings, reducing the need for air conditioning and heating, thus saving energy and reducing utility costs.

Community Gathering Spaces: Trees in parks and public areas offer places for people to gather, relax, and engage in recreational activities, fostering a sense of community.

Enhanced Property Values: Areas with well-maintained trees often experience increased property values and attractiveness for real estate.
Carbon Sequestration: Trees absorb carbon dioxide (CO2), mitigating the effects of climate change by acting as carbon sinks.

Traffic Calming: Trees can serve as visual and physical traffic calming measures, improving road safety and encouraging slower driving speeds.

Urban forest challenges | 4.02

The design and management of urban forests present numerous challenges, many of which are site-specific. Factors like changing urban context, poor soil condition and the intersection of tree roots with various underground facilities such as plumbing, sewage systems, or electricity cables can pose unique difficulties. (Copijn, 1977)

However, urban forestry also faces challenges that are inherent to its domain, such as the ever-changing nature of the growing urban forest. These inherent aspects are essential as they will consistently impact urban forestry design no matter its location. Before addressing the site-specific urban forestry challenges (Fig 11) in chapter 5, the following pragraphs will delve into the challenges posed by the essence of growth, urban densification, and climate change.

Fig 11, Otomachi Forest, Metropolitan central Tokyo, 2023

Essence of growth | 4.03

Each urban forest, no matter its location, is growing. It is a dynamic green infrastructure that is constantly changing. Described beautifully by bonsai master Kunio Kobayashi: The prove of the living of trees is that they grow every day. They manifest themselves by growing, that's there way of expressing life. (Interview Kunio Kobayashi, 2023)

The design of an urban forest must consider that the dimensions of trees will inevitably change over time. Various tree species exhibit different growth curves, with some growing rapidly like popular trees, while others, like oak trees, have a slower growth rate. Additionally, each growth location provides different conditions and resources for tree development. Consequently, predicting this dynamic growth process throughout a tree's lifespan can be quite challenging. (Dujesiefken, 2016)

In managing the urban forest, tree growth plays a pivotal role. It not only influences the maintenance requirements over time but also demands adaptability in the growth locations, which often lack the flexibility needed to accommodate these changes effectively. For example, this problem becomes evident when tree trunks clearly outgrow the available space for growth, resulting in damage to their surroundings, a notable deterioration in their health, or even the tree's demise. (Interview, Tadashi Touchi, 2023)

Drawing Time
When designing with living materials such as trees in the public space, Time is a very important aspect to take into consideration. Nevertheless drawing time is a challenging task since a drawing is almost always representing a single moment in time. Nevertheless the drawings and perspectives of many Urbanism and Architecture firms often show a static image of a single phase in trees there life. (De Wit et al., 2022)

As part of the graduation program we experimented with different drawing methods to express the passing of time. In this exercise (Fig 12) I discovered a way do draw the growth of a tree overtime with the use of aquarellcollor. When applying the water and pigment on the paper it naturally grows just like a tree.
As the water slowly spreads and the time is passing on the both the natural shape and growth is expressed in the drawing media.

By using different layers the gradient developed showing different sizes of the tree overtime within one drawing.

The combination of a technical drawing method with the fluid collar gradient that arose when applying aquarell collar revealed the delicate interaction between the growth of the tree and its defined context.

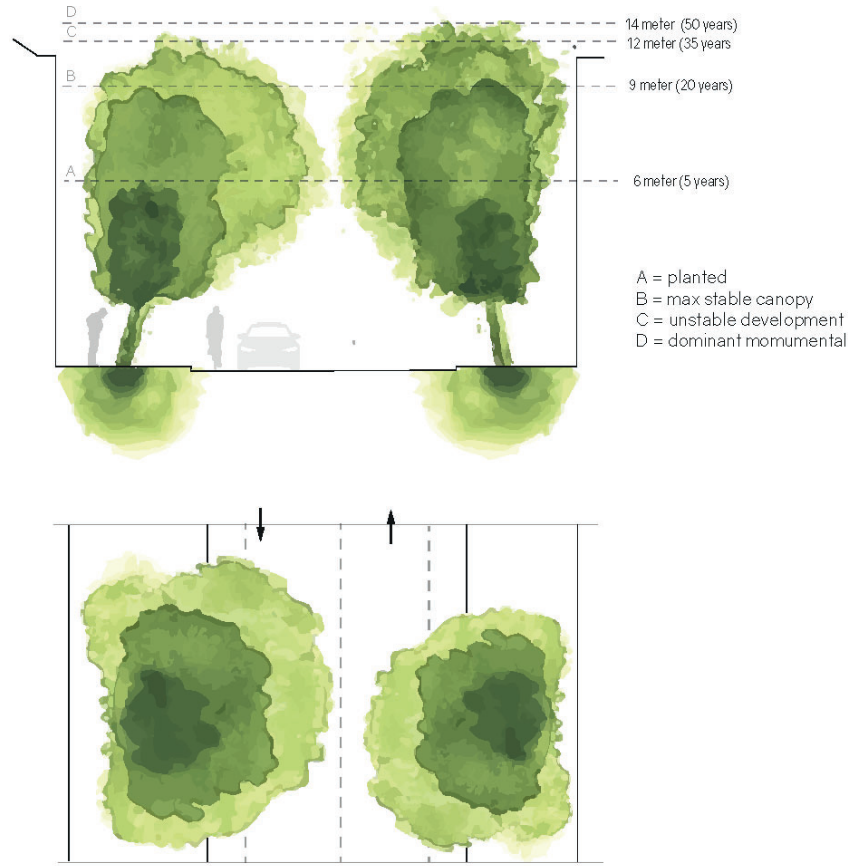

Fig 12, Drawing time workshop, 2023

Urban Denscification | 4.04

Due to the increasing urban populations worldwide, metropolitan cities are becoming denser each year. The growing demand for housing is driving the construction of new buildings in urban areas. Given the high cost of land in city centres, these areas are primarily allocated for housing development by major development firms. Consequently, this trend leaves very limited opportunities for the establishment of green infrastructure projects within city centres. (Fig. 14) The only available space for such initiatives is often the public spaces nestled between buildings. (Ferrini et al., 2017)

Paradoxically, existing urban city centres are in dire need of green infrastructure to ensure and enhance the quality of life within these densely built environments. (Konijnendijk, 2008)

Furthermore, the process of densifying city centres frequently entails the elimination of pre-existing trees and green areas to accommodate new construction projects. This practice can lead to the loss of mature trees and a reduction in the overall extent of tree canopy coverage.

Additionally, due to urban densification, a new trend has emerged where rooftop gardens (Fig. 13) are gaining popularity. Prof. Tomoki kato of landscape architecture company Ueyakato in Kyoto explained to me that the driving factor for the creation of rooftop gardens or iner couryard gardens is that residents tried to create in their residens what they called the shichu no sankyo the mountain aboad in the city, which meant that inside their homes they tried to create a space that made them feel like they have escaped out of the city and were in some sort mountain hermided or mountain residence. (Interview Tomoki Kato, 2023)

Fig 13, The garden at 120 Londen, 2023

Fig 14, Bank Londen, 2023

Climate change | 4.05

The effects of climate change on urban forests are gradually becoming more evident. Climate change not only impacts the health and habitat of trees in urban environments but has also dramatically altered the role of trees within cities. (Rahman et al., 2020)

Effect of climate change on trees
One of the most significant aspects of climate change is the rising temperatures. Many tree species have specific temperature preferences, and as temperatures gradually increase, we must adapt by planting species that are more heat-resistant. Moreover, existing urban trees that are less heat resistant need to find ways to cope with the increasing heat. (Smit, 2022)

Another intriguing aspect of climate change is the milder winters. Due to higher temperatures in winter, some insects can survive the winter and become increasingly problematic for the health of trees. The changing character of our winters also results in the early start of sap flow in trees. When followed by a sudden return to strong winter conditions, trees face a significant risk of internal damage. (Interview, Teunis Jan Klein 2023)

As the climate undergoes more extreme fluctuations, trees encounter multiple challenges. Dead branches are more prone to falling during increasingly intense winter storms. This necessitates a more proactive approach to tree maintenance by arborists to prevent the risk of falling branches or even entire trees.(Internship, Teijyuen 2023) The climate extremes also significantly impact rainfall patterns. A common trend during summers is the occurrence of more frequent drought periods followed by short but intense rainfall events. These brief rainfalls don't allow enough time for soils and trees to absorb the water before it is evaporated by high temperatures and direct sunlight. While most trees in the Netherlands have developed sufficient root systems to reach groundwater levels, newly planted trees with underdeveloped root systems can be vulnerable during these dry periods.

To prevent these newly planted trees from dying, manual watering is often carried out during drought periods. However, due to a system that prioritizes job opportunities offered by municipalities to the lowest bidder, newly planted trees often suffer due to insufficient watering schedules. (Gemeente Amsterdam Klaas-Bindert de Haan, n.d.)

Climate change and the role of trees
Simultaneously, the rising temperatures emphasize the importance of trees in cooling down cities. Trees with a greater cooling capacity are preferable for planting in hard-surfaced urban areas to mitigate the accumulation of heat within built environments. (Fig. 15) Additionally the role of trees in reducing stormwater runoff during heavy rainfalls. These alternating roles of trees should be taken into acount in the future design and management of the urban forest.

Fig 15, canary warf Londen, 2023

5 Technical design principles

Urban trees confront a multitude of challenges that frequently hinder their ability to reach maturity. In this chapter specific technical design topics are discussed. They are derived from various questions broad up by fieldwork observations, interviews and literature desk studies. (Fig. 16)
The initial segment of this chapter introduces these subjects in a theoretical manner. Following that, an analysis of three types of urban tree planters is conducted, drawing from a range of precedent studies encountered during fieldwork observations.

The concluding section of this chapter synthesizes findings and advocates for a novel approach to urban tree planting, grounded in the previously discussed topics.

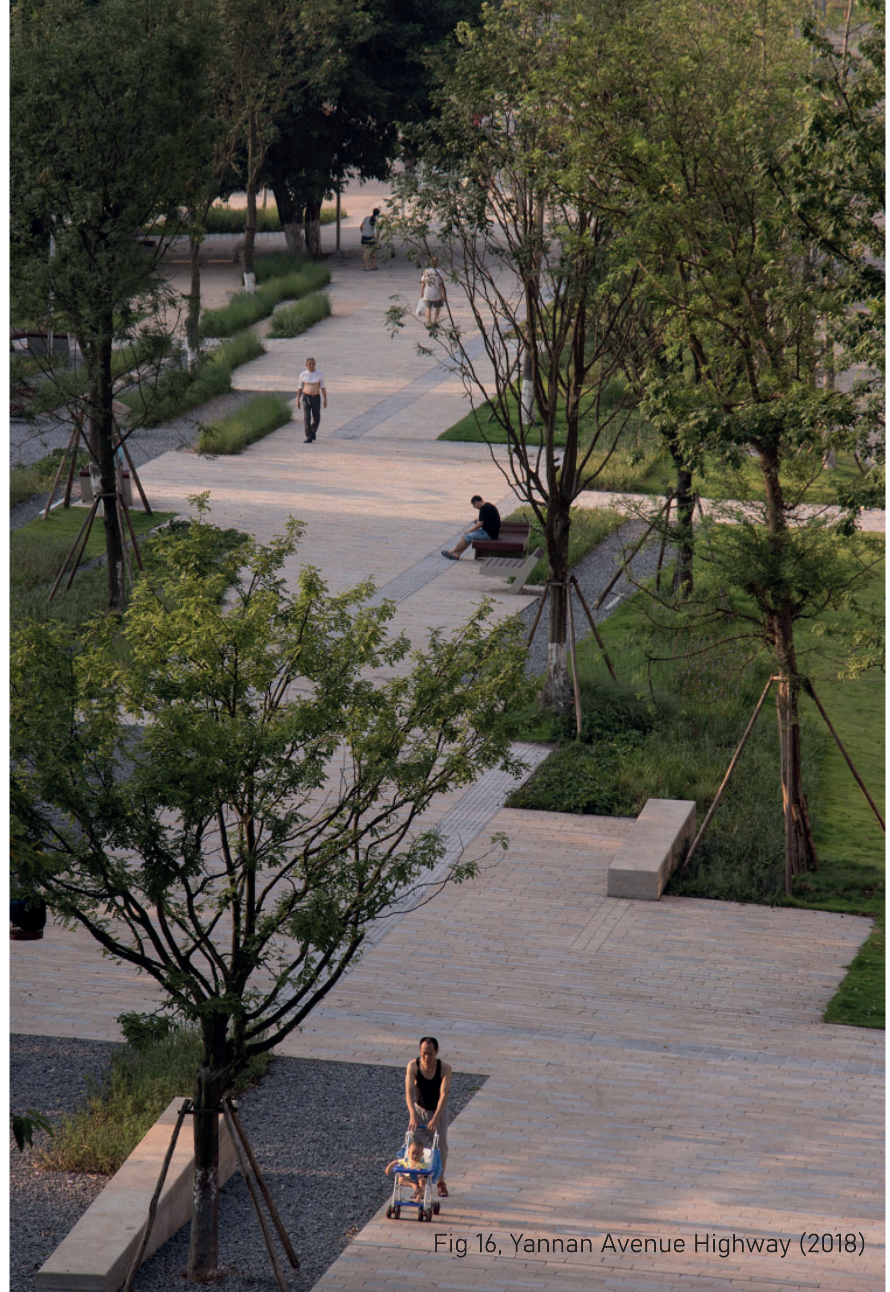

Fig 16, Yannan Avenue Highway (2018)

Species selection | 5.01

In the design of the technical growth location for urban trees, it is essential to consider a multitude of factors related to the distinctive attributes of various tree species. The selection of a particular species should be contingent upon the purpose or service the tree is intended to deliver. (Roozen & Smit, 2022)

For instance if the tree needs to provide shade, or mitigate wind speeds around the entrance of high rise buildings different characteristics of trees could be desired. Each tree species have a different natural growth, some species will have a formal upright growth and others will have a more widespread canopy. For instance, the choice of an upright poplar tree would be well-suited for a narrow street, whereas a wide-spreading oak tree would be a more fitting selection for open, spacious areas like parks. (Fig. 17) Depending on the available above and below-ground space, the correct selection of tree species is vital to minimize long-term maintenance costs, particularly in terms of structural canopy pruning. (Intership, Teijyuen 2023)

Another aspect to take into account is the way the tree will grow over time.
The growth performance of trees will be affected by many different variables but most of the tree growth performance could be directly related to their genes. Some trees will grow very fast during the first stages of their lives whereas others will continue to grow on a slow pace.
The ultimate goal would be to select '**The right tree for the right location**'. The selection of the tree species is mostly depending on the desired services the tree needs to provide, the urban spatial context and the long term perspective of that specific street or area.

Nevertheless, due to the ever changing urban context and developing proportions of the tree selecting the right tree species for the right location will always be a challenge.

Fig 17, The Swiss Touch in Landscape Architecture, (2015)

Dimensions & proportions | 5.02

A crucial aspect of the technical urban tree design is the amount of space needed for a certain kind of tree. Depending on the species selected one needs to have matching amount of above and underground space reserved.

As a general rule I would like to phrase bonsai master Kunio Kobayashi. He explained that: **'The proportions of the canopy should always be in harmony with the amount of roots'.** In other words the amount of water that is evaporated through the stomata in the leaves should be the same amount of water that is possible to be absorbed by the roots of the tree (Fig. 18)

The amount of water that is possible to be absorbed by the roots is depending on the quality and salt levels of the soil, the depth of the ground water level, and the amount of root surface area. (Interview, Kunio Koboyashi 2023)

Fig 18, 600 year old bonsai at Shukuen Bonsai museum, Omiya Japan (2023)

The Dutch institute 'normenbomeninstituut' has set guidelines for the growth location of different kind of tree species. Designers and municipalities use this platform to calculate and design spaces for trees The amount of rootspace is calculated based on the following inputs

- Tree species
- Canopy proportions
- Groundwater level
- Weight load of pavement/ traffic
- Depth of available root space.
- Life length of tree

After these variables have been given as input the output of the platform will be an estimated volume of soil. (Fig. 19)

Although this tool is very useful and it will often give safe and suitable guideline for the design of trees in urban environments; Due to the limited underground spaces available it is nearly impossible to plant trees according to their guidelines. This is resulting in many places within hardscape city centres without trees. Unfortunately these are the places where various services of trees are most needed.
(Handboek Bomen, 2023)

Tree proportions for Acer campestre
A. Crown Diameter: 7 m
B. Crown Projection: 38 m^2
C. Tree Crown Volume (TCV): 150 m^3
D. Above-Ground Obstacle-Free Zone: 4.2 m
E. Below-Ground Obstacle-Free Zone: 1.5 m
F. Rootable Space: 11 m^3 (with groundwater)
F. Rootable Space: 18.7 m^3 (no groundwater)

Example of Growing Site Dimensions:

Growing site dimensions,
(with access to groundwater)
(length x width x depth): 3.3 x 3.3 x 1 m

Growing site dimensions,
(no access to groundwater)
(length x width x depth): 4.3 x 4.3 x 1 m

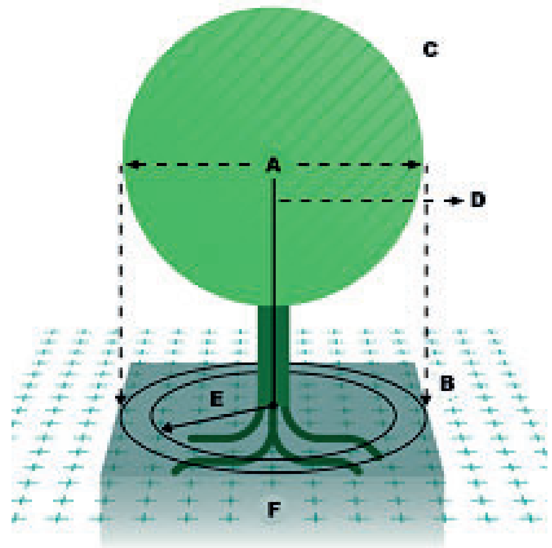

Fig 19, Handboek Bomen, 2023

Tree Roots | 5.03

One of the most critical aspects of trees revolves around the health and proportions of their root systems. Roots serve a fundamental role in the absorption of water and nutrients. Simultaneously, they ensuring the stability of the tree, store reserve nutrients and are responsible for the production of various hormones that orchestrate growth throughout the entire tree, including the canopy.

Tree roots can be differentiated into various groups and functions: (Fig. 20)

The tap root is the first root that grows if the tree was grown from seed. This dominant root grows downwards and accommodates for hormones that stimulate vertical growth of the trees canopy.

Lateral roots originating from the pericycle, extend horizontally from the primary root (tap root) and gradually contribute to the characteristic branching pattern of root systems. Their vital functions encompass firmly anchoring the plant in the soil, enhancing water absorption, and facilitating the uptake of essential nutrients crucial for the plant's growth and development. Lateral roots substantially increase the surface area of a plant's root system and are abundant in various plant species Additionally, they facilitate the production of hormones that promote horizontal growth in the tree's canopy.

The primary role of **root hairs** is to gather water and mineral nutrients from the soil, which are subsequently distributed throughout the entire plant. In the context of roots, the majority of water absorption takes place via these specialized root hairs. Root hairs play a crucial role in ensuring the overall health and nutrition of the plant, particularly through their interactions with symbiotic mycorrhiza fungi.

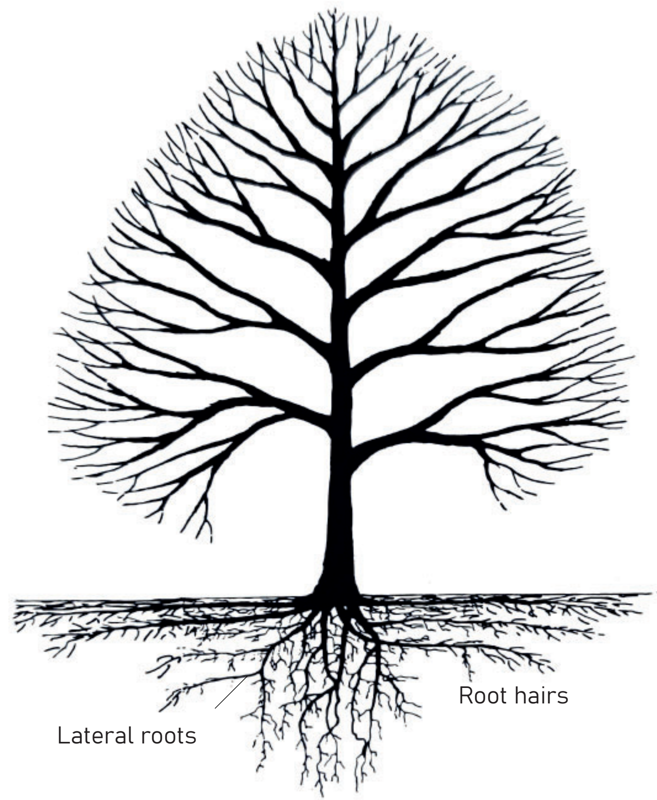

Fig 20, Japanese Landscape Contractors Association (n.b.)

Root biology
Tree roots rely on oxygen for a process known as aerobic respiration. This process is crucial for cell production and various activities essential for the tree's well-being, including the production of cells and the energy required to transport water throughout the trunk and branches in the canopy. When the soil surrounding the roots becomes excessively wet, it can lead to severe damage to the tree's health. Maintaining a delicate equilibrium between water, oxygen, and nutrients in the soil is vital for the overall health and vitality of tree roots. (Chan, 1989)

Research has demonstrated that tree roots engage in intricate interactions with soil biology, including mycorrhizal associations, as well as with the roots of neighbouring plants. (Taiz et al., 2015)
The amount of water and nutrients uptake by tree roots is strongly related to the total amount of surface area of the roots.

Fig 21, Boomdekwekerij (n.b.)

Soils | 5.04

In essence, soils must fulfill the essential requirements of supplying trees with an adequate balance of water, oxygen, and nutrients. The health of a tree is directly influenced by the quality of the soil it grows in. Various tree species exhibit distinct preferences when it comes to soil composition. As a result, the soil used for trees typically consists of a variety of materials to meet these specific preferences. (Bonsai Soil - Bonsai Empire, 2023)

Soil mixes are categorized as either organic or inorganic. Organic soil components include decomposed plant matter like peat, leaf litter, or bark and have a great capacity of absorbing water and nutrients In contrast, inorganic soil components consist of materials with minimal to no organic content, such as volcanic lava, calcite, and baked or fired clays which have a lower capacity to retain nutrients and moisture but they are providing effective drainage and aeration.

Decomposition of inorganic soil

The potential issue with organic soil components is that organic matter tends to break down into smaller particles over time as it absorbs and releases water and nutrients. This decomposition can result in reduced drainage capacity, leading to soil compaction and an imbalance between water and oxygen levels. The decomposition of soil can be effectively reversed by the presence of a healthy soil ecosystem. Earthworms, in particular, play a vital role in enhancing soil fertility and aeration. They achieve this by consuming organic matter, creating tunnels as they move through the soil, and depositing nutrient-rich castings (worm poop) behind them. This activity helps rejuvenate the soil, improving its structure and nutrient content.

Another approach to mitigating the effects of decomposition is to incorporate a balanced mixture of organic and inorganic materials into the soil. Inorganic components have the capacity to a consistently maintain good drainage and aeration properties because their particles do not break down over time.

Akadama

In the art of bonsai, creating a fine balance between oxygen and water while also supplying the tree with a soil component capable of efficiently absorbing and slowly releasing nutrients as required has been effectively achieved through the use of an inorganic material called Akadama.

Akadama is renowned for its exceptionally high Cation Exchange Capacity (CEC), but its scarcity due to volcanic origins and primarily being found in Japan makes this material relatively expensive. At a microscopic level, Akadama exhibits a porous nature. The tips of root hairs penetrate these pores in search of water and nutrients. During this process, Akadama soil particles tend to break down into smaller ones, promoting root ramification. This process is repeated until a finely ramified root system is established.

However, it's important to note that over time, the breakdown of Akadama particles will exponentially increase the surface area and decrease the airspace between the particles. This can lead to a gradual imbalance between water and oxygen, eventually necessitating intervention by the bonsai artist, which may include soil replacement, to maintain the tree's health and vitality. (Bonsai Mirai, 2018)

Organic potting compost | Baked clay Akadama | Pumice soft vulcanic rock | Lava rock

Fig 22, Bonsai soils - Bonsai Mirai (2018)

Cation Exchange Capacity
The ability of a soil particle to absorb and make nutrients available for root uptake is described by a concept known as Cation Exchange Capacity (CEC). Some soil particles have negatively charged surfaces, which attract and hold cations. When a cation like potassium (K+) is added to the soil, it can displace other cations, such as calcium (Ca2+), from the surface of the soil particle, thereby making these nutrients available for uptake by roots. This process is essential for nutrient availability to plants. (Taiz et al., 2023)

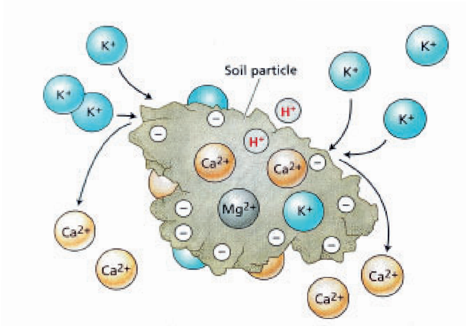

Fig 23, CEC, Taiz, L et al (2023)

Soil compaction
Another critical factor influencing soil quality is the weight placed on the soil surrounding tree roots. In urban environments characterized by limited space both above and below ground, the area beneath a tree is often utilized for various purposes such as traffic, pedestrian pathways, or the installation of underground utilities like plumbing, gas pipes, or electrical cables. The load from pavement and traffic atop the soil surrounding the roots compresses the soil particles, reducing the small airspaces between them. This compaction can significantly impact soil aeration and overall tree health (Copijn, 1977)

Conclusion
The decomposition of soil is frequently overlooked in the design and planning of trees in urban, hard-surfaced areas. This oversight occurs because there is limited interaction between the soil and its surroundings, preventing the natural rejuvenation that typically takes place when branches, seeds, and leaves fall onto the soil. These organic inputs help nourish soil life, including earthworms, which play a crucial role in enhancing soil structure and nutrient content. In urban environments with minimal contact between soil and organic matter, it becomes essential to consider alternative methods for soil health and tree vitality.

Organic soil components excel in their ability to absorb and retain water and nutrients, contributing to a rich source of organic matter that supports microbial life. On the other hand, inorganic soil components play a crucial role in ensuring effective drainage and aeration due to their stability and resistance to decomposition.
Combining these two types of components in the right proportions helps create a well-balanced soil environment that provides plants with both water and oxygen, essential for their growth and vitality.

While many urban tree pit designs consider the load and effectively divert it using various constructions, it's important to note that the decomposition of soil is often overlooked in the design and planning of trees in these urban, hard-surfaced areas. Addressing soil quality and rejuvenation processes, such as organic matter decomposition and soil life interactions, should also be a key consideration to ensure the long-term health and vitality of urban trees. Balancing load-bearing structures with soil health preservation is essential for sustainable urban tree management.

Underground Tree-pit designs | 5.05

The design of tree pits involves the consideration of multiple factors. Tree pits are typically employed in areas with restricted above-ground space and often require a paved solution beneath the tree's canopy.
In this paragraph, the concepts previously discussed in this chapter will be explored through the use of examples from reference projects in The Netherlands, London, and Japan (Fig 24).
The following concepts will be examined:

Soil compression
Soil decomposition
Soil rejuvenation
Irrigation
Aeration
Root direction
Soil volume
Overall life expantancy

Fig 24, Otomachi forest Metropolitan city center of Tokyol (2023)

Soil compression
One of the primary motivations that has driven the development of tree pit designs is to prevent soil compression in urban areas with intensively used hard surfaces. To mitigate soil compression, an external structure is constructed to redirect the loads imposed by the pavement and heavy traffic away from the soil.

GreenBlue Urban has developed a design that redirects the loads from the pavement using hollow plastic modular cases, called soil cells. (Fig. 25) This design enables soil to be placed between the cases without subjecting it to the pressure of the pavement loads. (GreenBlue Urban, 2022)

Soil decomposition
While numerous urban tree pit designs, such as those offered by GreenBlue Urban, take into account the load from pavement and traffic and effectively redirect it using various constructions, it's crucial to acknowledge that the decomposition of soil is frequently disregarded in the planning and design of trees within these urban, hard-surfaced environments.

The decomposition of soil into increasingly smaller particles due to the absorption and release of moisture and nutrients over time can lead to an imbalance between water and oxygen levels. This issue is encountered by both above-ground and below-ground tree planters over an extended period.

Fig 25, Tree pit design by Green Blue urban (2023)

Soil rejuvenation
In tree pit designs like green blue and many others, the soil is situated within the voids or cells beneath the pavement. However, a potential issue arises from the fact that these cells are often sealed off by various barriers. These seals, along with the surrounding concrete, obstruct the interaction of the soil with light, rainwater, and oxygen, rendering it an inhospitable environment for soil life to thrive and develop. (Fig 26)

Soil organisms such as fungi and earthworms play a crucial role in the rejuvenation process of the soil. When there is a stable symbiotic relationship between soil life and the tree, the tree should be able to thrive in accordance with its natural aging process. However, if the rejuvenation process of the soil is disrupted due to the absence of soil life, the gradual depletion of the soil will inevitably lead to a decline in the tree's health and growth performance over time. (Copijn, 1977)

A critical aspect of concrete tree pit designs is that once the system is installed, any interference with the soil, roots, or replacement of the tree becomes virtually impossible due to the rigid design of the tree pit. This limitation makes the concept and design unsustainable, as it cannot accommodate the inevitable decomposition and potential failure of some tree plantations over time. (Fig. 27)

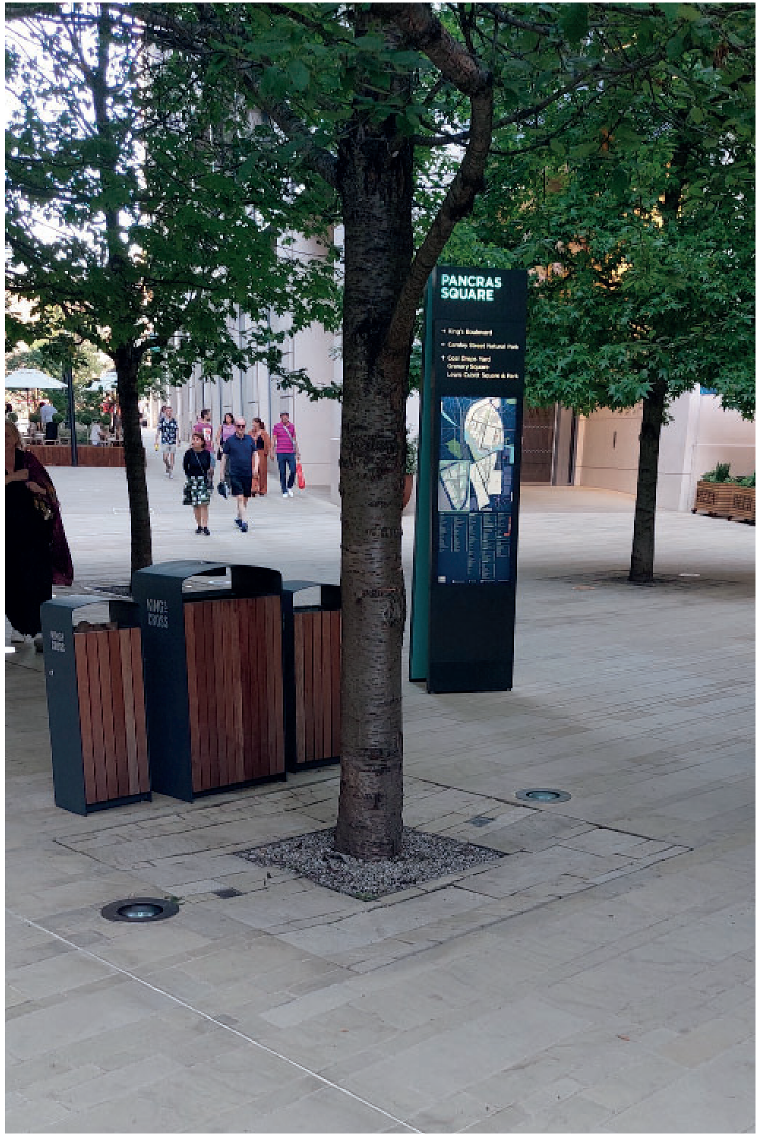

Fig 26, Tree pit design, king cross st. pancras London (2023)

Fig 27, dead tree, Bank, London (2023)

Irrigation
Rainwater can partially infiltrate the soil through the open tree grill. Tree grills are available in various designs and dimensions, but all of them share the common purpose of allowing rainwater to penetrate while still allowing people to walk on the grill near the tree trunk. (Fig 28)

Some tree pit designs have incorporated an artificial irrigation system. Typically, this irrigation system is automatically activated several times a day and can be connected to existing underground watering systems. In most cases, it's designed with a circular hose around the trunk, featuring several sprays directed towards the soil around the rootball.

Fig 28, Tree pit design, granary square London (2023)

Root direction
In underground tree-pit designs, actively guiding the tree roots is a crucial element. Tree roots are naturally drawn to various interests such as water, nutrients, oxygen, and temperature. They tend to thrive in soil temperatures above 15 degrees Celsius. However, when the soil temperatures reach around 25°C, roots switch their focus to suberization, as observed in the study by Kuhns et al. (1985).

Since the soil just beneath the pavement is warmer and has access to oxygen, trees tend to grow toward the edges of the soil and underneath the pavement. This often results in the pavement breaking and lifting upwards. As the roots continue to grow, they come into contact with the hard pavement, causing injuries and eventually forming a crust. This process repeats itself until layers of crust are created, pushing the pavement upward. (Fig 29) (Handboek Bomen, 2023)

In tree pit design, the roots are intentionally guided downward, preventing them from causing damage to the pavement. This represents a significant improvement compared to more traditional designs where the tree's growth location is less controlled and can lead to pavement damage. (GreenBlue Urban, 2022)

Fig 29, Technical tree design Soho London (2023)

Fig 30, underground fascilities London (2023)

Soil volume
The required soil volume for a tree to thrive is closely tied to the amount of root surface area available in a given space. Many calculations for determining the amount of soil needed for a specific tree size are based on practical experience. However, these experiences often assume a situation where artificial root ramification has not been considered as a potential factor.

Soil aeration
In numerous underground tree pit designs, aeration tubes are integrated into the plan. These tubes are frequently positioned around the tree's root ball, and in some cases, they are incorporated into the pavement design to maintain a more streamlined appearance. (Fig 31)

While the incorporation of aeration tubes does facilitate the penetration of oxygen deep into the soil, it's essential to recognize that if the soil has undergone decomposition, the use of aeration tubes may not adequately address the essential balance of oxygen and water required for the continued development of the root system.

Tree lifespan expactancy
Furthermore, within concrete tree pit designs where root rejuvenation is limited, the amount of soil volume required is determined by the goals regarding the tree's lifespan and duration of healthy growth.

Fig 31, Tree pit design, granary square London (2023)

Container tree design | 5.06

In numerous urban city centres, the lack of available underground space poses a challenge for planting trees below ground. As an alternative, many designers have integrated tree designs into aboveground planters. (Fig 32) Although this might seams like a perfect solution one has to be critical about the sustainability and longevity of the design.

In this paragraph, the concepts previously discussed in this chapter will be explored through the use of examples from reference projects in The Netherlands and London. The following concepts will be examined:

Soil compression
Soil decomposition
Soil rejuvenation
soil volume
Irrigation
aeration
Root direction
overall life expantancy

Fig 32, Container tree design for Regent st. London (2023)

Soil compression
An intriguing aspect of planting trees in above-ground containers is that soil compression, which typically poses a significant challenge in underground tree planting solutions, is not much of a concern. the trees have a open interactions with the elements such as rain water, air organic mater and insects.

Soil decomposition
The decomposition of soil into increasingly smaller particles due to the absorption and release of moisture and nutrients over time can lead to an imbalance between water and oxygen levels. This issue is encountered by both above-ground and below-ground tree planters over an extended period.

Soil rejuvenation
One advantage associated with the use of above-ground tree planters is the ability to intervene and improve the soil quality. This can be accomplished by manually aerating the soil, introducing soil organisms like earthworms, or replacing the soil altogether.

Soil volume
In many above-ground tree containers, the volume of soil allocated for tree growth is considerably less when compared to underground tree planting methods, often falling below 1 cubic meter. This reduction impacts both root development and water absorption capacity, necessitating a more frequent need for watering and fertilization. (Fig 33)

Irrigation
Although rainwater can often directly infiltrate the soil of above ground planters many of these system rely on a artificial irrigation method.
One potential approach could involve manual watering using a portable water tank capable of extracting water from a nearby source and delivering it to the designated area. However, this method has proven to be less practical for trees compared to geraniums, primarily due to the higher water evaporation rates associated with trees.

Other methods include the installation of an irrigation system within the above-ground tree planter. These systems often incorporate an automatic watering schedule, ensuring the tree receives a consistent and appropriate amount of water multiple times throughout the day.

Additionally, these systems can be connected to a moisture-measuring device that can trigger an alarm if the moisture content falls below a certain threshold. However, it's worth noting that the use of moisture measuring devices has not yet undergone academic peer review. Some potential criticisms may arise regarding their placement within the soil and the accuracy of these devices.

Fig 33, Container tree design for Harbour Qauy gardens. London (2023)

Soil aeration

Because the soil in most above ground tree planters is in direct contact with the external atmosphere, the interaction of the soil with oxygen generally maintains a healthy equilibrium of oxygen and water. Only over time, as the soil becomes compacted due to decomposition, the aeration of the soil might diminish. One potential solution to address this issue is to blend organic and inorganic soils to create a composition that extends the soil's longevity in maintaining the balance between oxygen and water.

In many above-ground containerized tree solutions, a common practice is the inclusion of aeration tubes to facilitate the penetration of oxygen deep into the soil. However, it's important to note that if the soil has become significantly compacted over time, the use of aeration tubes may not be sufficient to create the desired optimal growth conditions for the further development of the root system. (Fig 34)

Fig 34, Container tree details at Regent st. London (2023)

Root direction

The root direction and available space are pivotal factors for containerized trees above ground. When the pot's sides are solid, the roots naturally tend to grow towards the sides and eventually start circling around the corners. If you later need to transplant the tree into a different pot or open soil, altering the initial root direction becomes challenging. As the roots thicken over time, this can lead to self-constriction, ultimately causing structural damage and breakage to the tree's root system. (Fig 35)

Fig 35, Container tree design for Canary Wharf, London (2023)

Rooftop integrated Tree design | 5.07

In numerous urban city centres, the lack of available above and below ground space poses a challenge for urban greenery and planting. As an alternative, many designers have integrated tree designs onto building façades or on rooftops. Although this might seams like a beautiful integration of both landscape and architecture the sustainability that these projects might suggest can be questioned. (Fig. 36)

From a maintenance perspective, establishing healthy trees on building facades, such as the Wonderwood project in Utrecht or the famous Bosco Verticale in Eindhoven, presents numerous challenges. The picture on the following page illustrates the difficulties faced by tree workers in maintaining a balanced tree canopy. Additionally, because trees naturally grow toward the light, the side of the tree facing the building often exhibits less growth and foliage compared to the side growing toward the light source. Fig. 37)

From a technical design standpoint, there are critical considerations regarding structural support for these trees. To promote tree growth, an adequate amount of soil is required to provide nutrients, water, and oxygen. The substantial weight of the soil, especially when wet, can create a significant load. Architects must find ways to support this added weight, often resulting in a substantial increase in steel and concrete usage, thus increasing the carbon footprint. To implement sustainable trees on buildings, it's essential to reduce the overall weight, necessitating root pruning and root ramification techniques.

Fig 36, Rooftop tree deisgn by Urban Jungle project (2023)

Regarding irrigation, all these trees require an external irrigation system. Given the reduced soil volume due to weight concerns, frequent watering, sometimes multiple times a day during hot summer days, becomes necessary. An interesting project illustrating artificial irrigation is the Urban Jungle project by Boomkwekerij Ebben. This project involves artificially watering the tree through integrated irrigation tubes within the root ball. The design of the “boomveerconstructie” allows the tree to sway slightly in the wind while maintaining a relatively lightweight construction.

The transplantability of these trees may be questioned due to the twisting of roots within the root ball design. If the process of soil decomposition has occurred, soil replacement becomes necessary which could be challenging if the tree is placed onto facades or ontop of rooftops.

while the maintenance of trees on rooftops and building facades poses significant challenges, the demand for integrated trees in densely populated city centers continues to rise. Ensuring the sustainability of these tree integration designs requires that maintenance and the potential for transplanting trees to new locations are considered right from the initial design phase. By incorporating these considerations into the design process, it becomes possible to create sustainable designs that minimize tree loss and maximize the longevity and adaptability of urban greenery.

Fig 37, Wonderwood by Stefano Bouri, Utrecht (2023)

Technical core principles | 5.08

The scarcity of space, both above and below ground, in densely built city centers frequently leads to a lack of trees in many urban areas. Trees in urban environments often experience slower growth due to poor soil conditions. Furthermore, underground utilities and infrastructure make it challenging for tree roots to develop properly. In addition, the combination of soil decomposition and compaction due to heavy traffic and pavement calls for a revised approach in today's urban forestry planning.

Although many urban tree pit designs take into account the load and employ various constructions to manage it effectively, it's crucial to recognize that the limited interaction between the soil and its surroundings hinders the natural rejuvenation process of the soil. The depletion of the soil over time will inevitably lead to the degradation of the tree's health.

Moreover, in these intensively used urban spaces characterized by constant changes and high activity, trees seldom have the chance to attain maturity before urban development necessitates their removal. In many instances, replacing the original tree with a new, smaller tree seems to be a much more cost-effective solution than attempting to alter the initial urban development or transplanting the original tree. However the replacement of the larger, mature tree results in the loss of its accumulated value.

Summarizing the conclusion drawn from this paragraph into a design brief the following concepts could be stated:

In many hardscape urban environments, there is insufficient space for underground root development. Therefore, it becomes crusial to expand the root surface area within a more confined space to accommodate the placement of trees in critical areas within the city center.

When implementing soil cells to support paved solutions beneath the tree's canopy, it's crucial to consider the rejuvenation or replacement of the soil in cases where soil decomposition has occurred over time.

Aboveground containerized tree solutions should consider the presence of twisting roots within the confined space to ensure that the tree can be transplanted once its temporary service has been fulfilled.

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New technical principles for urban forests

In the previous section of this chapter a variety of challenges that have been derived from the in-depth analysis across various subjects within the technical core principle domain have been discussed. In this paragraph, we will revisit these challenges, proposing potential solutions through the implementation of innovative technical principles in urban tree design.

Diminished Rootspace
One of the primary factors contributing to the scarcity of trees within urban areas characterized by extensive hardscaping is the deficiency of adequate space, both above and below ground. An alternative approach to address the manifold challenges associated with this spatial limitation could involve the adoption of artificial fertilizing and watering. Throughout this process it becomes possible to grow healthy roots within a smaller space.

Additionally, the development of a healthy root structure facilitates easy transplantation year-round, offering the possibility to relocate trees when urban development would typically require their removal.

It is worth noting that this method for designing tree growth locations within urban environments has seen limited implementation to date. Nevertheless, the adoption of this method holds promise as a solution to a variety of challenges.

Soil compression
First and foremost, the combination of soil compression and decomposition stemming from the implementation of soil cells to divert the load from pavements has been determined to inevitably lead to a decline in tree health over time.

Soil rejuvenation
Soil rejuvenation can occur If organic plant material from the tree canopy, such as leaves and branches, falls onto the soil, it can be decomposed by various soil organisms like earthworms, fungi, and bacteria.

External stability
Due to the confinement of roots within above ground continares and bunker tree systems the primary function of tree roots becomes the absorption of essential nutrients, water, and oxygen. The role of providing the tree with stability, which typically occurs alongside the absorption function, must be addressed through external means.

While this may initially appear counter intuitive, there are numerous examples where trees are supported by external structures. Notably, the techniques employed in Japan for character trees, which involve supporting long branches to promote their growth and beauty, have proven to be effective.

Additionally, methods to ensure tree stability, such as using cables to prevent shallow-rooted trees on top of parking garages from toppling during storms, are widely employed both in Japan and in other countries.

Aeration:
From the starting point of the design for metropolitan trees sufficient aeration and drainages should be taken into acount. This can either be aceived by sufficient soil selections or by appliyng atrificial aeration tubes into the trees growth locations design.

Water and Fertilizers:
The constrained soil volume in contianerized trees and bunker trees significantly limits the capacity for water and nutrient absorption, necessitating alternative sullutions suchs as artificial watering and fertilization.

6 Maintenance core principles

Urban trees must adhere to various regulations and safety measures within their surroundings. Specific guidelines regarding roadsides trees have led to the implementation of structural pruning techniques. A crucial aspect of tree maintenance lies in recognizing that trees continue to grow, therefore the structural maintenance should be an integral element of urban forestry design.

In the following chapter, we delve into the existing maintenance regulations and examine how they are approached. Different countries employ various strategies for pruning street trees, with particular interest in Japan, where pruning methods often extend beyond safety considerations to encompass the aesthetics of tree shapes.

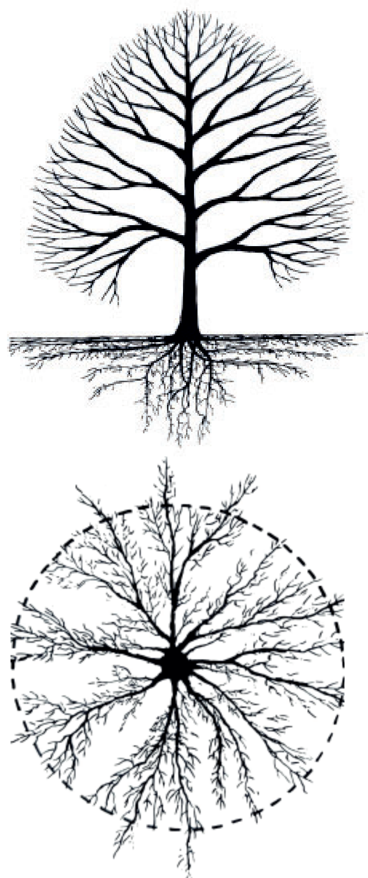
In addition, after various precedent studies have been addressed and conclusions have been made. New alternative ways of tree maintenance are discussed in the last part of this chapter

Growth regulation | 6.01

Maintenance of trees serves various purposes, with one of the most prevalent reasons in urban environments being the need to address undesirable growth proportions. This could manifest as branches hanging too low, obstructing pedestrians or vehicles on streets, or when branches grow excessively close to building façades.

Different countries employ distinct rules and regulations in this regard. It is imperative to comprehend the rationale behind these rules in order to incorporate them effectively into the design process.
In this thesis, maintenance literature from both Dutch and Japanese sources is employed to address various aspects of urban forestry maintenance that require consideration. While the Japanese urban forestry methods differ from those described in Dutch handbooks, both approaches address similar issues but offer different perspectives.

Another intriguing aspect to consider is the drawing style and level of detail used in illustrating trees. While the Dutch guideline report depicts the tree as a simple green mass, the Japanese illustration meticulously delineates the branching patterns, root structures, and the surrounding elements like buildings, sewage systems, and traffic signals. (Fig. 38) The illustration on this page visually demonstrates the interaction between tree elevations and a bottom-up drawing, highlighting the contrasting approach employed in Dutch more generalized drawings. This approach enhances the accuracy and reliability of the drawing significantly. Therefore, the Japanese approach to the illustration of pruning concepts is preferred and applied in the following paragraphs.



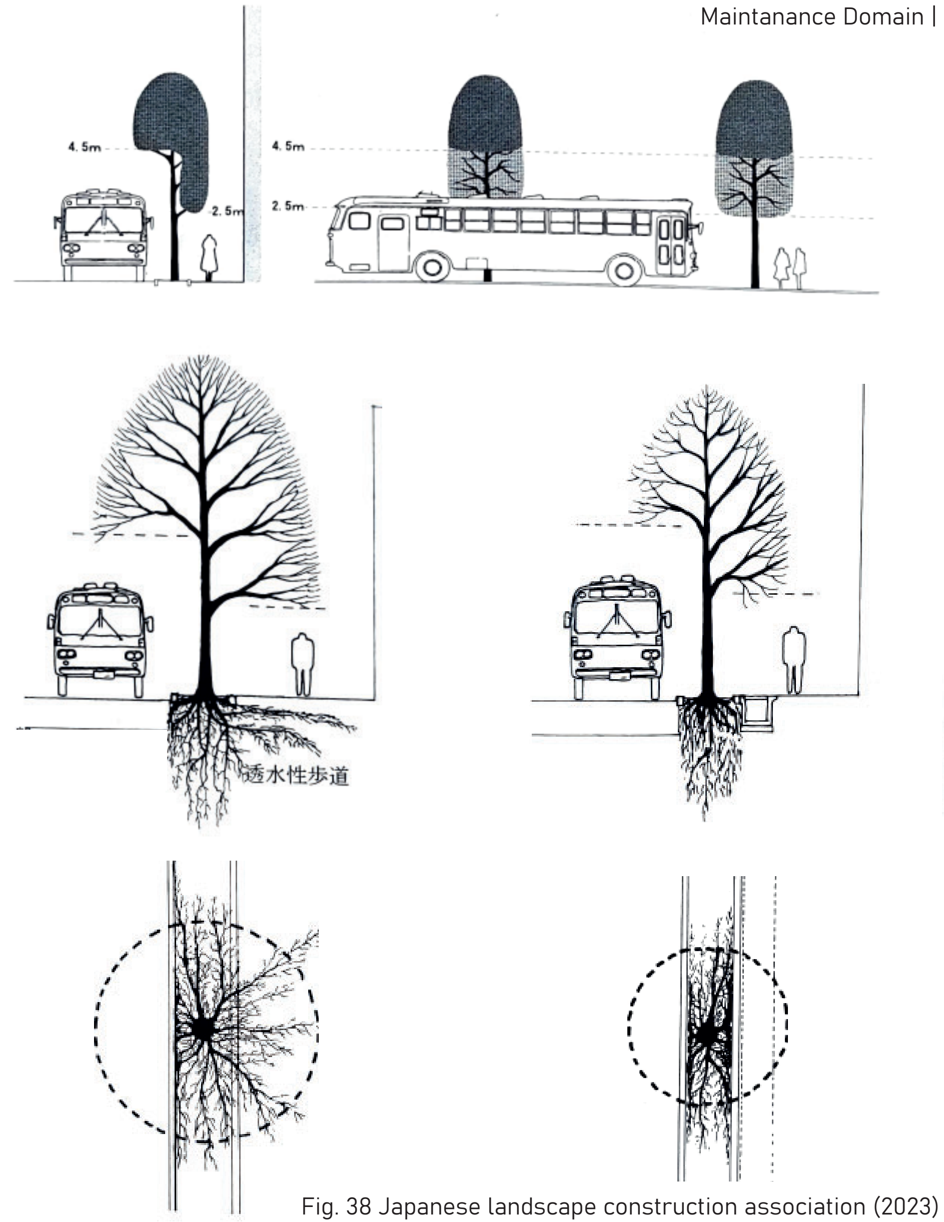


Fig. 38 Japanese landscape construction association (2023)

Canopy pruning | 6.02

As an illustrative example to explain the concept of 'crown lifting', schemes from Japanese tree guideline reports are presented. In a general sense branches above pedestrian areas should be consistently pruned to a height of 2.5 meters, while branches above roadways must be pruned to a height of 4.5 meters. Although these guidelines are relatively straightforward, their practical application necessitates a consistent and high level of maintenance.

The Japanese guidelines also have their rules for pruning methods for canopies close to buildings. The distance in the illustration between the building and the canopy, named C and can be calculated with the following formula: (Fig. 39)

W = (b - dx - C) X 2

One intriguing aspect of this formula is its relationship between the canopy proportions and the street width. By typically setting the distance from the canopy to the buildings (C) to a minimum of 1 meter, and then relating it to the width of the street, it provides a straightforward estimate of the maximum allowable crown size. What can be inferred from this is that on narrower streets, the crown width reaches its maximum proportions more quickly, necessitating regular pruning to maintain the prescribed dimensions. This underscores the importance of proactive maintenance practices in managing urban trees in constrained spaces. (Japanese landscape contractors association, 2023)

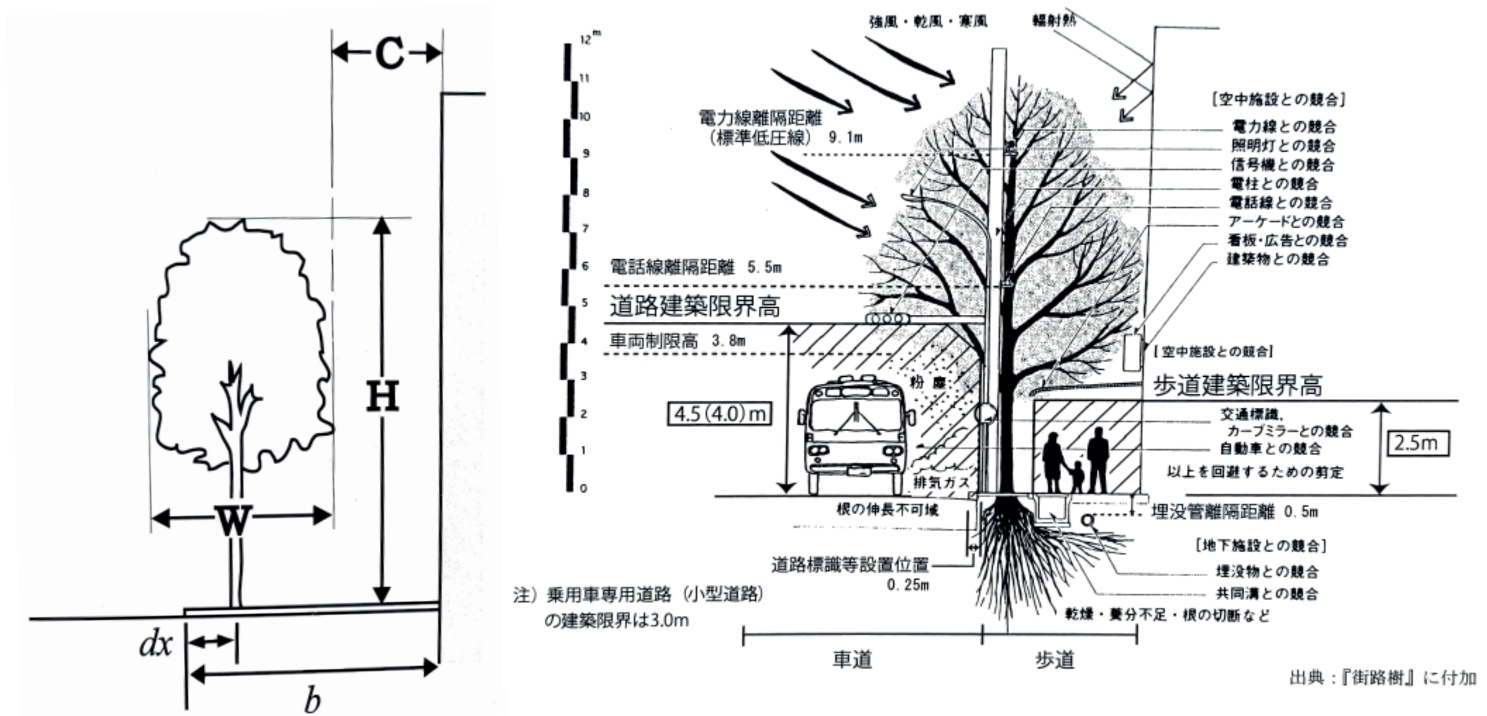
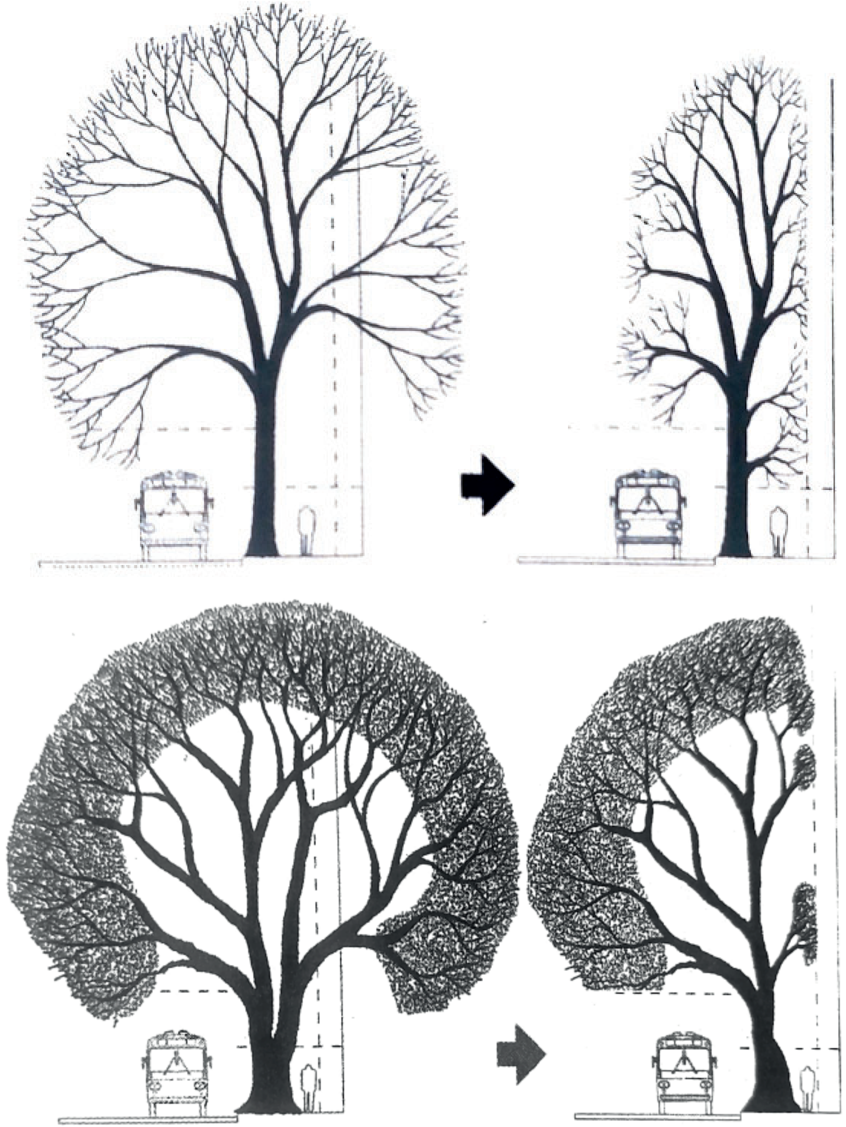


Fig 39. Japanese landscape construction association (2023)



Road side canopy pruning

In addition to addressing low-hanging branches, there are situations where it becomes necessary to reduce the overall height and width of tree canopies to ensure that a tree safely fits within a specific urban area. (Handboek bomen, 2023)

For example, when trees are planted in proximity to surrounding buildings, Japanese tree management recommends pruning the canopy in a way that the trunk maintains an upright form. The branches near the building and above the roadside are carefully pruned to ensure a balanced canopy.

The scheme below illustrated an interesting conclusion. One can observe that the further a tree's trunk is planted from a building, the larger its canopy can grow, and the longer it will take before extensive structural pruning management becomes necessary. However, due to the presence of existing buildings and limited space, often caused by traffic considerations, trees are frequently planted in areas situated close to buildings, positioned between the footpath and fast traffic roads. (Fig. 40)

When designing new streets or renovating old ones, one could make a compelling argument for a new street structure that prioritizes the long-term management and maintenance of trees. This approach may influence the decision to place trees farther away from buildings, diminishing their maintenance and ensuring their health and longevity in the years to come.

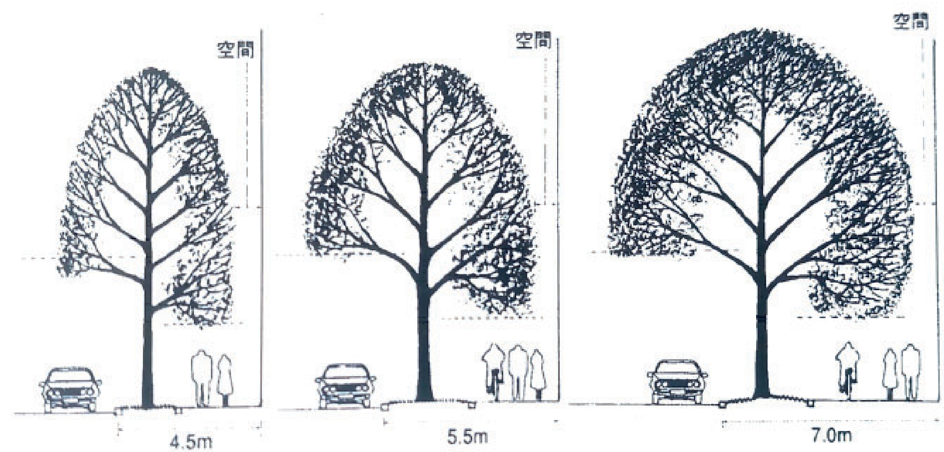


Fig. 40 Japanese landscape construction association (2023)

Japanese Canopy restructuring method

The scheme presented by the Japanese Contract Association describes a method known as “Canopy restructuring” This precise and deliberate selection of pruned branches over time aims to achieve a branching pattern that appears natural. This pruning approach is applicable to a limited number of tree species that are disease-resistant, even when most of their leaves are absent. When comparing the initial and final images of this scheme, it becomes evident that both the overall width and height of the tree have undergone a substantial reduction. (Fig 41)

Tree doctor Hisanori Hashimoto demonstrated and explained this concept through his long-term tree management plan for the trees surrounding the Hongan-ji Temple in Kyoto. The Shimin Ryokuchi project sought to harmonize the temple’s greenery with the urban street trees in Kyoto City. Given that the urban street trees were considerably larger than those within the temple’s walls, Hisanori Hashimoto decided to undertake this long-term restructuring effort. The objective was to create a more balanced and aesthetically pleasing landscape when observing the trees both inside and outside the temple walls.
(internship, Ueyakato landscape, 2023)

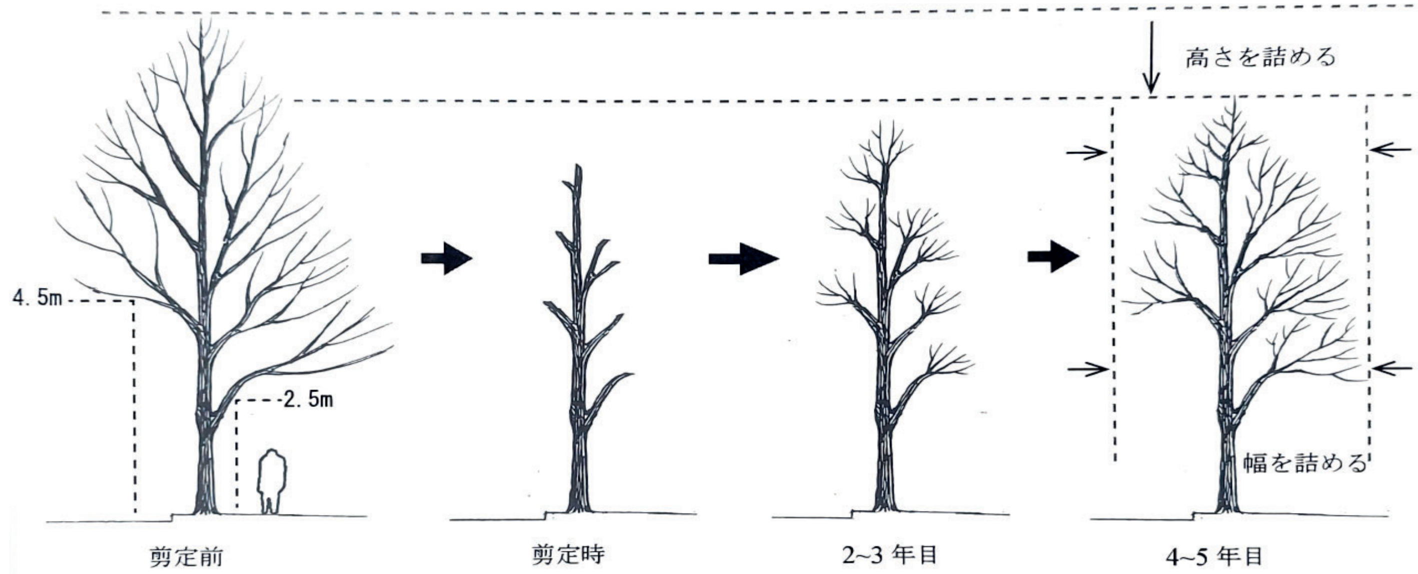


Fig. 41, Hisanori Hashimoto, Ueyakato landscape (2023)

In contrast to the structural pruning of branch systems for trees close to buildings in Japan, some Dutch cities have not actively maintained the branch structure of trees near buildings. As a consequence, these trees tend to grow towards sources of light and the available space within the urban canyon. Although this creates a visually appealing landscape, it's crucial to recognize that this approach can greatly compromise the health, safety, and overall lifespan of these street trees.

While the Japanese strictly follow their prescribed guidelines for the proportions of roadside trees, their trunks and branches have consistently maintained a straight and "natural" appearance, resulting in a well-designed branching structure. Thanks to these efforts, these trees are expected to enjoy a longer lifespan. In contrast, the Dutch trees in the picture have undergone architectural developments over time, making it impossible to restructure their branch systems. Furthermore, their shape and limited space make them unsuitable for effective transplanting preparations, reducing their potential for successful transplantation and longevity.

In recent years, the increasing power of storms, driven by climate change, has led to a higher incidence of falling branches or even entire trees. To mitigate the risk of these hazards, dead branches are routinely removed, and the overall canopy size is reduced.

Fig. 42, Amsterdam Tree accident (n.b.)

Fig. 43, Graaf florisstraat Rotterdam (n.b.)

Soil management | 6.03

Over time, the quality of soil can undergo significant changes due to various factors. In many cases, undesirable alterations in soil quality can be mitigated with different interventions. While prevention is often preferable to addressing issues later, it remains essential to understand how soil quality can be improved. This paragraph discusses various approaches to soil management. Several factors can contribute to changes in soil quality:

For example, **soil compaction** is a process caused by external factors like heavy machinery or vehicle traffic compressing the soil particles, reducing pore space, and making it denser and less permeable to water and air. If soil becomes too compacted it can become too dense for roots to penetrate the soil effectively. (Copijn, 1977)

Soil decomposition is a process that occurs as a result of the absorption and release of water and nutrients, leading to a gradual increase in soil density. In the absence of soil life, this process can compact the soil to such an extent that it hinders further root development. (Bonsai Mirai, 2018)

To mitigate this issue, several strategies can be employed. Core aeration, for instance, involves removing soil cores to create vertical channels for improved air and water circulation. (Fig. 45)

Deep tilling is a method that deals with compacted layers beneath the surface by utilizing specialized air blowing devices to remove soil, improving root penetration without harming the roots. (Fig. 44)

In certain cases, the introduction of soil organisms such as earthworms can also assist in reversing the process of soil compaction and improving soil conditions.

Fig 44, Deep tilling, Boomontzorging.com (2017)

Fig, 45 Core aeration (Van Gaal, 2017)

Soil pollution can occur due to various factors. It can result from acid rain caused by air pollution, as well as from the application of salts to roads for ice melting purposes, which then infiltrate the soil. Additionally, excessive use of fertilizers can lead to soil becoming overly salty, making it more challenging for trees to absorb water through osmosis.

In urban areas, preventing soil pollution can involve minimizing runoff from contaminated areas that could potentially affect the locations where trees are planted for growth.

The remediation of polluted soil must be tailored to the specific type of contamination that has occurred. While in some instances, introducing specific plants that can absorb and detoxify contaminants may suffice, unfortunately, in most cases, excavation and replacement of the polluted soil become necessary. (Fig 46)

Soil depletion occurs when essential nutrients are gradually exhausted from the soil, negatively impacting plant health and productivity. In the absence of adequate amounts of dead organic matter that can be decomposed by fungi, bacteria, and insects, the soil will gradually diminish in nutrients over time. This occurs as trees absorb nutrients from the soil for their growth and overall health, leading to a gradual decline in soil fertility.
To address this issue, enriching the soil with organic matter, such as compost or well-rotted manure, is effective in replenishing nutrients and improving soil structure. Another option is to manually introduce beneficial microorganisms like mycorrhiza and soil organisms such as earthworms, which can contribute to long-term soil rejuvenation.

Soil pH imbalance, whether it's leaning towards acidity or alkalinity, can impede the accessibility of nutrients for plants. Urban tree management often encounters soil acidity issues, primarily due to polluted air in urban areas, leading to slightly acidic rain. As this acidic rain infiltrates the soil, it can lower the pH level. In acidic soil, crucial nutrients such as phosphorus, calcium, and magnesium become less accessible to trees, potentially resulting in nutrient deficiencies that impact overall tree health and growth.

On the other hand, alkaline soil can restrict the accessibility of micronutrients like iron, manganese, and zinc. Urban trees established in alkaline soil may display signs of nutrient deficiencies, impacting their vitality and appearance.

Fig 46, Urban forest dweller (Stewart, 2020)

Analysis and management | 6.04

Many arborist companies offer tree analysis services to assess the overall health of trees and determine the most suitable methods for maintenance. In this paragraph, various analysis methods are discussed to ensure proper tree care.

Two primary types of analysis could be distinguish: manual and automatic. Manual analysis necessitates a person visiting the tree to assess specific health issues. Tree officers use various manuals and guidelines to comprehensively evaluate the tree's overall health.

During such a tree inspection, they can assess the tree's growth, identify any dead branches, and determine if pruning is necessary. It's also possible that a local resident has reported concerns to the municipality regarding the tree's health or the presence of fallen branches. In most Dutch cities, all trees are cataloged in a database, and they undergo periodic inspections, which can vary in frequency based on the tree's location and type. For example, this might occur once every two years.

In contrast, automatic analysis involves the use of devices installed in the soil or around the tree trunk to collect digital data, enabling a more data-driven assessment of tree health.

Soil measurement devices present an intriguing prospect for managing urban forests, especially when they are seamlessly integrated with existing municipal databases. There are various types of soil measurement devices, each serving a distinct purpose. The most commonly used soil measurement devices provide information about soil moisture content, typically ranging from 0% to 100%, but often hovering around 25%. By employing these devices, arborists can proactively address the watering needs of trees that are facing severe drought conditions. (SoilMania – Focus on Soil, n.d.)

Although the initial cost of implementing such technology can be substantial, its potential impact is significant, particularly for newly planted trees, those struggling with health issues, or trees situated in containerized environments requiring artificial irrigation.

If the data from these devices is effectively integrated into municipal databases, it could also facilitate more accurate predictions, ultimately leading to cost savings and a more efficient deployment of these devices in the future.

While the prospect of automated analysis for tree health and maintenance requirements holds promise, it's essential to remember that trees are living organisms, and the trained eye of an arborist will always be necessary to ensure their well-being. However, given the expansive size of urban forests in metropolitan cities, the implementation of automatic or predictive maintenance analysis will inevitably become a necessity.

The automatic soil measurement device has the capability to measure various aspects, including:

Soil moisture content
pH value
Electrical conductivity (salt levels)
Oxygen availability
Temperature

Fig. 47 Soil moisture measure device by TreeMania, (2023)

Year cyclus of trees | 6.05

Trees exhibit seamless responses to seasonal changes, as illustrated in the scheme (Fig. 48) depicting their annual cycle. A significant portion of a tree's seasonal behaviors is governed by fundamental principles:

One such principle is Photoperiodic Triggering, wherein trees intricately synchronize their actions with variations in day length. This precise photoperiodic adaptation governs the timing of bud break in spring and leaf drop in autumn, facilitating a seamless alignment with shifting seasons. The quality of daylight, encompassing wavelength and spectral composition, wields significant influence over critical processes such as leaf development, photosynthesis, and the initiation of flowering.

Furthermore, Temperature Thresholds underpin this orchestration. Distinct to each tree species, these thresholds dictate the emergence from bud dormancy, the commencement of flowering, and the onset of fruit development. They function as nature's precision instruments, ensuring that each seasonal act is enacted in precise accordance with the annual calendar.

Understanding the activities of trees during different seasons enables precise maintenance actions, such as various pruning practices and tree transplantation. Incorrect timing of these actions, during different phases of tree activity, can lead to tree mortality

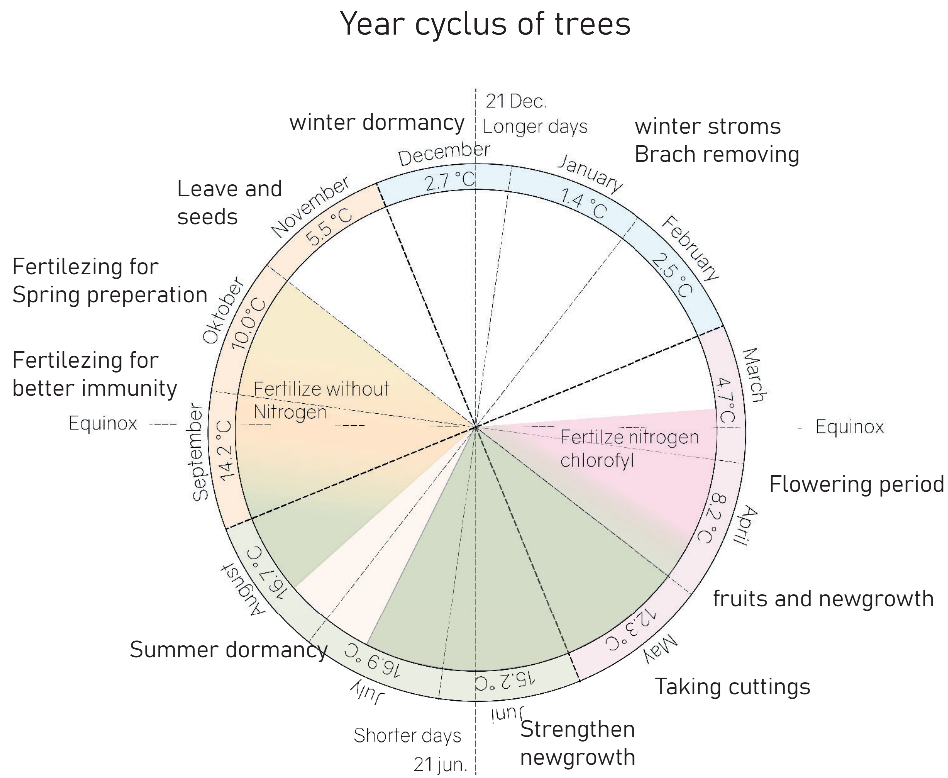


Fig. 48, Year cyclus of trees

Winter (December - February): During winter, trees enter a period of dormancy, conserving energy and resources. Humans take advantage of this season to perform tree maintenance tasks such as pruning dead branches or planting new trees in preparation for spring.

Early Spring (March - April): With the arrival of spring, trees break dormancy, and buds swell, leading to the emergence of leaves and flowers. Humans respond by engaging in tree planting activities and assessing tree health, with arborists offering care recommendations.

Late Spring (May - June): Trees reach full foliage, displaying lush greenery. Flowers bloom, potentially leading to fruit production. Human activities during this season include fertilizing, mulching, and addressing diseases or pest infestations through the expertise of arborists and gardeners.

Summer (July - August): Summer sees trees in full bloom, providing shade and habitat for wildlife. Humans benefit from this shade and often water trees during dry spells. Recreational activities near trees, like picnics, become more popular.

Early Autumn (September - October): As autumn approaches, leaves begin to change color, and chlorophyll production decreases. Humans appreciate the beauty of changing foliage, engaging in activities such as leaf peeping and nature walks. Gardeners prepare trees for winter by adding protective mulch or wrapping trunks in colder climates.

Late Autumn (November): In late autumn, trees shed their leaves as part of their natural cycle. Humans participate in leaf cleanup, raking and collecting fallen leaves. Some individuals also perform pruning or trimming to enhance tree health and readiness for winter storms.

(Bonsai Werkzaamheden Kalender - Bonsai Empire, 2023)

Tree Transplantation | 6.06

In some instances, due to a significant change in the urban environment the transplantation of a tree might be desired.(Fig 49)

Jorn copijn, a dutch tree doctor and activist has written a section about the tree transplantations in a his book 'bomen laten leven' that he open up to the public in 1977. in this sections he mentioned the following:

With the advent of modern transportation tools and a deeper understanding of soil, roots, and tree protection, the process of transplanting trees has become considerably more straightforward than in earlier times. Before delving into the technical aspects of tree transplantation, 'Copijn' emphasizes the significant opportunities that arise for enhancing the urban landscape through this practice.
The impact of a mature tree on the urban landscape is incomparable to that of many small trees. Small trees often require years of care and maintenance, which they frequently do not receive. Given the less-than-ideal growing conditions in urban areas, the chances of a small tree maturing into a large, canopy-contributing tree that benefits the urban microclimate are relatively low.
It appears that urban landscape architecture does not always keep pace with the advancements in urban planning. In many suburbs, the practice of planting neat rows of single-species trees persists, despite the vulnerability of such monoculture plantings to diseases.
Why not strategically plant large, mature trees in essential locations within the urban landscape? The concept is to prioritize "character trees" over mere street trees—solitary trees or groups of trees that have a substantial visual impact and significantly enhance the urban microclimate.
Right from the outset, starting with the initial sketch, it is crucial for landscape architects to be involved, fostering strong collaboration between architects and landscapers.
Now, the focus shifts to preparing our mature trees in their original locations for their new roles. lets advocate for a fundamental shift in urban planning. Let us move away from the conventional practice of planting rows of young, vulnerable trees. Instead, prioritize the planting of large, mature trees in strategic locations.

Nearly 50 years ago, Jorn Copijn envisioned the untapped potential of transplanting mature trees to strategic locations within the urban landscape. Remarkably, despite the continuous development of tree transplantation techniques, many trees in urban environments are still planted as relatively small mono-species trees in simple rows. (Copijn, 1977)

Fig 49, Tree transplantation Copijn (2023)

Transportation methods | 6.07

Every project, context, tree species, and tree structure is unique. Depending on the available space both below and above ground, different methods for tree transplantation can be chosen. Currently, five distinct methods for transplanting large trees have been developed, as illustrated in the scheme below: (Fig. 50)

Each method offers specific advantages and is chosen based on the particular requirements of the project and the characteristics of the tree being transplanted.

1. Tree Mover:
The tree mover is a specialized truck equipped with four large blades designed to lift a tree out of the soil in a single motion. While efficient for smaller trees, it may not be suitable for larger specimens, as the blades can potentially damage the tree's root system. However, in situations where it is applicable, this method offers rapid transplantation without the need for additional vehicles.

2. Crane with Tree Base:
This method is commonly employed for tree transplantation. Before lifting the tree, an external structure is installed beneath the root system. Adequate space is required around the tree to accommodate the installation of this external structure. When lifting the tree, the forces are evenly distributed beneath the root mass. Additional vehicles may be necessary for long-distance transportation. Tree Crane

3. Crane without Tree Base:
When space constraints prevent the installation of a tree base, and the tree's weight permits, a soft rope is used to secure the tree for transplantation. Pruning the canopy is recommended to enhance stability by shifting the weight to the bottom and reducing swaying caused by wind. However, it is important to notice that there is a risk of cambium damage, which could potentially lead to the tree's demise. Additional vehicles may be required for long-distance transport.

4. Tree Crane with Bare Roots:
In situations where tree roots are entwined with underground cables, tubes, and sewage systems, a delicate approach is necessary. This method involves using air pressure to carefully remove the soil around the roots and disentangle them from underground infrastructure. This process allows the tree to be lifted. It's important to note that the soil around the roots contains crucial fungi and bacteria that facilitate nutrient absorption for the tree.

Unfortunately, these symbiotic relationships are disrupted when this method is employed. Pruning the tree canopy is advisable to enhance stability and minimize swaying during transport. External stability, both vertical and horizontal, is crucial since bare roots offer no inherent support post-transplantation. This method demands extensive and precise post-transplant care.

5. Tree Puller:
The tree puller method is suitable for very heavy trees with minimal transportation distance. It involves installing a sled beneath the root mass, and ropes are used to pull the tree to its desired location. However, this method can only be utilized if the site conditions permit its application.

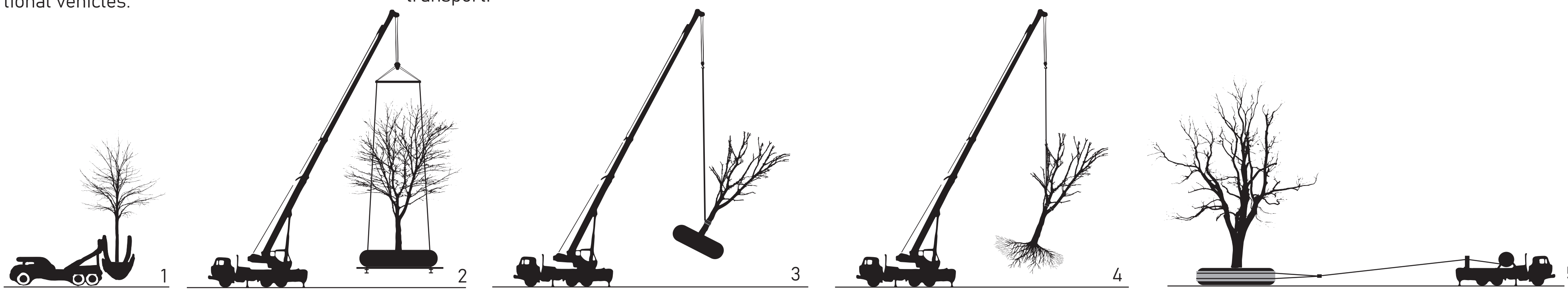


Fig 50, Tree transplantation Methods (2023)

Conclusion | 6.08

The maintenance of trees within any urban environment should be integrated as a critical starting point for urban forestry design. The technical design of urban spaces should be developed with the capability to seamlessly accommodate the diverse requirements of tree maintenance. While various methods for canopy pruning, soil management, tree transplantations, and tree health analysis are at our disposal, it's evident that the technical design of the growth medium for urban trees has not fully evolved to meet these demands.

An essential and critical aspect of promoting the growth of mature trees within urban landscapes is the practice of protecting and transplanting medium-sized trees instead of choosing to replace them with smaller trees when urban development necessitates their removal.

The fact that these excisting trees have already attained a reasonable size is a testament to their resilience and tenacity. As stewards of our urban environments, we bear the responsibility of relocating these medium-sized trees to pivotal locations within the city.

In these critical locations, large mature trees can stand as proud and central focal points. They have the potential to create a substantial visual impact and significantly enhance the urban microclimate. By preserving and transplanting medium-sized trees to strategic positions, we not only preserve the character of our urban landscapes but also contribute to a greener, more vibrant, and climate-resilient urban future.

Summarizing the most important subjects addressed in this chapter into a design brief would state the following concepts for new technical and strategic interventions:

Trees should be strategically positioned within the urban fabric to minimize the need for canopy pruning. In cases where canopy pruning is necessary, it should be easily accessible for maintenance workers.

Transplanting a tree should ideally be a process that can be carried out at any time, without requiring extensive long-term root formation preparation and without the need to cut significant parts if the root system.

Soil around the roots of urban trees should be capable of being maintained through two primary means. Firstly, through the natural process of soil rejuvenation, which occurs when a healthy ecosystem of soil life and organic materials creates a fertile environment. Secondly, when external interventions are necessary, the soil should be readily accessible for maintenance purposes.

The growth of trees should strategically reduced when heavy maintenance in the near future is evidend.

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New maintanance principles for urban forests

Trees in urban environments inevitably undergo growth, leading to various maintenance requirements over time. As an integral component of urban forestry management, the maintenance of trees should be thoughtfully integrated into the design process, ensuring a strategic approach to tree care and longevity.

During the initial tree planting phase, it is essential to incorporate a comprehensive maintenance plan right from the start. This may encompass a range of measures including pruning regimens and soil revitalization. It is important to note that the improvement of urban forest resilience and longevity relies on both the careful management of newly planted trees and the maintenance of existing ones.

Adaptation
Excisting Trees in metropolitan city centres that have attained a reasonable size should be protected and apprciated. The fact that these excisting trees have already attained a reasonable size is a testament to their resilience and tenacity.
As stewards of our urban environments, we bear the responsibility to relocate these medium-sized trees to pivotal locations within the city when urban development would require there removal. Trees and humans form a symbiotic relationship within metropolitan city centres. By taking good care of the trees they will ultimately take care of us by adding their various ecosystem services and values to the environments we live in.

A**lternatives to structurally pruning**
Normally, when a tree starts to outgrow its location, consistent pruning of the canopy is needed to constrain its overall proportions. Additionally, it's important to note that some tree species withstand thorough pruning better than others. In cases where trees reach specific sizes that necessitate annual pruning to maintain a sustainable and healthy upright structure, the long-term maintenance costs for such trees can escalate. Nevertheless, regardless of the amount and quality of pruning, the trunk will inevitably expand over time, causing issues with the pavement around the trunk. If the the urban context permits transplantation preparations, as an alternative to traditional canopy pruning, an intriguing concept involves around transplanting oversized trees to new locations. Such an approach not only has the potential to reduce long-term maintenance costs but also allows the tree to mature and increase its accumulated value. As the tree grows, it enhances its capacity to provide a wide range of ecosystem services, further benefiting the environment and the urban landscape.

Another approach to minimize the need for structural pruning involves better tree placement. If trees are strategically located in areas where they have enough above-ground space to develop their trunk and branch systems in a balanced and upright manner, the need for consistent pruning can be reduced.

Soil rejuvations
The overall health of trees is inherently linked to the quality of the soil and its capacity to supply water, oxygen, and nutrients. Typically, in natural environments where there is a direct interface between the tree's canopy and the soil, a process involving the decomposition of fallen leaves, seeds, and branches by microorganisms such as bacteria, fungi, and insects contributes to the maintenance or even enhancement of soil quality over time. Regrettably, in numerous urban city centers with extensive hardscaping, the soil surrounding tree roots often lacks interaction with organic matter, resulting in the absence of soil biota causing soil depletion. This often leads to a notable deterioration in the health of the trees.

As a potential remedy to this inherent issue in urban forestry, one alternative approach involves the deliberate introduction of soil biota and organic matter to artificially rejuvenate the soil.While this approach may not constitute a permanent solution to the challenge of soil depletion, it can serve as an initial measure to restore the health of existing trees. Over time, this may enable the possibility of transplanting these trees and reimagining urban design in a manner that facilitates natural, automatic soil rejuvenation.

7 Spatial strategies

This chapter shifts its focus to a larger scale and a longer time frame concerning the management of trees in the urban forest. While the previous chapters discussed the technical and maintenance aspects of urban trees, this chapter explores how these techniques and maintenance practices can be applied at a broader scale throughout the lifespan of trees in the city.

Given that both the urban environment and the trees in city centers are continually changing, trees may not always align with their surroundings over time. Therefore, this chapter delves into the domain of spatial strategies, where we examine the potential of transplanting trees to new locations. The first paragraph explores the zones of intersection, serving as a foundation for understanding the spatial challenges. Subsequently, a range of spatial typologies are elaborated upon in detail.

The chapter concludes with a reflection on the potentials and limitations of these spatial strategies.

Fig 51, road side street trees, Soho london (2023)

Zones of intersection | 7.01

This illustration delineates three distinct areas of the tree where intersections or changes can occur as the tree's proportions or the urban environment evolves.

The first zone of intersection relates to the tree crown. Trees can attain remarkable size and age, and throughout their growth and development, the proportions of the tree crown are in constant change. Especially in the case of roadside trees, the changing proportions of the tree crown can lead to an imbalance between the tree and its urban context.

In the second zone, which highlights the tree trunk, various changes can occur. Not only can the thickness of the trunk create challenges over time in its growth location, but also the surrounding area of the trunk may undergo alterations. For example, in market or event spaces, these areas are subject to constant change. In such instances, relocating trees could be a compelling solution to maintain flexible urban environments.

The third zone underscores the intersection between the roots and underground facilities. As the root structure expands over time, it can lead to various types of damage to both pavement and underground facilities. Additionally, the maintenance of underground facilities often necessitates the removal of existing trees.

Urban development and Tree growth
Transplantation decision making

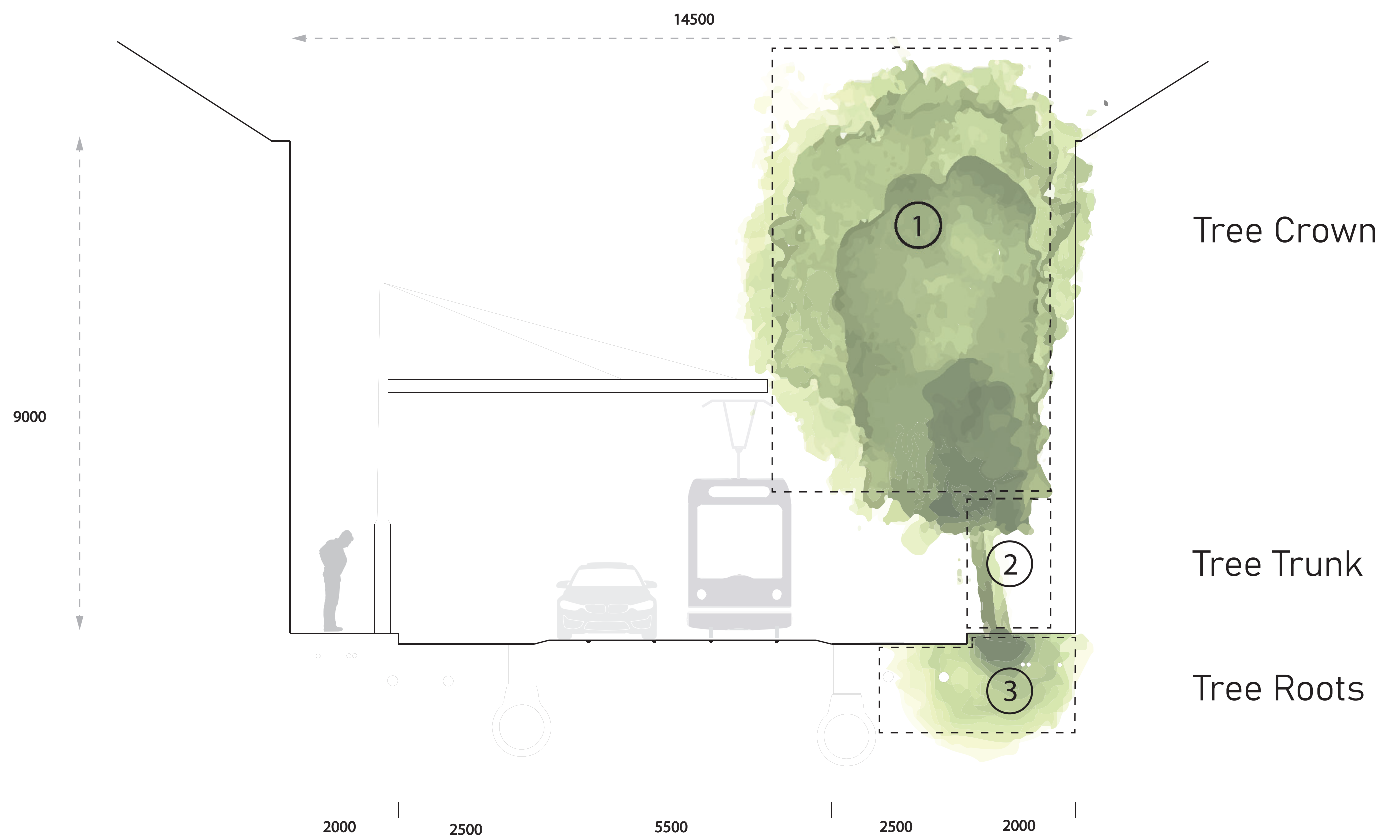

Fig 52, Transplantation descision scheme

Spatial Typologies | 7.02

Given the dynamic nature of both trees and the urban environment, tree design and management should consider the full lifecycle of trees within urban settings.Depending on the situation of the urban context and the proportions of a tree one could argue to relocate a tree to a new location where it can continue to grow.

The graph (Fig. 63) on this page is divided into 7 spatial typologies representing trees in a specific life stage in the urban environment. These stages range from 1 to 7, with each stage indicating a progressively larger tree. Stage 7 in the scheme represents large trees that will no longer be transplanted. These trees often hold significant cultural value as they have spent their lives in various locations throughout the city.

As a tree outgrows its spatial typology in the urban context, there's an option to transplant it to another suitable location within the city. This approach ensures that the tree's growth is well-matched to its surroundings.

However, determining when to transplant a tree is a decision that requires careful consideration. The following paragraphs provide descriptions of the 7 typologies, starting with field-grown nursery trees.

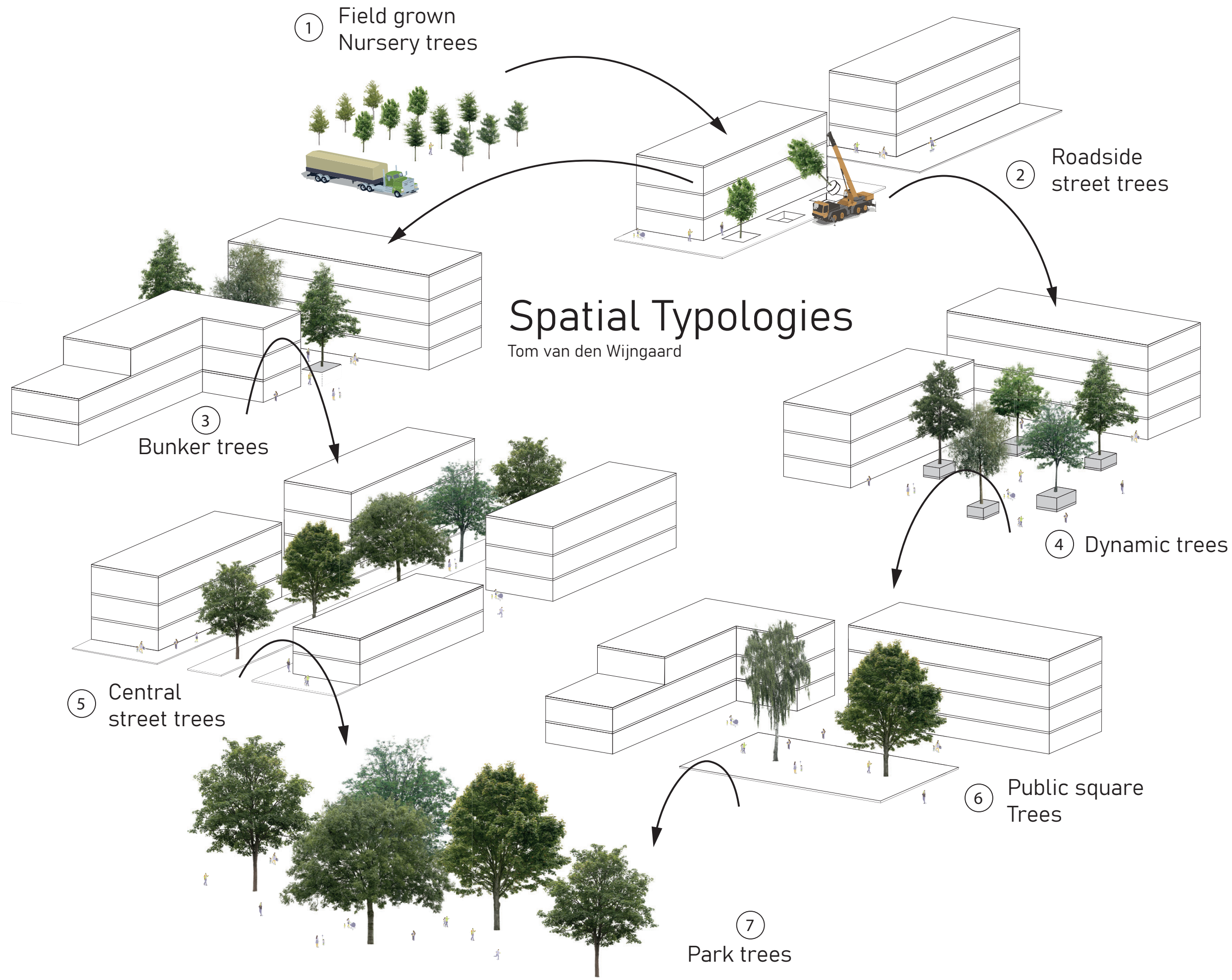

Fig 53, Spatial strategy scheme

Field grown nursery trees | 7.03

Most trees introduced into urban forests originate from field-grown nurseries. These trees are typically cultivated in expansive fields, with growth closely monitored to meet specific size criteria, including tree height and stem diameter. Nursery conditions are optimized to encourage rapid and robust growth. (Fig. 64)

Upon reaching the desired dimensions, these trees are harvested and transplanted into the urban environment. This transplantation can occur in various spatial typologies, including sidewalks, gardens, parks, central tree locations, rooftops, and public squares. Due to the relatively small proportions of field-grown nursery trees when they are introduced into the city, it is a common practice to plant them along roadside streets.

Fig 54, Field grown nursery trees, Ebben (n.b.)

Road side street trees | 7.04

Roadside street trees, especially when planted in close proximity to buildings, fall under a spatial typology that imposes the most restrictions on their canopy proportions. This spatial typology is positioned as the first category in the 'Spatial Typologies' diagram.

The maximum allowable canopy proportions are directly linked to the width and layout of the street. Most urban streets prioritize the space needed for cars, which often results in trees being planted in the narrow area between the pedestrian walkway and the road, close to the buildings.

The closer the tree is planted to a building or other obstructions, the more frequent and consistent maintenance and management of the tree crown becomes necessary. Unfortunately, such maintenance is often lacking, which is why roadside street trees in Dutch cities rarely reach maturity.
(Fig 55)
The maintenance of underground facilities in narrow streets significantly affects the health and longevity of trees. Every 30-60 years, the underground sewage system must be renovated, which often involves the replacement of all the trees, espacially in narrow street.

Transplanting trees falling under this category can greatly extend the lifespan of trees in the urban environment.

Fig 55, Distorted road side street trees, Soho london (2023)

Bunker trees | 7.05

The third category of trees in the 'Spatial Typology' diagram is known as "bunker trees." These trees are situated within a construction that redistributes the loads of the pavement and people, relieving pressure on the soil surrounding the tree's roots. Bunker trees are predominantly found in densely urbanized areas where space is limited.

For bunker trees, the primary limiting factor is often the trunk's development. As seen in the pictures, bunker trees typically have a special type of grill or structure surrounding the trunk. This design allows pedestrians, cyclists, and even cars to approach the tree closely without compacting the soil around the roots.

One potential improvement in the design of bunker trees could involve the incorporation of a flexible grill that can adapt to the thickness of the tree's trunk. Alternatively, when bunker trees outgrow their current location, they can be transplanted to other suitable sites.

Fig 56, Bunker trees, St. Pancras London (2023)

Dynamic trees | 7.06

The fourth category in the "Spatial Typologies" diagram is "dynamic trees." These trees have their roots contained in aboveground boxes or containers, offering several benefits.

Dynamic trees are often used when there is limited underground space for root growth due to the presence of numerous underground facilities in densely paved urban areas. Aboveground containers provide a solution to enable tree growth in such constrained locations.

What sets these trees apart is their ability to be relocated at any time. This feature makes them well-suited for highly dense and constantly changing urban areas like marketplaces and event spaces.

The main limiting factors for this category are both the root structure and the canopy. When the roots have filled the container completely or the canopy has become too large for easy relocation within its container, trees in this category may be moved to the next phase within the "Spatial Typologies" diagram.

Fig 57, Container tree design a glasshouse st. London (2023)

Central street trees | 7.07

Central street trees are classified as the fifth category in the "Spatial Strategy" diagram. In contrast to roadside street trees, which face limitations in canopy growth due to their proximity to surrounding buildings, central street trees have the ability to develop large canopies because they have more available above-ground space. This distinction allows central street trees to reach greater sizes and proportions. Nevertheless, the size and proportions of central street trees can still be influenced by the layout and width of the streets, imposing certain limitations.

Transplanting large central street trees necessitates careful preparation, Unforenately this is not always feasible due to the limited space available for adequate root intervention.

Fig 58, Centre street trees near Oxfort circus London (2023)

Public square trees | 7.08

Trees in public squares constitute the 6th and final category in the hardscaped urban environment. In most cases, these trees can grow to enormous proportions since there are hardly any above-ground obstructions. Transplanting public square trees might be considered when urban development necessitates their removal. Especially when public square trees have reached remarkable proportions, transplanting them to new locations could preserve their accumulated value. However, transplanting large trees in public squares can only be carried out if the urban context allows for sufficient preparation.

Fig 59, Public square trees, Rotterdam by Treebuilders (2023)

Park trees | 7.09

The last category in the spatial typologies diagram involves park trees. These trees often have an enormous amount of space and proportions so large that transplanting them would not be desirable in most cases. Throughout the life of trees in the spatial typologies diagram in the urban environment, their proportions are constantly managed by tree workers to match their surrounding urban context. In the last category of park trees, the trees are left to grow in any shape or way desired by the tree itself.

The strategy described in the diagram implies that over time, all trees that continue to grow in the urban environment end up in the parks. At some point, this means that the existing parks will be full of large trees. At this stage, some trees might get cut, while others remain in a specific phase in the diagram.

Fig 60, Great Cherry tree, Rukigien Garden, Tokyo (2023)

Conclusion | 7.10

Trees in the urban environment are in constant interection with the urban context. Since both the urban environment and the proportions of the trees are ever changing inevetably there will be situations where trees no longer match their urban context. In most cases we see that when trees that dont match their urban context they are removed and replaced by small nursery trees. This often occurs in situations where trees are closely situated near surrounding structures and buildings or in streets with a high density of underground facilities that require maintenance. During these underground facility maintenance operations, existing trees often need to be removed.

The spatial mismatch between the urban forest and the urban fabric often prevents trees from reaching maturity. A long-term, integrated spatial strategy is frequently lacking. Once trees are planted in specific locations, the only intervention to match the tree with the urban context is consistent pruning and growth regulations. While this is done effectively in some cases, there are many examples where tree growth is not regulated, leading to dangerous and distorted tree architecture, ultimately resulting in the removal of the trees.

Using the spatial typology diagram, various situations have been analyzed and described. Each typology presents unique challenges that various actors and initiators must address. From the moment a tree is planted, a comprehensive, long-term strategy should be devised, considering the tree's growth stages, the evolution of the urban context, and the responsible parties involved in urban forest management. Adopting a proactive approach can significantly increase the longevity and resilience of the urban forest.

Summarizing the conclusion drawn from this paragraph into a design brief the following concepts could be stated:

The ever changing nature of both trees and the urban environment ask for a long term adaptive aproach to secure a continues match of the trees proportions and its urban context over the lifespan of metropolitan trees.

From the moment a tree is planted in the urban context, an assessment of the various stages of the tree and the responsibilities of the involved actors and initiators should be conducted to enhance the longevity and resilience of the urban forest.

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New Spatial Strategies for the management of urban forests

In this chapter, various situations have been analyzed and described using the spatial typology diagram. One of the primary conclusions is that trees, especially in narrow streets, rarely reach maturity. Whenever the urban context or the tree's proportions change, a mismatch between the tree and its surroundings occurs. In many cases, this has led to the removal of medium-sized trees and the introduction of new small nursery trees.

Adaptive Urban Forestry management
As an alternative to this approach, the transplantation of existing metropolitan trees each time the urban context or the tree's proportions change could enhance the sustainability and longevity of the urban forest. This aproach is giving trees the opportunaty to addapt the the changing urban context. This could result in a stady continues growth of the urban forest when looking from a long term perspective.

The spatial typology diagram illustrates different situations where trees are situated within the urban environment. Each typology presents its unique challenges concerning the alignment of urban context and trees. Depending on the urban context and the choice of tree species, a mismatch is bound to emerge sooner or later.

Each time a tree has reached its limited proportions for that specific spatial typology transplanting the tree to a new better matching typology could enhance the overall value of the urban forest and its longevatey

Organisation & responsibility
The orchestration of tree transplantation involves several challenges. Firstly, adequate preparation is often required to enhance the success rate of the process. A proactive approach is essential, meaning that the intended transplantations need to be known in advance so that necessary preparations can be made, aligning with urban development projects.

The responsibility for initiating tree transplantations to new typologies can vary in specific situations. Ultimately, the tree's owner is accountable for taking action, which, in most cases, falls upon municipalities. However, tree workers or residents often bring attention to dangerous or unhealthy trees, prompting the municipality to decide whether transplantation is advisable.

Timing & limitations
The successful transplantation of trees revolves around precise timing. Coordinating tree transplantation preparations with the maintenance of underground facilities and street upkeep requires effective communication among various organizations.

There are also limitations on which trees can be transplanted successfully. Firstly, if the space around the roots is insufficient for adequate preparations, the success rate of tree transplantations is significantly reduced. Additionally, the overall size of the tree's canopy must match the space required for transporting the tree through the city to its potential new location. If transplantation has been delayed for many years, some trees might have developed such distorted tree architecture that transplantation becomes undesirable or even irresponsible.

Unfortunately, close communication between various organizations has not yet proven to be sufficient for the maintenance and management of metropolitan trees in challenging locations. New platforms that stimulate this communication and encourage an adaptive long-term strategic approach need to be developed in order to successfully implement adaptive urban forestry management methodologies.

8 Data-driven management

Many cities bear the responsibility for the care and management of a significant number of trees within their boundaries. To fulfil this responsibility, municipalities often collaborate with private companies that handle tasks such as tree planting, maintenance, pruning, and the removal of fallen trees or branches. In the modern era, municipalities like Rotterdam maintain extensive digital databases containing various details about their municipal trees. (Dataplatform platform Rotterdam, 2023.)

These databases encompass information such as planting dates, tree heights, species, monumental status, and overall health indicators. These digital repositories of tree data serve as a crucial starting point from which urban forestry can be effectively managed, analyzed, designed, and maintained.

In this chapter, various aspects of current-day urban forestry management are addressed, with a primary focus on their potential, challenges, and uncertainties.

Fig 60, Rotterdam, Netherlands (n.b.)

Data-driven management | 8.01

Digital databases of individual trees have the capacity to analyse the urban forest comprehensively. These datasets can help with the overall management of the urban forest. They can provide critical information about the maintenance needs, locations, lifespan expectancies, but also design recommendations. In this paragraph we look at the various applications the use of Data-driven urban forest management can bring.

Within the methodology scheme, data-driven management acts as the central hub, facilitating interactions with the other three domains across different scales and timeframes, each contributing uniquely to urban forest management.

The technical domain primarily concentrates on designing suitable growth locations for individual trees. Maintenance management places its focus on the well-being of tree groups, while the spatial strategy domain zooms out to consider the management, maintenance, and policies governing the urban forest at a larger scale. In an ideal scenario, every domain should seamlessly upload its data to the central database. This interconnected approach enables effective communication, adaptation, and proactive responses to the dynamic changes and developments within both the urban forest and its surrounding urban context. Throughout this chapter we delve deeper into each interaction between the domains

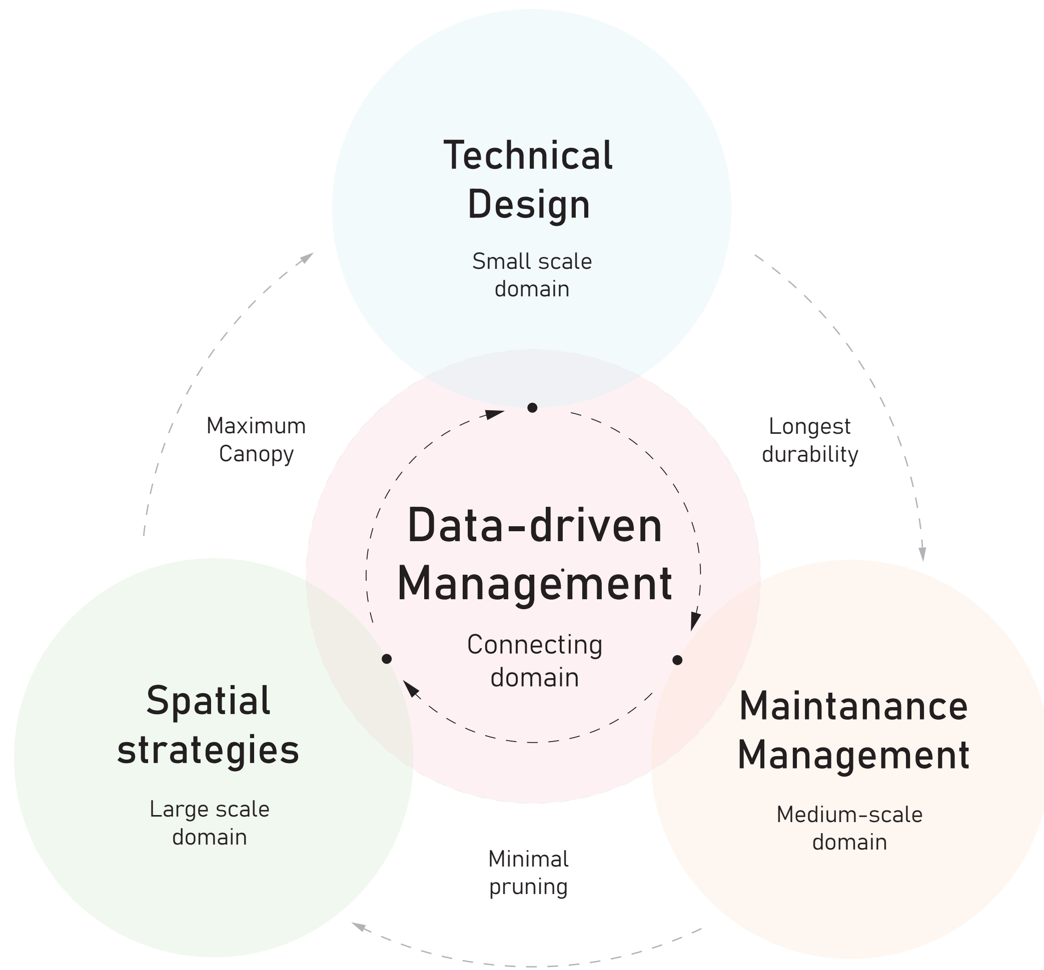

Fig 61, Mobile Forestry Methodology

Maintanance Domain | 8.02

Municipalities like Rotterdam possess extensive datasets concerning their urban forests. (Bomen, Rotterdam dataplatform, 2023) These datasets are enriched through regular data collection efforts conducted during individual tree assessments, often performed by private tree maintenance professionals. These assessments provide a wealth of data points that can be systematically integrated into the municipality's existing database. Gemeente Amsterdam Boombeheer, 2023.) Notably, contemporary databases commonly include comprehensive details related to the following aspects:

Tree Species and Variety: Precise identification of the tree species and its specific variety or cultivar is crucial for managing urban forests effectively.

Tree Location: Accurate geographic coordinates or addresses of individual trees are recorded to facilitate maintenance and monitoring.

Tree Health and Condition: Regular assessments gauge the overall health and condition of each tree, including signs of diseases, pests, or structural issues.

Tree Size and Growth: Data on tree height, canopy spread, and trunk diameter at breast height (DBH) are documented to track growth patterns and assess maturity.

Maintenance History: Records of past maintenance activities, such as pruning, fertilization, or pest control, help inform future care plans.

Planting Date: Knowing the tree's age, or its planting date, aids in predicting future maintenance needs and overall lifespan.

Environmental Conditions: Environmental factors like soil type, sun exposure, and proximity to buildings or infrastructure are considered when evaluating a tree's health and growth potential.

Root System Assessment: Assessments may include information on root health, depth, and potential root-related issues affecting nearby infrastructure.

Ecosystem Services: Some databases incorporate data on the ecosystem services provided by trees, such as carbon sequestration, air quality improvement, and stormwater management.

Public Safety: Records of any potential safety hazards associated with trees, such as overhanging branches or leaning trunks, are documented for public safety purposes.

Inventory Updates: Regularly updating the database with new assessments and changes in tree status ensures its accuracy over time.

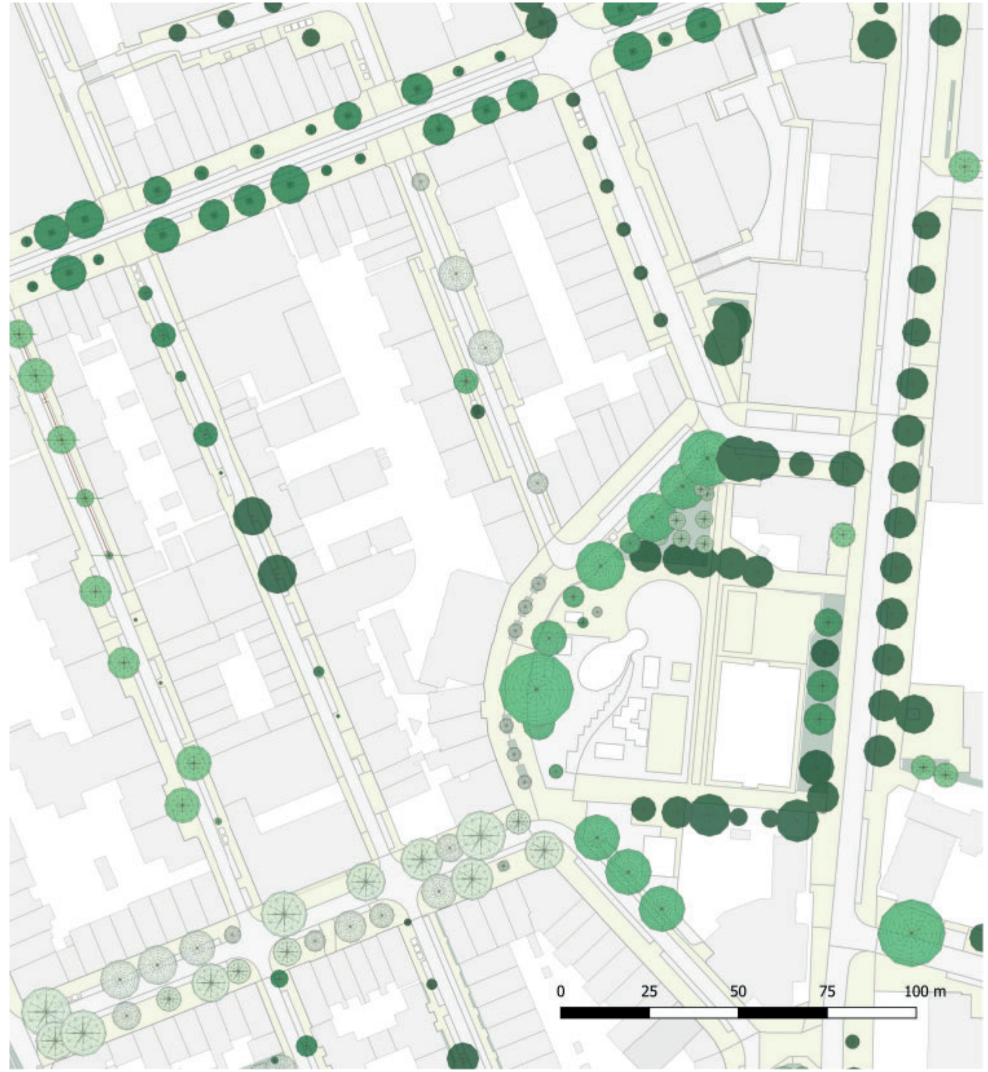

Fig 62, Tree data-base analysis

Technical Domain | 8.03

The diverse range of tree data proves invaluable for municipalities in several ways. While these datasets are essential for monitoring the maintenance and immediate needs of urban trees sush as pruning schedules, pest control, and any required remedial actions they also have a broader impact on urban forestry management.

For example, some municipal data-bases include not only the information about the urban forest and its various details but also data on facilities that could impede tree growth or plantation. The city of Rotterdam has created a digital twin of the city, comprising information about the precise locations of plumbing, sewage systems, electricity cables, and gas tubes. This data not only helps in identifying potential clashes with tree roots but also provides valuable insights for the technical design of individual trees.

The integration of diverse datasets regarding the interplay between the urban forest and its surrounding urban environment holds the potential to inform crucial long-term strategies and design interventions. (3D stadsmodel Rotterdam, 2018)

For example, municipal databases can support the formulation of long-term strategies for urban forest management, aiding in the establishment of well-defined goals and objectives. These databases can contribute to the crafting of policies concerning tree preservation, tree planting initiatives, and tree protection. Such data-driven insights enable municipalities to establish guidelines that foster the growth of a robust and sustainable urban forest.

In the following paragraphs, we delve into various spatial urban analyses that can serve as a foundation for enduring urban forestry strategies and design implementations.

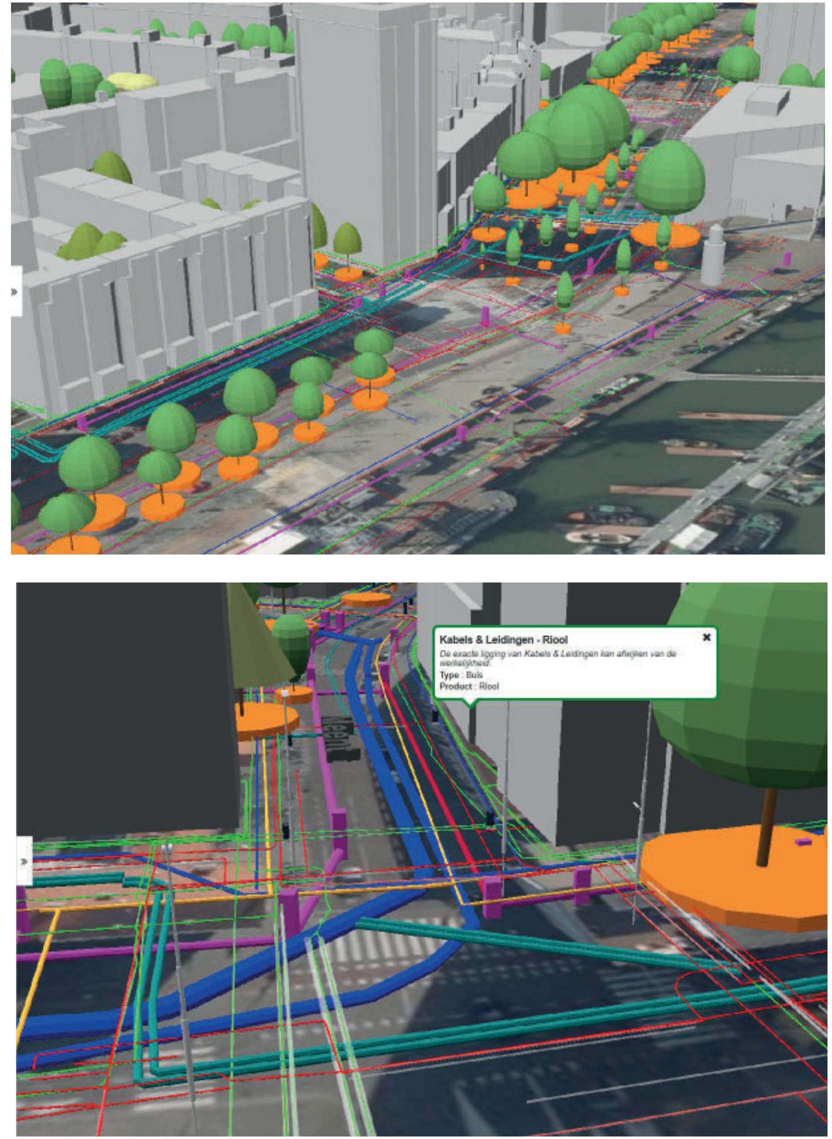

Fig 63, Underground infrastructure, Rotterdam 3D (2023)

Open-sourced data from municipalities provides valuable information for creating various maps that can aid in urban planning and environmental analysis.
Many of the data collected by municipalities are available for download and can be visualized with the use of programs like QGIS. Some common maps that can be generated through the interpretation of such data include Tree Canopy Cover Percentage, Urban Heat Island Effect or for instance Inhabitant Density.

Urban heat Island effect
An intriguing map that can be generated using GIS is the Urban Heat Island Effect map, which visualizes temperature differences resulting from the accumulated heat of hard surface areas that radiate heat at night. By using QGIS, this map can be reclassified to highlight specific temperature differences.

In this map, the hottest areas are depicted as black, indicating an increase in air temperature of nearly 2.8 degrees compared to temperatures outside the city. This significant difference presents an interesting opportunity for the implementation of street trees to address these heat-related issues. The map clearly shows that large trees have a substantial cooling effect, particularly when surrounded by tall buildings, leading to a noticeable temperature reduction in their vicinity. In contrast, smaller trees, represented as smaller black dots on the map, have a far less impactful cooling effect on their surroundings. These data interpretations can provide valuable guidance to landscape architects when considering various design implementations to cool public spaces within city centers, such as Rotterdam (Datasets - PDOK, 2023.)

Population density
Using Geographic Information Systems (GIS), various datasets regarding population densities can be visually represented on maps, providing valuable insights into the green space requirements of specific areas.

These types of analyses serve as valuable tools for strategic planners, helping them identify areas within the city with the most pressing need for new urban forestry initiatives. (Dataplatform Platform Rotterdam, 2023).

Tree database analysis
Another interesting analysis could involve studying the existing trees in the urban forest. For instance, examining areas with the youngest trees may provide insights into the various factors that contribute to the challenges faced by trees in those locations, shedding light on the unique conditions affecting their growth or forcing their removal. Alternatively, studying the largest trees enables the recognition of tree species that typically develop the largest canopies, creating an understanding of which tree species to strategically plant.

By merging diverse datasets, a comprehensive analysis of the urban forest becomes possible allowing for the creation of long term strategies and anticipating management. A critical aspect of aplying these digital twin databases within the management of the urban forest is the continuous need for updates to ensure accuracy and reliability.

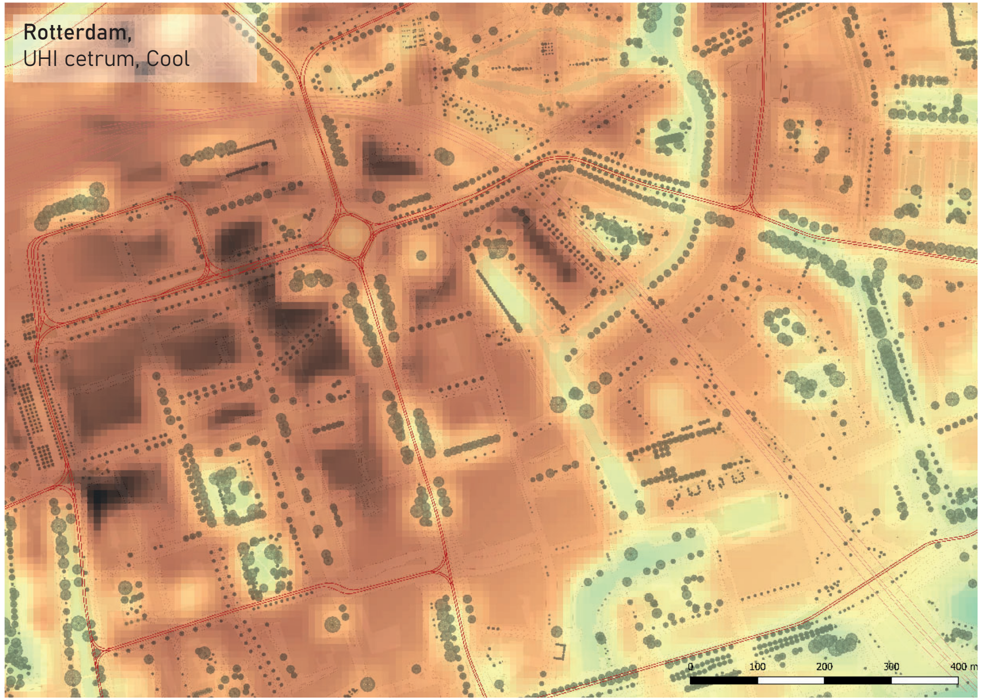

Fig 64, Urban heat Island Rotterdam Stadsdriehoek

Visual Green index
The visual Green Index is an intriguing map that allows for the identification of areas with either a lush green or heavily hardscaped appearance. This index is calculated based on three inputs: the number of trees on the street, the visible greenery from surrounding gardens, and the amount of grass and shrubs visible from the street. Green surfaces are measured in square meters and are considered as a percentage of the total square meters of that street when viewed from a top-down perspective. For longer streets, the percentage of greenery is adjusted to provide an accurate comparison of visible green across different areas of Rotterdam.

These datasets enable the identification of bottleneck areas within the city that warrant closer attention from urban planners and landscape architects. Utilizing QGIS, the map can be reclassified to emphasize specific differences. For example, it can be categorized to highlight areas in the city that lack trees or, conversely, to emphasize areas with abundant tree cover. This analysis aids in pinpointing areas where targeted interventions and planning efforts are needed to address urban and environmental challenges effectively. (Dataplatform Platform Rotterdam, 2023).

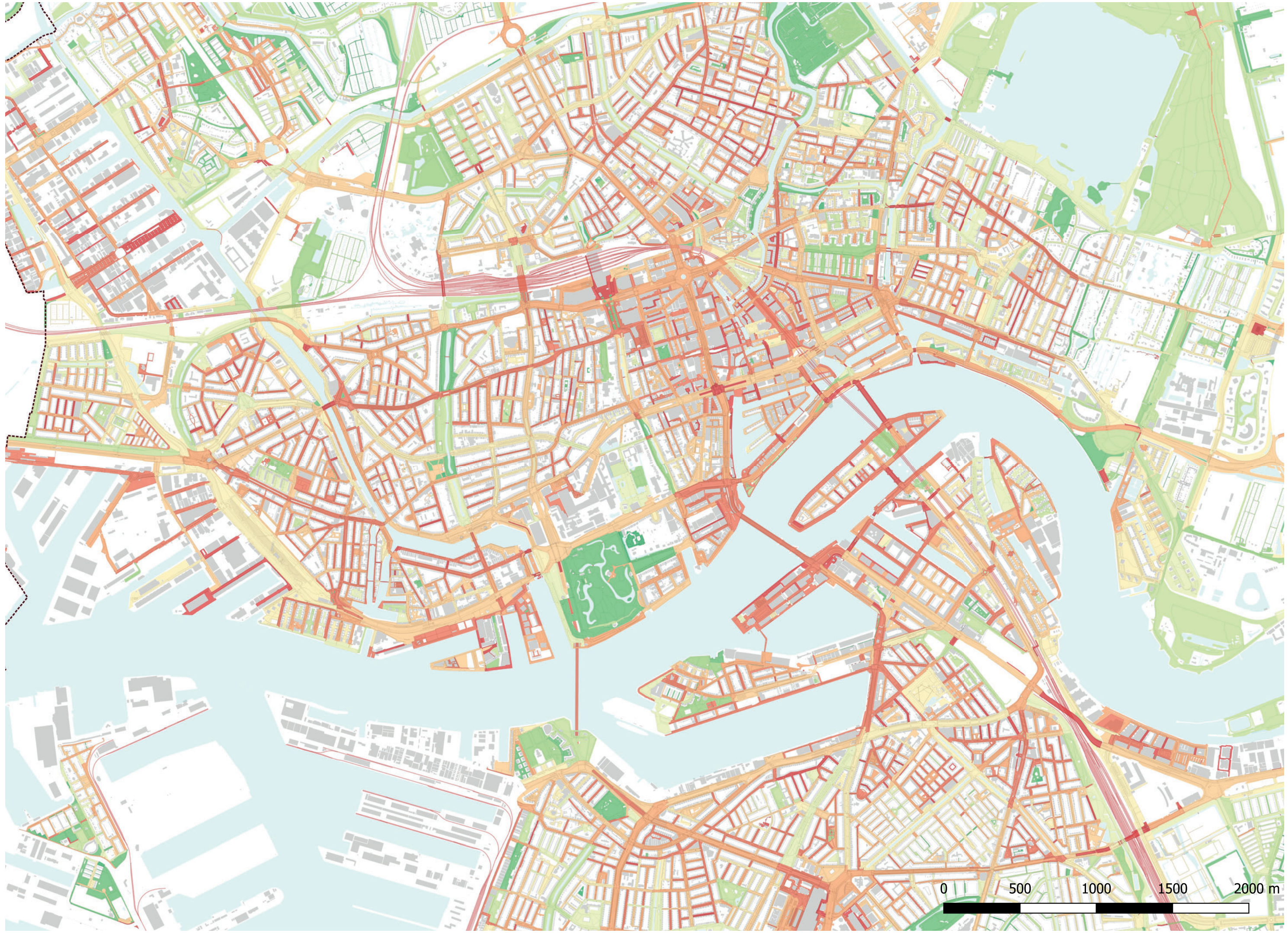

Fig 65, Visual treet index

Utilizing smart databases to generate maps can serve as an initial step for a variety of design interventions. Data related to urban heat island effects, air pollution levels, and available above and underground space, can help urban planners and landscape architects to make more informed decisions about tree species selection and placement.

Strategy & policy design

Trees can serve various purposes to enhance the liveability of city centers and depending on the urban context and aivaileble space in that particular area one can deside to choose for a specific purpuse and coresponding tree selection. By analyzing and quantifying various aspects of the urban context policymakers can leverage this information to establish new objectives for green infrastructure, such as urban forests. For example, by examining neighborhoods with high population densities and urban heat iland problems, policymakers can set specific targets for achieving desired canopy cover percentages within defined timeframes.

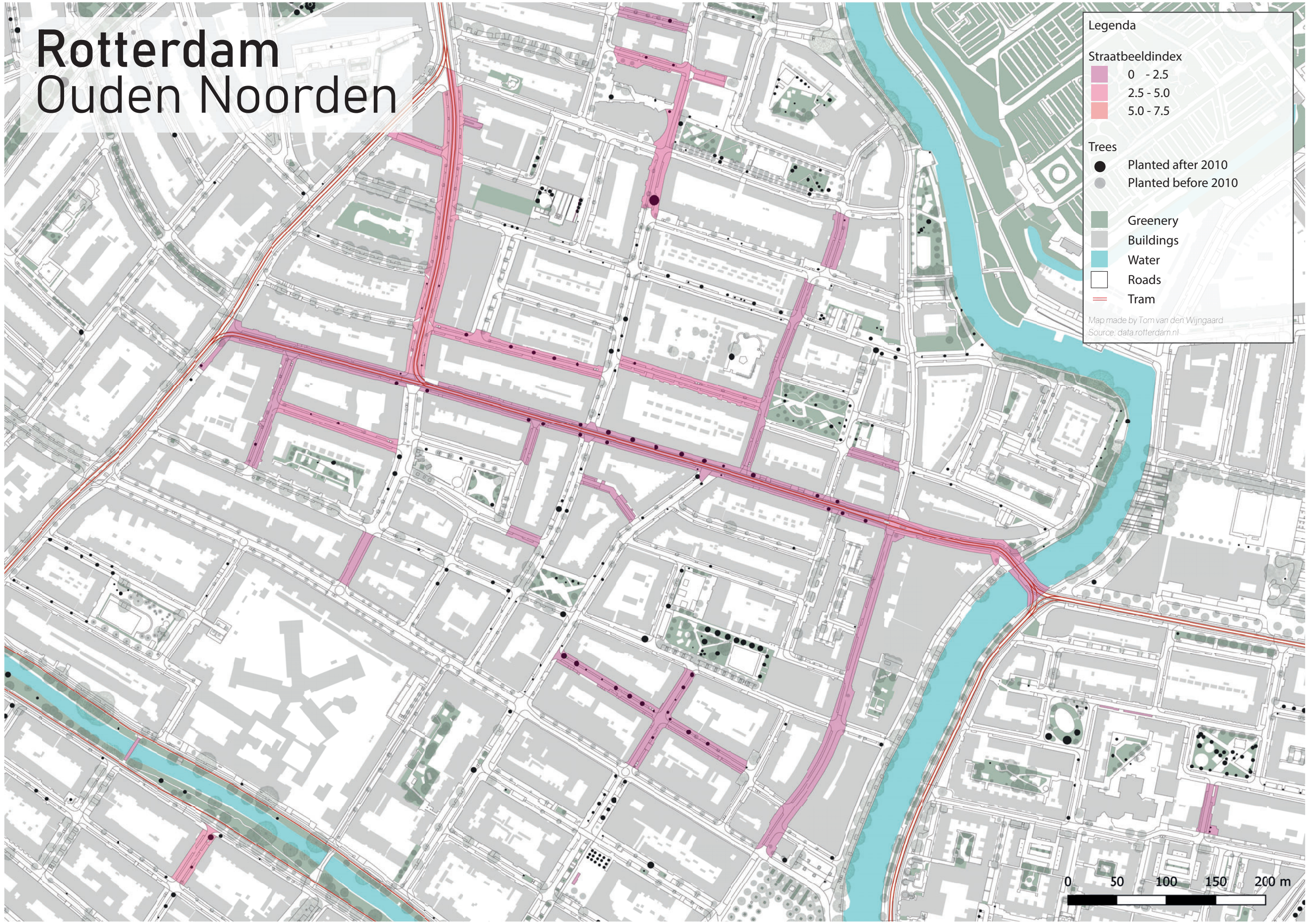

Fig 66, Oude Noorden Rotterdam

Urban forestry design placement
Beyond its role as a design tool for overarching strategies and policies, the visualization of data about the urban context in conjunction with the urban forest can also facilitate precise decision-making regarding the optimal placement of diverse tree species. As an illustration, the analysis of Rotterdam's visible green index map can readily identify streets and squares with minimal tree coverage, presenting opportunities for new urban forestry design interventions. Additionally, by examining underground infrastructure in relationz with above-ground requirements, a foundation for tree selection is established.

On the map presented on the previous page, multiple aspects are combined into a single representation, allowing for comprehensive analysis. Initially, streets with minimal visible greenery are highlighted using various shades of slightly transparent pink. Trees planted after 2010 are represented as dark black crown shapes, while those planted before 2010 are depicted as light black crown shapes, emphasizing the newer tree plantings. roads, buildings, waterbodies and greenery are depicted with various collors.

As an initial observation, it becomes evident that areas lacking trees appear to correspond to narrow streets and spaces with smaller, recently planted trees, possibly influenced by the presence of tramlines, which restrict available above-ground space.

The areas highlighted in pink, indicating a complete absence of trees, could serve as an excellent starting point for further investigation and the potential design implementation of future urban forest projects. The ultimate aim is to ensure the placement of the right tree species in the right location, optimizing the benefits of trees while minimizing maintenance costs. Taking into account diverse demands and the availability of tree species, several factors come into play when selecting the most suitable tree species for these particular locations.

Considering that the areas on this map identified as potential design locations for urban forest development mostly consist of narrow streets, the introduction of wide-grown tree species would not be suiteble since they will lead to a high maintenance cost due to their undesirable size proportions. This already affects the selection of species and reduces the potential services the trees can provide. For example, planting trees with the aim of significantly improving air quality or carbon sequestration would not be well-suited for this location. On the contrary, planting trees that could enhance psychological well-being, reduce wind and traffic speeds, or contribute to improving health and cultural significance would be more suitable for this location.

Fig 67, London Bank (2023)

Data-driven management | 8.06

As described in the previous paragraphs, a data-driven approach to urban forestry design and management holds great promise. However, it's important to acknowledge that the dynamic nature of both the urban context and the urban forest presents numerous challenges when striving to make well-informed design and management decisions. The continuous updating of data to ensure the reliability of conclusions drawn from the dataset plays a crucial role in data-driven management. Therefore, consistent use, experimentation, and interpretation of data-driven urban forestry management by multiple organizations and initiators are essential for establishing a usable platform.

In this paragraph the various constrains and potentials of data driven urban forestry management are elaborated upon.

Organisation & Orchestration
Given the enourmous scale of the urban forest and its management by various organisation a data-driven aprouch for both the design and management can significantly improve ochestration.

In most municipalities the design and management of the urban forest is executed by various organisations. Tree are provided by nurceries, planting is often done by contractors, orchestration by landscape architects and maintanance and management is organised by municipalites that often outsource the maintanance. All these organisations need different information for the excecution of their work. Additionally during their work allot of information is also gathered and created. A data-driven aproach that is connected to a open-source platform can secure sifficient knowledge and data for improving the resilience and longevity of trees in the urban environment.

Analysis & Predictions
As described a critical aspect of data-driven design and management lies in the continuous updating of data to ensure the reliability of conclusions drawn from analyses. These databases also hold significant potential for the integration of long-term perspective policies. While urban trees typically grow slowly and become significant contributors to various ecosystem services once they reach substantial canopy proportions, it is crusial to account for potential future changes in the urban landscape.

Predicting the precise future changes to the urban context remains challenging. However, the utilization of intelligent databases can proactively address issues related to tree removal. Municipal databases that consistently update information about urban development long before actual construction begins could enable the preservation and potential transplantation of medium-sized trees to new locations.

Research & quantifications

The value of trees for a city encompasses a wide array of elements. They offer not only technical and cost-effective benefits but also social and cultural values that are related to the mental health and well-being of the people who use the spaces around them. Since the true value of trees is not always fully understood, researchers are now making efforts to quantify their benefits, such as the cooling effect and biodiversity enhancement, to assist municipalities in creating sustainable financial budgets and policy based strategies.

This process has significant implications because with this data, we can estimate how many trees need to be added to a specific area within a given time frame to achieve various goals.
For example, if we know the specific cooling performance of a specific tree species and we are aware of how much cities will continue to heat up due to the effects of climate change, we can determine the number of trees that need to be planted right now to enjoy the benefits trees can provide in the future.

In a extensive report called 'valuing london's urban forest results of the London i-Tree Eco Project' the airpolutant removal of trees has been has been calculeted to financial effect. (Valuing London's Urban Forest, 2015) With the help of I-tree not only the financial value of airpollutant removal is quantified but also aspacts such as cooling capacity, biodiversity enhancement, building energy savings ,carbon sequestration and stormwater alleviation.

Although the technical quantification of trees is a effective way to convince municipalities to regard trees in the urban environment as assets instead of costs, the social and cultural value of trees should not be forgotten. The quantification of the social and cultural benefits of trees is slightly more complex since this might be differently perceived from person to person. One might experience more stress reduction from a different tree specie than someone else.

The power of data-driven urban forestry design and management is an evolving field, one that holds immense potential for making predictions and addressing a range of issues, from the unfortenate need for tree removal due to urban development to health concerns stemming from inadequate tree maintenance.

Fig 68, I-tree 2.0 NL, Photo: Parool Amsterdam (2023)

Clonclusion | 8.07

As numerous municipalities strugle with budgetary constraints while being tasked with the intricate and costly management of their expansive urban forests, the gradual accumulation of diverse databases now opens the door to a more data-driven urban forestry management approach. This approach not only aids in gaining deeper insights into the management and maintenance of urban forests but also harbors substantial potential as a versatile design tool and as a foundation for crafting diverse strategies for the future.

By analyzing various data sources, such as temperature patterns, canopy cover percentages, and urban heat island effects, urban planners and landscape architects can identify areas where the strategic planting of specific tree species can have the greatest impact.

This data-driven approach helps tailor tree selection and placement to address the unique needs of different urban environments effectively. However, the careful generation of new data is essential to provide reliable and up-to-date information that designers can use.

Given the vast volume of data from diverse sources and the ever-evolving nature of both the urban forest and the urban environment, generating these datasets may require the inclusion of estimations and predictions.

Data-driven urban forestry management not only offers a strategic approach for the design and maintenance of urban trees in the present but also holds significant potential for calculations and predictions of the collective ecosystem services provided by the entire urban forest. While climate change models forecast temperature increases over specific timeframes, incorporating research-based quantifications of tree-driven ecosystem services into data-driven urban forestry management allows for the evaluation of the effectiveness of strategies pertaining to future innovations in urban forestry. This integration facilitates informed discussions about enhancing the urban forest's sustainability in the face of evolving environmental challenges.

Summarizing the most important subjects addressed in this chapter into a design brief would state the following concepts for new technical and strategic interventions:

How could digital twin data sets of the city be implemented to the effectively strategic planning of transplanteble forest?

How can the incorporation of growth curves and urban planning strategies into data-driven urban forestry management help mitigate the loss of trees caused by poor maintenance and prioritization of urban development?

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New data-driven management principles for urban forests

Given the extensive scale of metropolitan urban forests, a data-driven approach to urban forestry management holds significant potential. Nonetheless, it's essential to acknowledge that both the urban forest and the urban context are in a constant state of change. Trees in urban environments grow slowly, and their static nature means they rarely attain substantial proportions where they can make a significant contribution to the wide range of benefits they could potentially provide. A data-driven aprouch can have several implications that help to improve the urban forest resilience and longivaty.

Data-driven Transplantations management
An alternative approach to address the uncertainties of urban development and the growth curves of trees lies within the concepts of the technical, maintenance and spatial strategy alternatives discussed in previous chapters.

Transplanting medium-sized trees not only has the potential to mitigate the need for the removal of trees during urban development but also presents a viable alternative to the costly practice of structural pruning. Once a tree attains its maximum dimensions, it can be relocated to a new site, facilitating its continued growth without the requirement for extensive and expensive pruning interventions. This iterative process can be iterated, ultimately contributing to the establishment of a urban forest contianing large trees that has transitioned through various locations. When a tree approaches a size that makes transplanting impractical, it can be repositioned to large green spaces such as parks, where it can thrive until it naturally reaches the end of its life, characterized by the inevitable decline in its health.

Although the implementation of this alternative long-term urban forestry strategy requires a completely different approach and may involve increased maintenance, by effectively incorporating data-driven management, it has the potential to significantly reduce the loss of medium-sized trees in urban environments due to the effects of urban densification and climate change. Given the large and complex timeframe and scale of the urban forest, its management could be one of the most significant constraints when it comes to incorporating tree transplantation.

Data-driven organisation & orchestration
Data-driven management within the context of tree transplantation has various implications. It can serve as a tool for monitoring the location and condition of trees under various circumstances. As a platform, it can assist in orchestrating and sharing information among different organizations. It can be a valuable tool for locating, analyzing, and documenting various design interventions. Additionally, like traditional urban forestry methods, it can play a crucial role as a maintenance platform for addressing pruning schedules, watering cycles, growth performance, and many other maintenance actions.

Data-driven design & maintanance
Furthermore, urban forestry databases, when integrated with other databases encompassing both above-ground and underground urban contexts, including sewage systems, electricity cables, housing, tramlines, and more, hold great promise as analysis and design tools for future urban forestry initiatives.

Data-driven research & quantification
Incorporating a data-driven approach into this tree transplantation strategy would empower municipalities to benefit from long-term lifespan analyses of different tree species that have thrived in various areas within the city. This adaptable strategy offers an avenue for improving the precision of species selection through the ongoing experimentation with diverse tree species in a range of locations. This implementation has the potential to make a substantial contribution to the knowledge base of landscape architects, tree nurseries, residents, urban planners, and arborists.

Particularly in the context of climate change and the increase of urban heat islands effect, expanding the knowledge base by quantifying the diverse values of trees can be immensely valuable for developing future strategic plans aimed at enhancing liveability in metropolitan city centers.

9 Site fundamentals

In the second section of this thesis, the conclusions and alternative design concepts will be put to the test through an integrated design for the city centre of Rotterdam. The initial phase of the design comprises a comprehensive analysis that follows a logical sequence, gradually zooming in on the city of Rotterdam.

The following paragraphs will be discussed in this chapter:

Analysis methodology | 9.01

As described in the preceding chapters, the urban forest encompasses various facets that require careful consideration. In the analysis of Rotterdam, we will assess both the technical design and maintenance aspects, as well as the data-driven strategic plan.

A significant portion of the Rotterdam analysis will rely on data interpretation using QGIS. Rotterdam is particularly commendable for its comprehensive collection of various databases related to its public spaces. The city not only maintains an extensive database of all its trees but also boasts various data regarding underground infrastructure, including sewage systems, electricity cables, plumbing, and gas pipes. During the analysis phase, the Municipality of Rotterdam has generously provided access to several databases to support this thesis's site analysis.

Liveability site analysis | 9.02

The concept of liveability in hardscaped city centers can be approached from various angles. On one hand, it can be assessed through physical aspects like air quality, temperatures, walkability, and the overall maintenance of pavements, roads, and public spaces. On the other hand, liveability can also be evaluated based on psychological factors such as stress reduction, nearby parks, noise management, the sense of safety.

To comprehensively address both the physical and psychological aspects of liveability, the analysis of Rotterdam includes factors such as the urban heat island effect, population density, urban green space percentages per neighborhood, and the visual green index per street. By utilizing these diverse perspectives, specific areas will be identified for testing the impact of adaptive forestry initiatives on the liveability of these neighborhoods.

Fig 69, Markthal Rotterdam, Photo: unkown

Liveability site analysis | 9.02

The first two map used to identify areas for the city of Rotterdam that show challenges and usies regarding the liveability was by combining maps to understand the urban heat island effect and the population density.

In the map below one can see ow the urban heat island effect is distributed. the Red collow indications areas that have a increased airtemperature of 2.5 degrees celcius in comparisong to the darkest blue collor in the map. This airtemperature difference can be adressed to the various hard sufaced masses within the city center that can heat up during warm days. They accumilate the heat and give it back during the night and day by radiation. The area"s with the mosturban heat iland effect is could significantly benefit from the implemenation of trees.

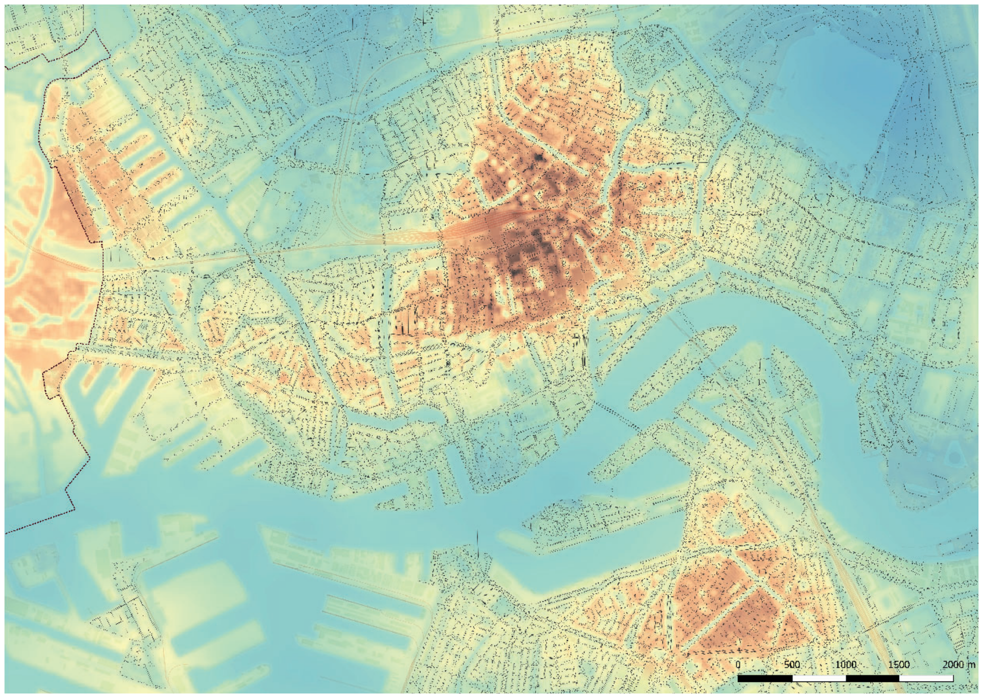

Fig 70, Urban heat island effect, Rotterdam

Fig 71, Population density, Rotterdam

Population density

The map displayed above illustrates the population density per square kilometer. Understanding where the majority of inhabitants reside is a crucial factor in determining where the implementation of adaptive forestry would have the most significant impact. The map reveals that both the northern and southern parts of Rotterdam exhibit high population densities. Specifically, the Bloemenhof neighborhood in the south and the Oude Westen neighborhood in the north stand out prominently in this regard.

The Bloemenhof neighborhood exhibits an increased urban heat island effect. However, upon closer examination of the neighborhood, the visual green index per street indicates that there aren't many streets posing significant challenges for tree planting. Given that adaptive forestry solutions are not the sole remedy for this area, further analysis is warranted for the densely populated northern region of Rotterdam.

Percentage of green

The map below illustrates the percentage of greenery per neighborhood. In the top right corner, Kralingse Plas stands out with a notably high score in this regard. Conversely, the central areas of Rotterdam, encompassing neighborhoods such as Oude Westen, Centrum, Cool, and Het Stadsdriehoek, exhibit relatively low levels of greenery. By considering both population density and greenery density, specific neighborhoods emerge as prime candidates for the implementation of adaptive forestry solutions to enhance livability. These areas are of heightened interest in the further analysis of Rotterdam.

Fig 72, Greenery density, Rotterdam

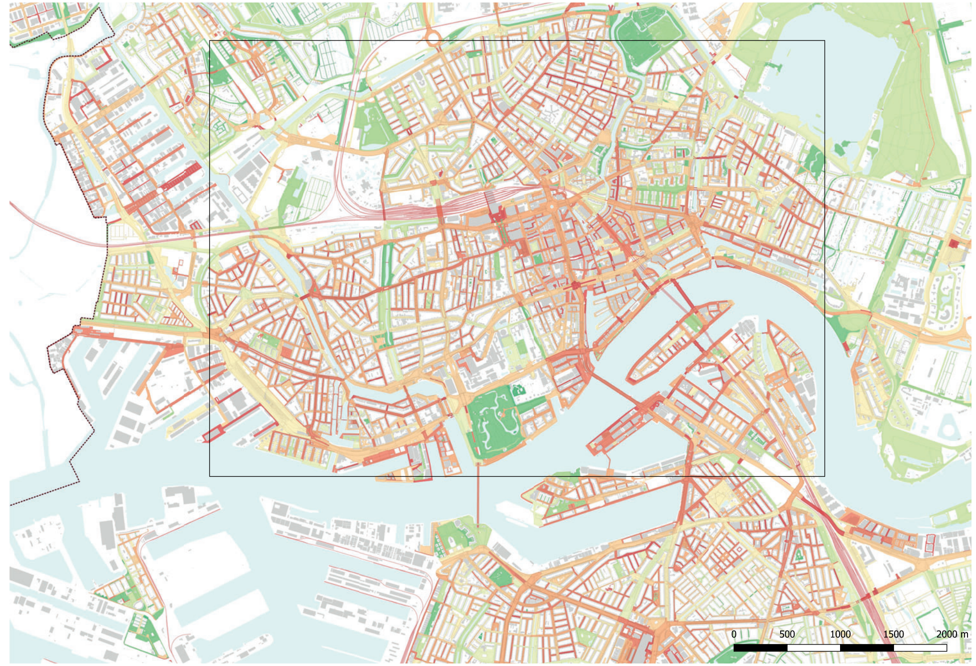

Fig 73, Visual green index, Rotterdam

Visual green index per street

The Municipality of Rotterdam has employed a combination of diverse datasets to create this significant map. The map displays a calculated Visible Green Index, which relies on factors such as the total surface area covered by trees, grasses, shrubs while also taking into account the presence of private gardens in the vicinity. Consequently, this map reveals the streets in Rotterdam with the least amount of tree canopy cover. Moreover, it highlights streets that boast a substantial amount of greenery and trees. This map has pinpointed intriguing streets in Rotterdam that have proven to be invaluable for this thesis. In-depth analysis of this map raises several pertinent questions, such as why these streets lack trees, whether these areas correspond with the greenery density map, and how the absence of trees on these specific streets affects the urban heat island effect

The map displayed on the next page is the result of applying various filters in QGIS, focusing exclusively on streets with the lowest tree coverage. These streets play a pivotal role in the implementation of the adaptive forestry design.

Rotterdam site Analysis | 9.03

The map on this page shows a combination of atributes. Firstly in light green it is showing the parks and grasses and with dark green it is showing the trees. The red lines are showing the location of the tramlines. The various shades of pink are highlighting the areas with the least amount or total absence of trees.

The first observation that can be drawn from this map is that streets characterized by narrowness tend to have fewer trees.

Additionally, the widest streets and squares where the absence of trees is particularly noticeable, highlighted in dark pink, are concentrated around the neighborhoods of Cool and Stadsdriehoek.

A third noteworthy conclusion, derived from the combination of these attributes on the map, is that the presence of tramlines in narrow streets often correlates with the absence of trees.

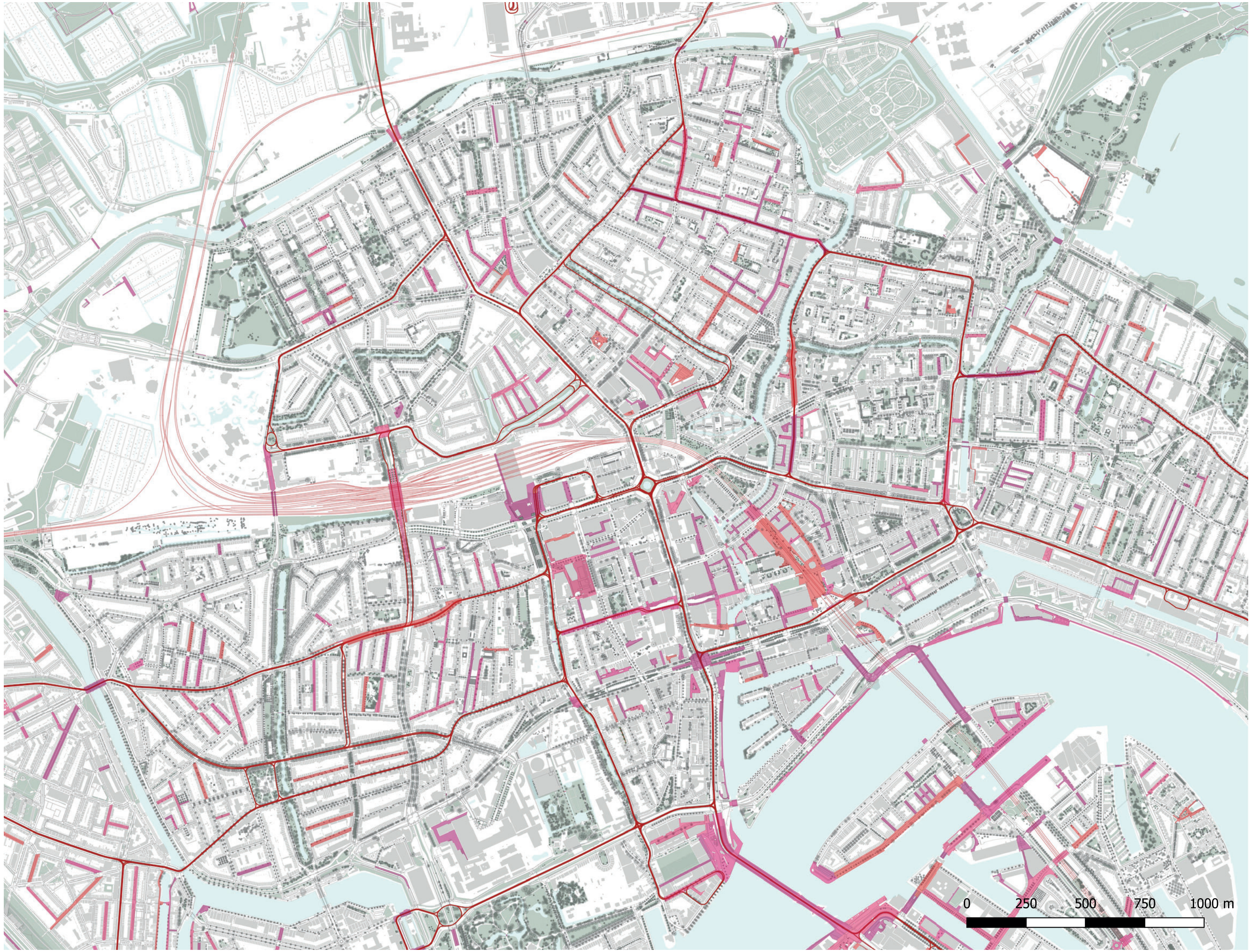

Fig 74, Site analysis map, Rotterdam

Neighboorhood selection
The analysis of previous maps has led to this selection of specific neighborhoods. Each of these neighborhoods exhibits unique spatial characteristics that contribute to the lack of trees.

In the case of the Oude Noorden neighborhood, the absence of trees is primarily a result of narrow streets combined with the presence of tramlines.

The Stadsdriehoek + Cool neighborhood has been chosen for further analysis beacause it demonstrates a deficiency of trees in various squares and shopping streets.

Lastly, the Oude Westen neighborhood illustrates the shortage of trees in several parallel streets with similar street typologies worth further analysis

Within the next analysis we delve deeper into the understanding of urban forestry challanges within these specific locations.

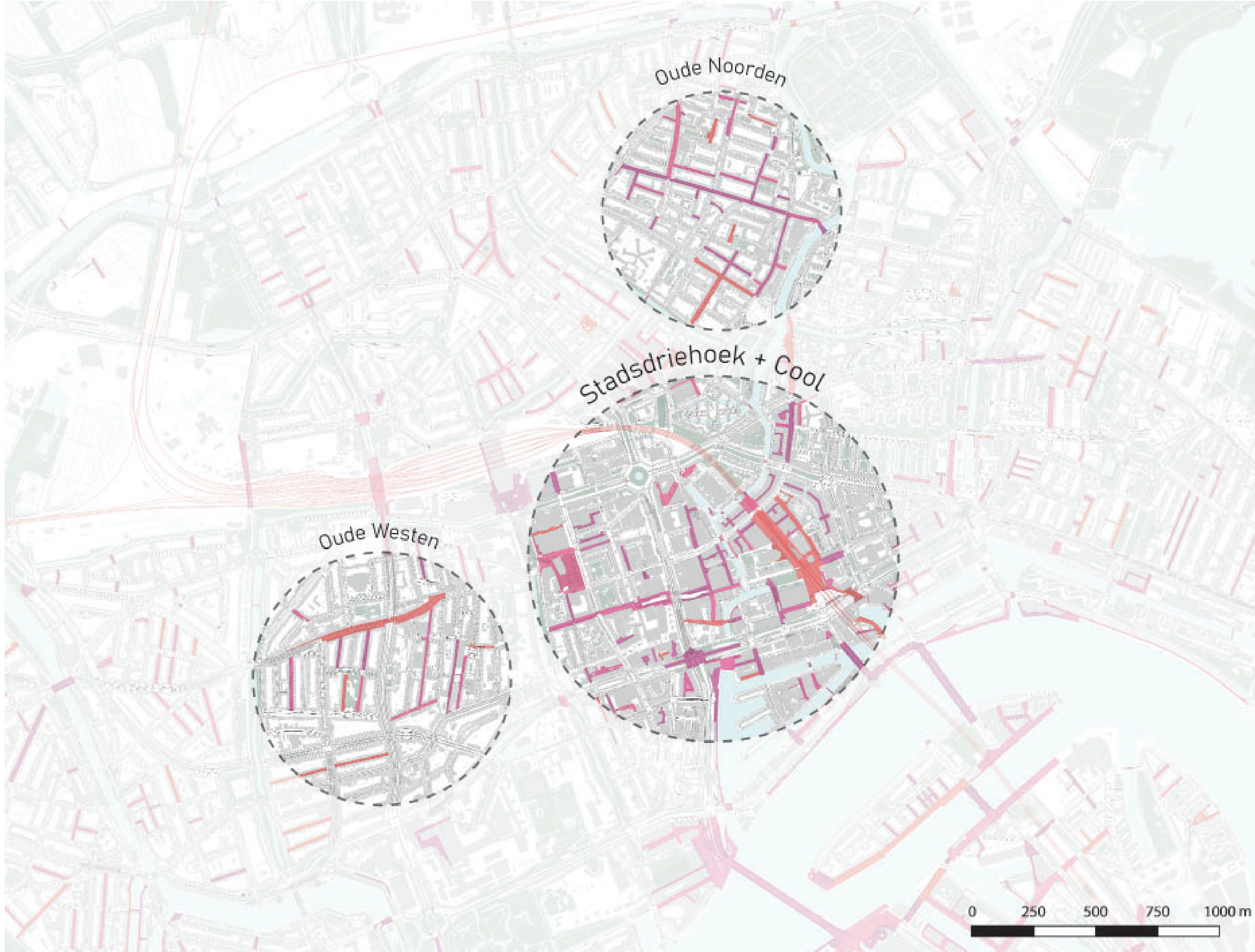

Fig 75, Neighbourhood selection, Rotterdam

Oude Noorden | 9.04

The previous selected neigboorhoods of rotterdam will be analysed using the following combintations of data. In the legend one can see that the trees planted after 2010 are highlighted in a dark black colour, while those planted before 2010 are depicted with slight opacity. Different shades of pink highlight streets with a low score in available green space. The tram line, shown as red lines, emphasizes the lack of aboveground space.

The majority of trees in this neighbourhood are situated relatively close to the surrounding buildings. These streets are predominantly narrow. Consequently, regular pruning is necessary for these trees, resulting in most streets having very small or limited tree coverage.

In the illustration, trees planted after 2010 are highlighted in a dark black colour, while those planted before 2010 are depicted with slight opacity. This visual representation reveals that all newly planted trees have relatively small proportions, and even after a decade of growth, they still maintain small canopies. Consequently, streets with low percentages of tree canopy cover underscore the absence of trees or the presence of small canopy sizes.

some of the streets that are highlighted are illustrated on the next page.

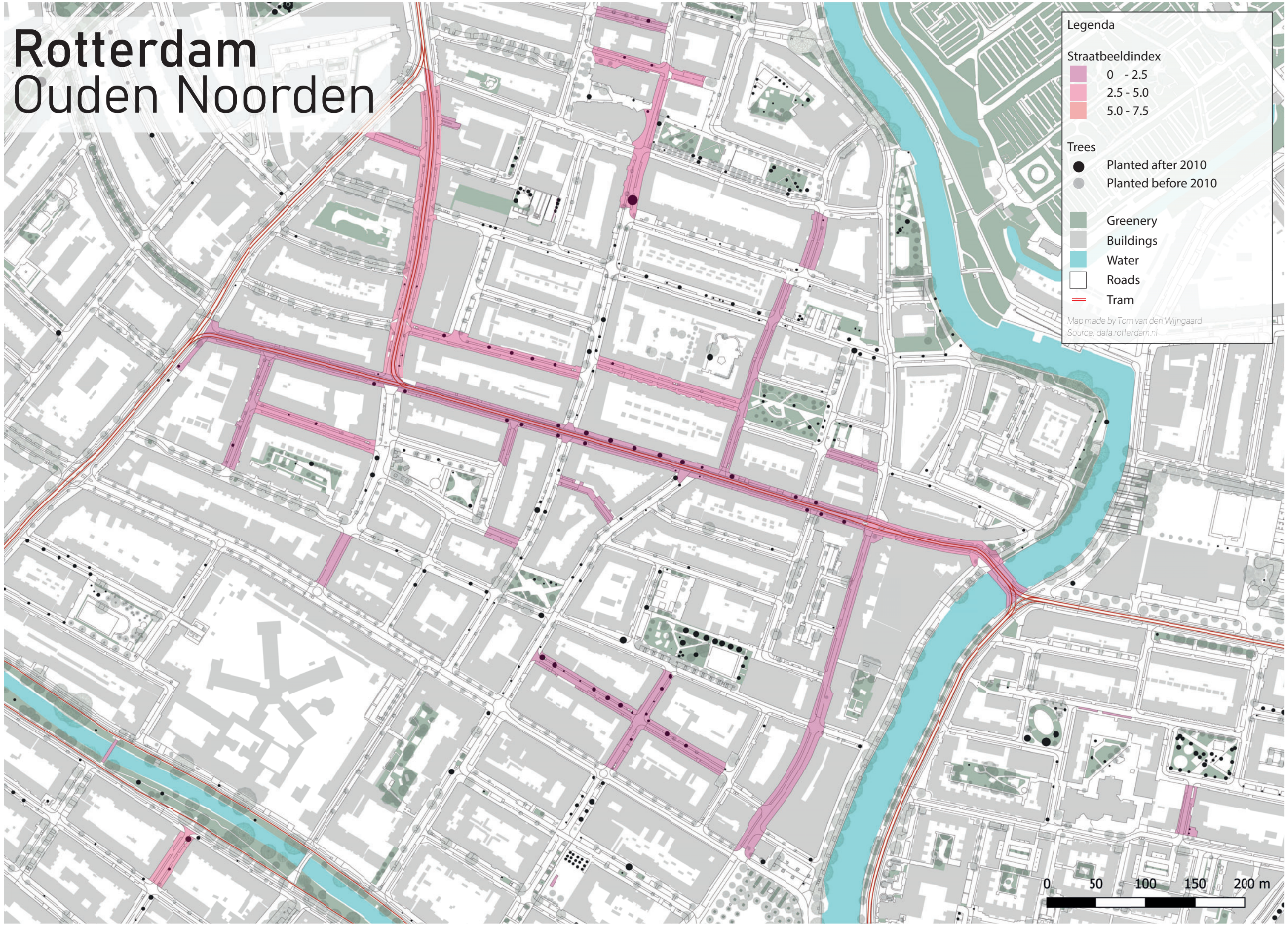

Fig 76, Oude noorden, Rotterdam

Fig 78, Angiestraat, Rotterdam

Fig 80, Zaagmolen straat, Rotterdam

Fig 79, Angiestraat, Rotterdam

Fig 81, Zwart Janstraat, Rotterdam

Stadsdriehoek + cool | 9.05

The city centre of Rotterdam is constantly in development. One interesting way that this can be seen is throughout the fact that most trees in this area are planted after 2010. While some of these trees show reassemble canopy proportions it can be assuming that either they were planted at large canopy proportions or the trees have show relatively fast growth during the past decade.

This particular area of rotterdam used to be the historical city centres. During the second world war this area has been bombed. The modern urban charachter that is often atributed to rotterdam is very well visible in these area. Altough these new modern streets are often more wider than most historical narrow streets in the nederlands in many of these streets there is still a total absence of trees.

It's intriguing to note that this particular area of Rotterdam, known for having the highest number of visitors, features numerous hardscaped streets. Notably, both the 'Schouwburgplein' and the square at the 'Markthal' are highlighted in the data analysis. The connecting streets in this area that are also highlighted hold significant potential for the implementation of Adaptive forestry solutions.

Some of the streets that are highlighted are illustrated on the next page.

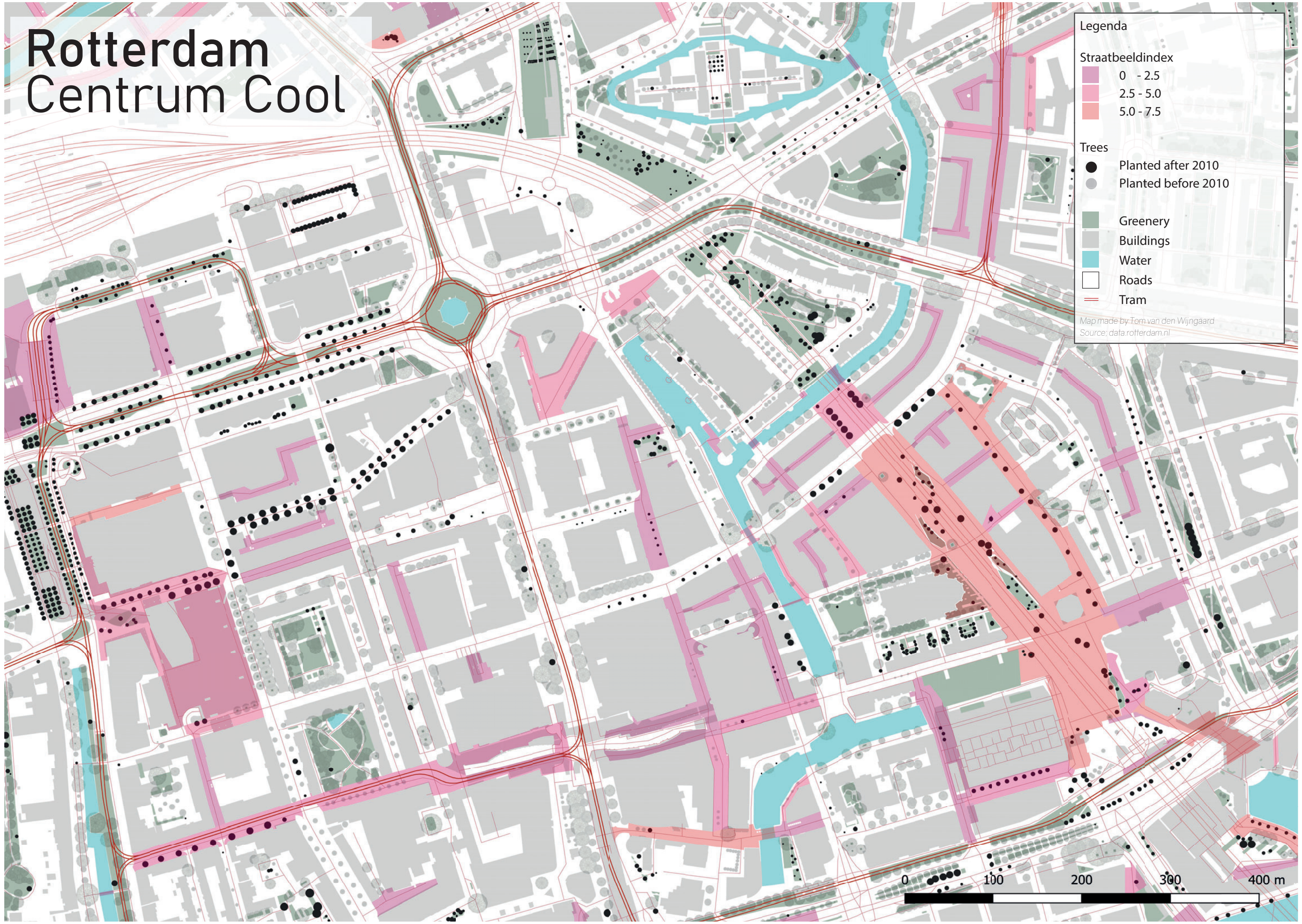

Fig 82, Stadsdriehoek Cool, Rotterdam

Fig 83, Beursplein, Rotterdam

Fig 85, Fransjonkerstraat, Rotterdam

Fig 84, Hoogstraat, Rotterdam

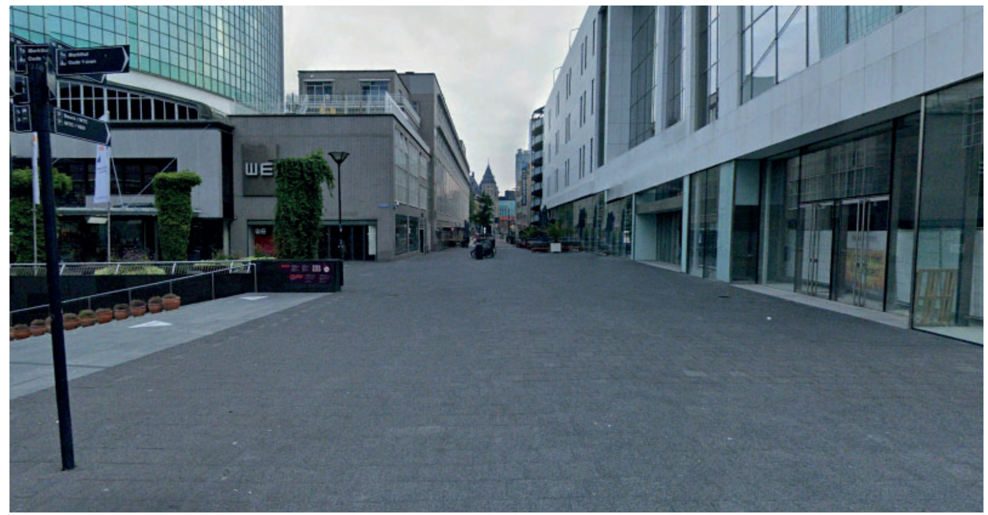

Fig 86, Westerwagenstraat, Rotterdam

Oude Westen | 9.06

The area is notably characterized by the absence of trees in its narrow streets. Interestingly, in these highlighted streets, if there are any trees at all, they were often planted after 2010. This put emphasis of the challenges in both the design and maintenance domain for the trees in these streets.

The pictures provided depict various streets that are highlighted in the map. The design of these streets should take into consideration that the closer a tree can potentially be planted to the center of the street, the larger its canopy can grow before regular pruning becomes necessary to maintain a stable, upright form. Unfortunately, this consistent pruning is often overlooked, resulting in the replacement of trees when their proportions become dangerous or generally unfavourable.

Many historical cities in the Netherlands feature streets with similar proportions, and most of these streets encounter similar challenges when it comes to the availability of both above and underground space for trees. While trees in these streets can offer significant benefits for enhancing both physical and psychological liveability, the need for consistent pruning makes traditional urban forestry methods unsustainable and cost-ineffective. These streets indeed hold great potential for adaptive forestry implementations as an alternative to the continuous pruning, offering a more sustainable and efficient approach to urban greenery management.

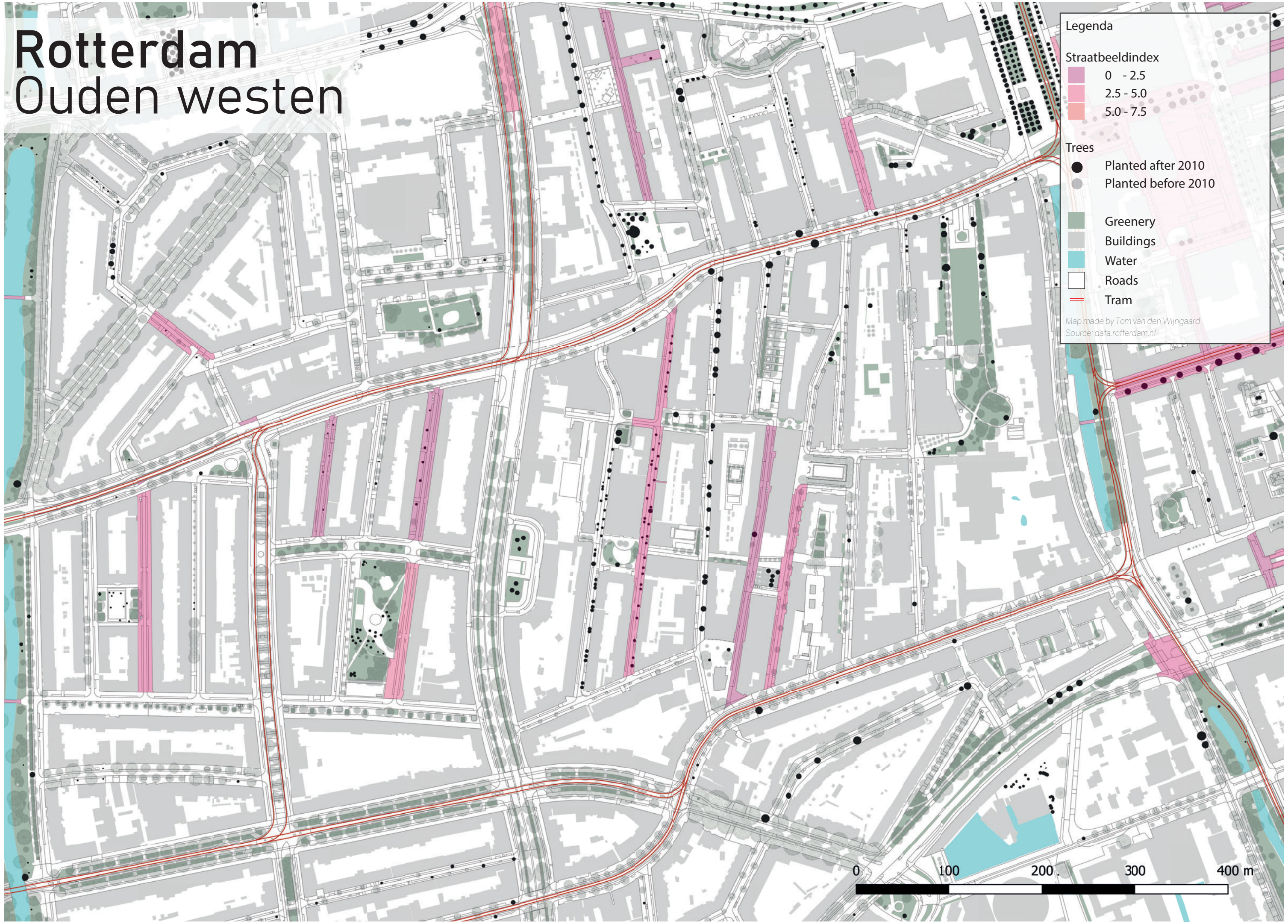

Fig 87, Oude Westen, Rotterdam

Fig 88, van der Poelstraat, Rotterdam

Fig 89, Jan porcellisstraat, Rotterdam

Fig 90, Volmarijnstraat, Rotterdam

Fig 91, Adrianastraat, Rotterdam

10 Design implementation, schouwburgplein as a public tree nursery

In this thesis chapter, the examination of conclusions and alternative design concepts will occur through the practical application of an integrated design for Rotterdam's city centre, with the overarching goal of enhancing the quality of life in urbanized areas. Within the site analysis section, various regions in Rotterdam have undergone thorough examination, considering their spatial context, urban forest canopy, and the opportunities and challenges they present for enhancing the quality of life. The design implementation phase focuses on Schouwburgplein in the heart of Rotterdam as the focal point for the design realization but these selected neigboorhoods place a crusial role as contributors to the Adaptive forestry Implementation at the schouwburgplein

Schouwburgplein | 10.01

The 'Schouwburgplein' in Rotterdam has undergone several transformations over time. Being a central part of the city, it receives a significant number of visitors. The square has maintained its hardscape identity due to the presence of an underground parking garage and the requirements of contemporary events hosted there. An examination of various datasets reveals that the square is notably affected by urban heat island effects.

Schouwburgplein possesses a distinct urban identity, which is both an advantage and a consideration in its design. The preservation of this character must be a key aspect of the design approach since it has proven to be a landmark for many visitors of rotterdam. However, the presence of the underground parking garage imposes limitations on traditional tree planting methods. Introducing a new topsoil layer could diminish the square's urban identity and presents significant technical challenges in terms of irrigation.

To enhance the square's livability while preserving its urban identity and flexibility as an event space, the implementation of aboveground containerized trees holds great potential.

Fig. 92 Schouwburgplein, Photo:Claire Droppert

Adaptive forest nursery | 10.02

In the context of this thesis's design, an examination of the possibilities of adaptive forestry is undertaken by converting the city's central square into a public tree nursery.

A fundamental aspect of this concept revolves around the relocation of existing trees from different areas within Rotterdam. The primary objectives are the conservation of Rotterdam's existing trees and the creation of opportunities for these trees to grow and offer benefits to various locations throughout the city. Due to their mobility the trees can be relocated temporarily to various hardscaped area's within the city for improving the liveability of rotterdams city centres.

Adaptive forest management by the arborist
An essential component of nursery management is the daily presence of an arborist. This individual is responsibility for overseeing the maintenance, configuration, and safety of the nursery. Among the arborist's duties are watering the trees, conducting necessary root and canopy pruning, administering fertilizers, and, when required, repotting the trees to accommodate additional root space and soil volume.

The arborist bears the responsibility of ensuring that the trees maintain robust health and an aesthetically pleasing appearance. The arborist's role encompasses both technical aspects and the aesthetics of the forest. Similar to the captivating beauty found in bonsai, the trees on Schouwburgplein must exhibit inspiring beauty to enhance the square's overall quality of life. While the perception of beauty is subjective, through engagement with public preferences, a more targeted approach can be taken to establish a visually appealing and memorable forest.

Liveability
The project's primary goal is to elevate the quality of life experienced on Schouwburgplein. The trees, as part of the adaptive forest concept, serve a dual role. They not only provide essential technical ecosystem services but also contribute to the soft psychological enhancement of the environment. These contributions include the creation of a calming and pleasant atmosphere that enhances the overall well-being of those in the area.

Furthermore, the forest has the potential to foster engagement among users of the public space due to its adaptable configurations.Both local residents and visitors can actively track the evolution of the adaptive forest throughout the project's duration. With changing seasons, new opportunities for interaction emerge, promoting seasonal awareness and contributing to the well-being of individuals' mental health.

Fig 93, Impression Mobile forestry nursery, Schouwburgplein

Design layout | 10.03

The layout of the adaptive forest design on Schouwburgplein takes into account several key restrictions. A crucial aspect of the nursery's operation involves the import and export of trees to and from the square. Furthermore, to facilitate various tree repotting procedures, a temporary office building and crane are installed on the north side of the square. This placement is strategic because it offers adequate space for trucks to efficiently load and unload trees.

The office building serves as a storage facility for various tools and materials essential for the arborist's maintenance and management of the nursery. Additionally, it can function as an information hub for local residents and visitors, providing details about the nursery. To strategically position the trees while allowing for spontaneity and flexibility, designated tree corridors are designed within the square. These corridors must remain free of trees at all times, only being utilized during specific times to create a wide, open area for various temporary events.

There are three distinct areas dedicated to specialized tree care. Along the long eastern side of the square, trees are linked to an automatic irrigation system. These trees remain in the same location for extended periods and are not frequently moved. The area requiring intensive maintenance is situated near the information office. Here, trees are manually watered and nurtured to ensure their health and aesthetic appeal. Typically, these are the trees that face challenges or have recently been introduced to the square.
The third location is positioned in the shadiest part of the square. It serves as a haven for trees struggling to adapt during the hot summer months, reducing water evaporation significantly. This approach can lead to a substantial reduction in the overall water requirements for the trees.

Fig 94, Impression Maintanance HUB, Schouwburgplein

Fig 95, Topview design, Schouwburgplein

10 Urban tree nursery plan | 10.04

The design implementation of the Adaptive forest tree nursery on Schouwburgplein encompasses various aspects across different timeframes and scales within the city of Rotterdam. To explain the design, a series of illustrations is provided, depicting different moments in time that correspond to the larger scale of Rotterdam. This approach helps viewers grasp how the Adaptive forest nursery evolves over time and its relationship with the broader urban context.

Urban tree nursery year 1:

During the initial year, 30 trees situated at Rotterdam Handelsplein will be relocated to Schouwburgplein to establish the foundation of the arboretum. They will be housed within S1 container measuring 150cm x 150cm x 120cm.

The trees will be positioned on the square in various configurations. These arrangements can be altered as needed for events or artistic projects, allowing for experimentation to create diverse spatial atmospheres.

Each day, these trees will receive care from a the arborist responsible for monitoring moisture levels, handling waste and weed control, and addressing any immediate issues or unforeseen circumstances.

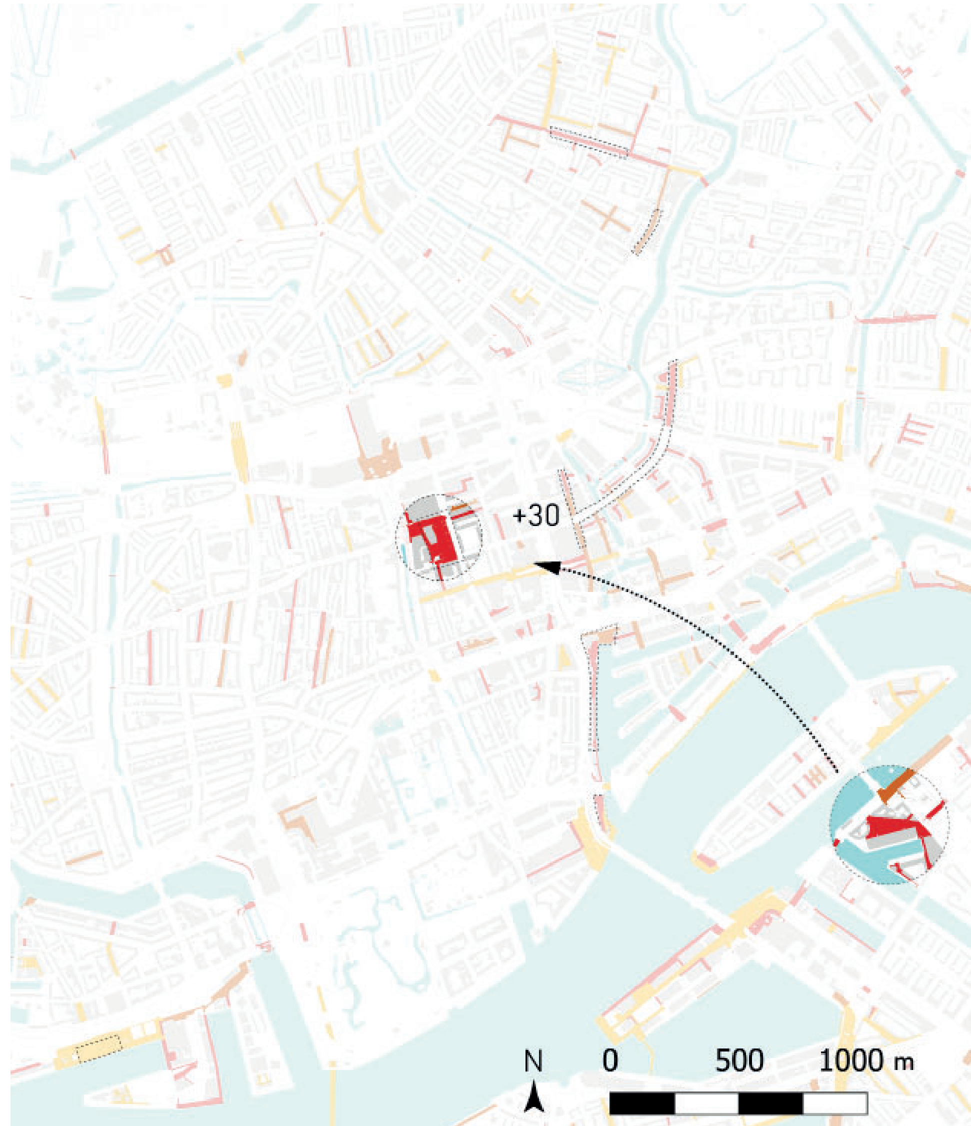

Fig 96, Large scale design strategy, year 1

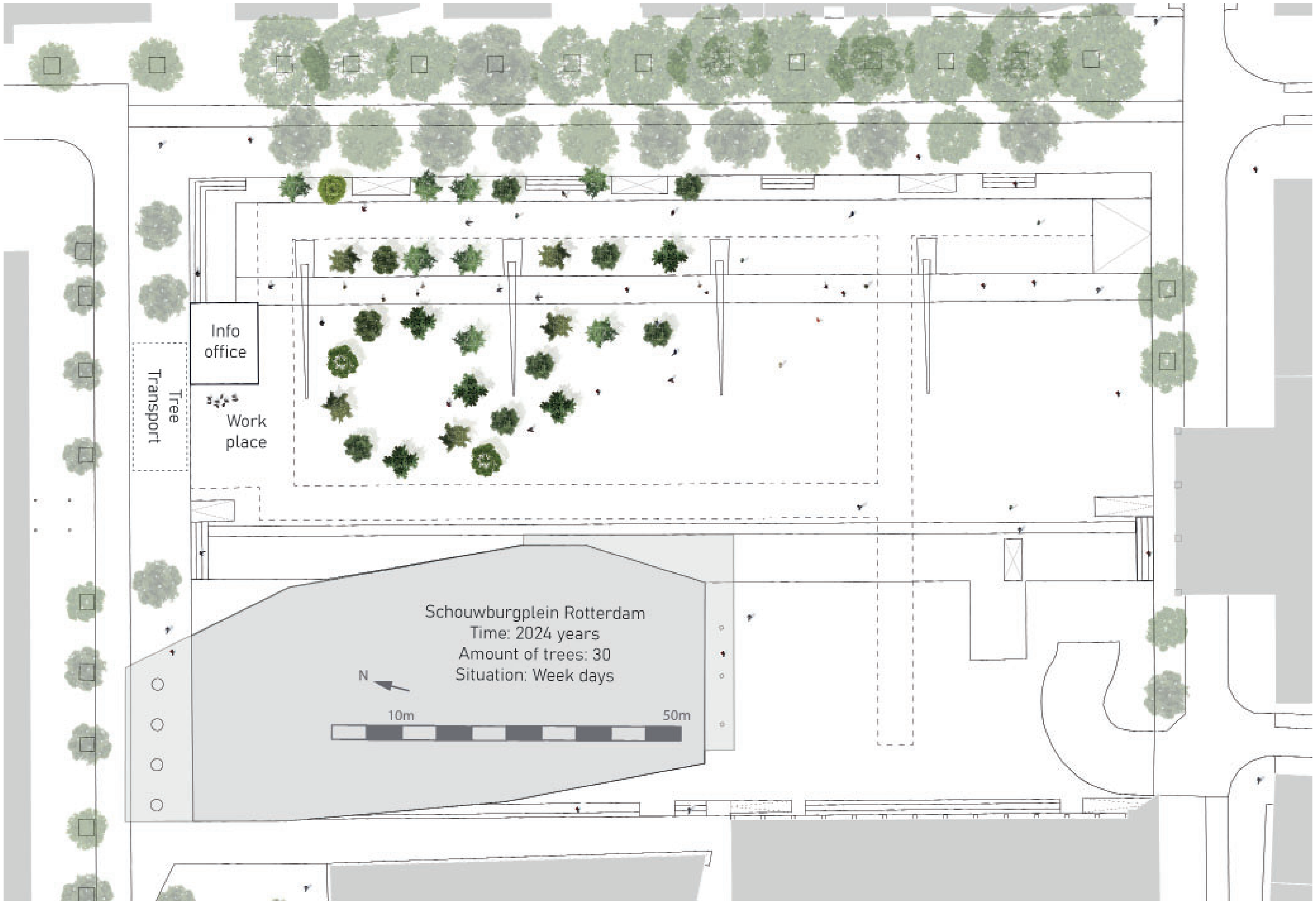

Fig 97, Schouwburgplein development year 1

Urban tree nursery year 3:

After the adaptive forest have been situated for 3 years on the schouwburgplein and the arborist have shown that the trees continue to grow well, The trees that have been growing in smaller containers at the 'marine terein' are transplanted and added to the forest on the 'schouwburgplein'. They will be repoted into s1 containers with fresh soil giving all the ingredients to show sufficient growth in the comming years.

Some of the trees on the square have displayed significant growth, indicating the need for larger containers. The arborist will relocate them to S2 containers if their growth demands additional space to accommodate further canopy growth.

The ambiance on the 'Schouwburgplein' is gradually taking on a more forested character. The trees on the east side of the square are connected to the automatic irrigation system. These trees, primarily in S2 containers, are gradually forming a corridor-like pattern for visitors to enjoy. In the central part of the square, a more random arrangement is slowly creating a natural forest atmosphere.

Fig 98, Large scale design strategy year 3

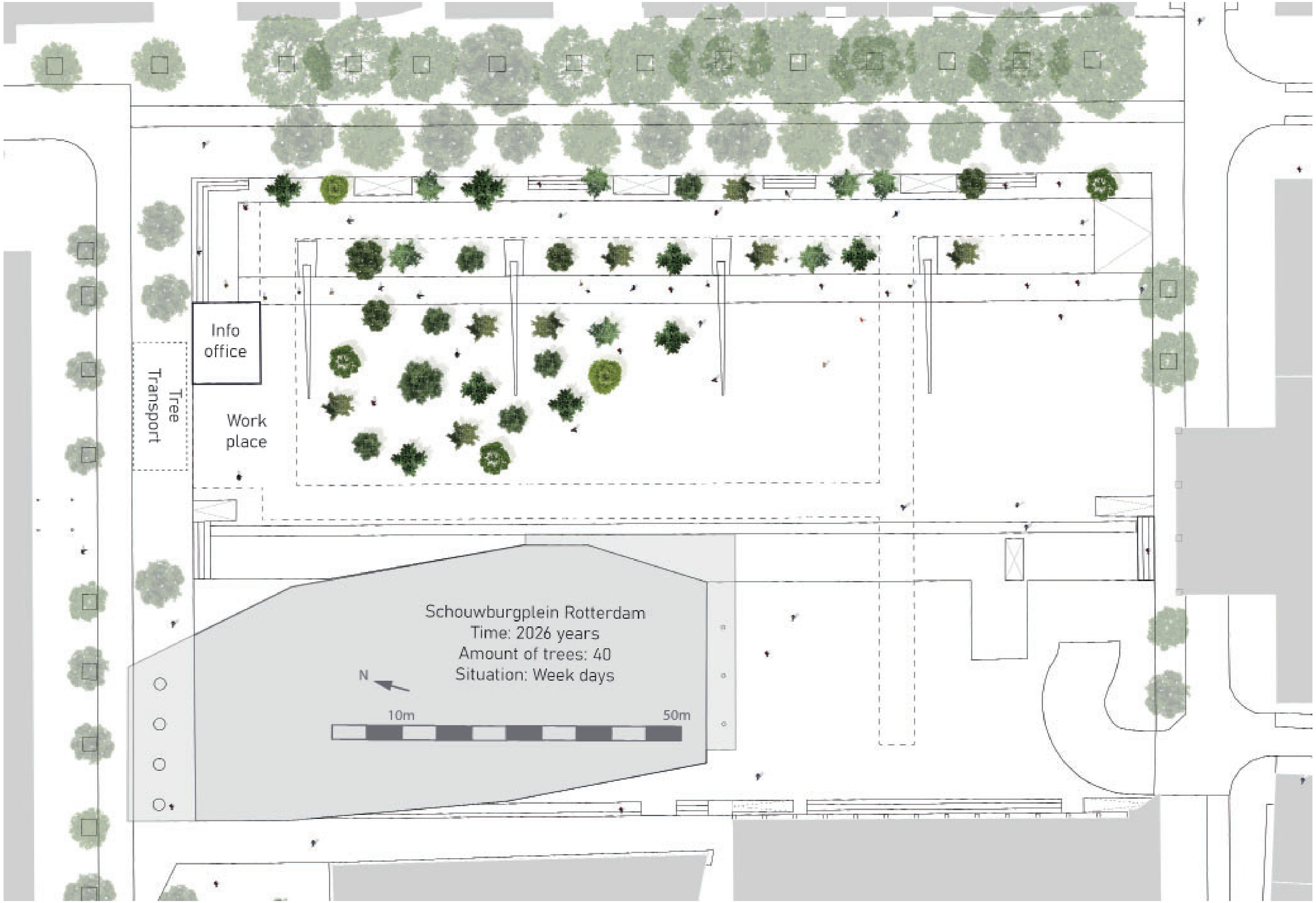

Fig 99, Schouwburgplein development year 3

Urban tree nursery year 5:

After five years, the trees have experienced multiple seasons and have grown significantly, necessitating a repotting procedure. Some of the existing S1 containers will be replaced to accommodate new trees, while larger S2 containers will be employed to house those trees that have exhibited substantial growth. These larger trees require more soil to provide adequate nutrients, oxygen, water, and root space to balance their foliage.

Tree Importation:
In a comprehensive two-year transplantation preparation process, a total of 20 trees are being introduced into the Schouwburgplein forest. These trees have each encountered unique circumstances where transplantation could offer significant benefits. Some of these trees began to demand extensive annual pruning to prevent safety hazards or distorted tree architecture caused by the surrounding buildings.

Additional trees facing challenges such as soil depletion, compaction, and soil decomposition will also be transplanted to the square, where they will receive dedicated care and nurturing from the arborist to support their growth.

Tree Exportation:
After five years, the initial trees are ready to leave the nursery and find new locations throughout Rotterdam, enhancing green landscapes in areas where trees typically struggle to thrive due to limited underground space and infrastructure constraints. The first batch of 10 trees is transported to a nearby street called Meent using specialized carts equipped with air pressure lifting mechanisms, operated by human effort.

Once at Meent, these trees will contribute to various aspects of public space, including stress reduction, traffic calming, and the enhancement of mental well-being. Because they remain in proximity to their original site, maintenance will continue to be overseen by the arborist based at Schouwburgplein, ensuring their continued health and vitality.

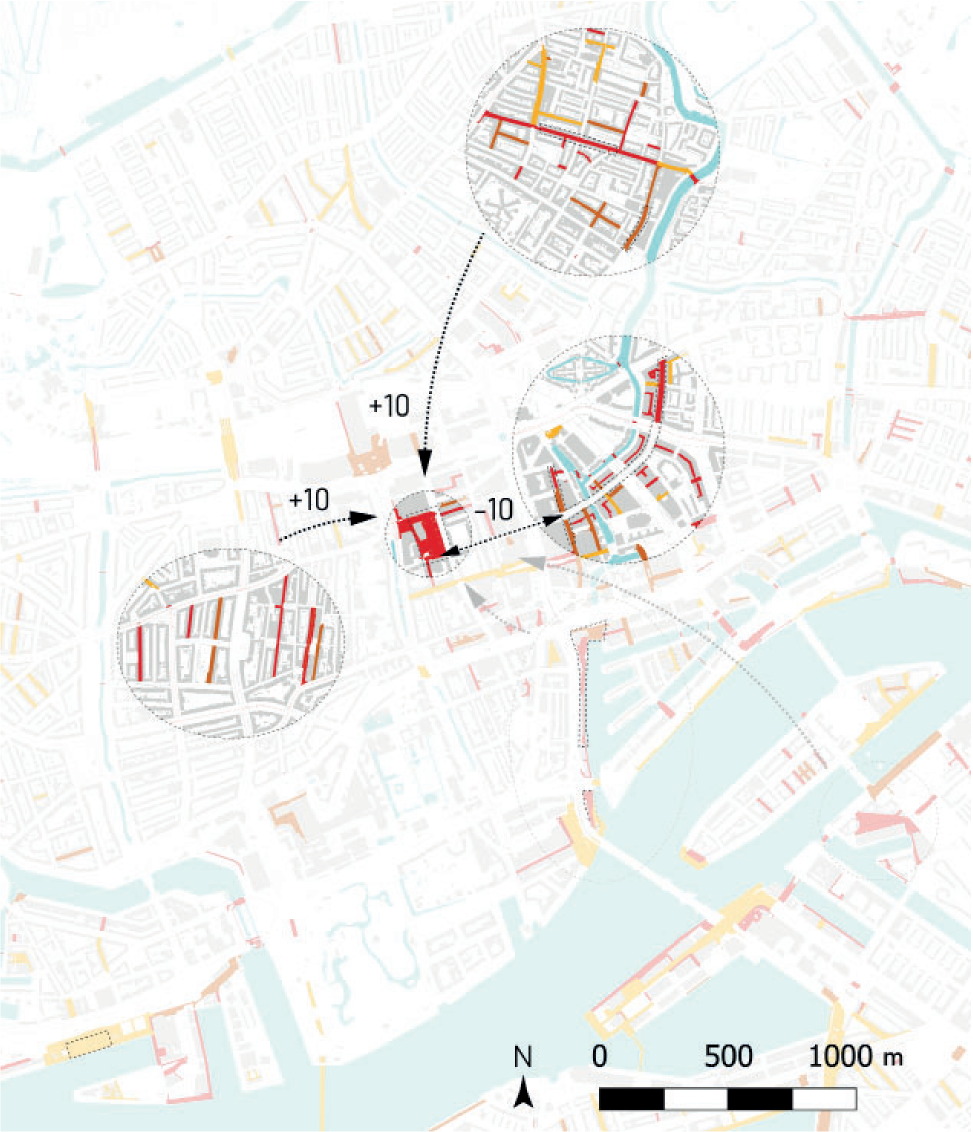

Fig 100, Large scale design strategy year 5

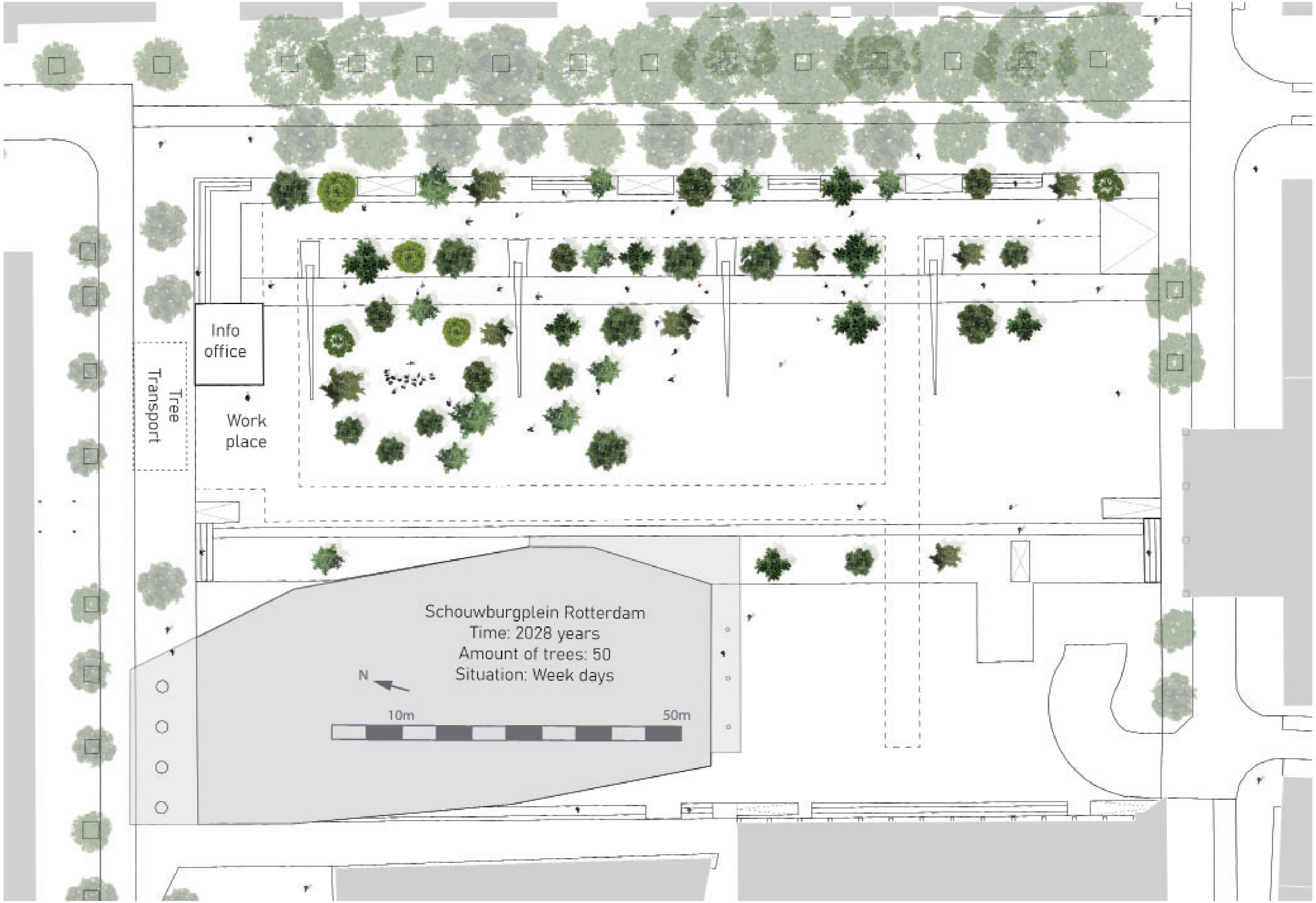

Fig 101, Schouwburgplein development year 5

Urban tree nursery year 7:

After seven years, with the adaptive forest consisting of 70 trees it has started to look like a real forest. Various trees have shown significant growth and many trees have been repotted into s2 containers. The trees are slowly filing large parts of the square creating cool spaces and hotter sunny spaces. With a total of 95 different trees that have been growing on the schouwburgplein one can slowly start to see the square as a real nursery.

Tree Importation:
An increasing number of trees, which faced various difficulties at their original locations, are being transplanted and added to the nursery. These trees either struggled to maintain their health and growth or had outgrown their original spots. Through a careful process of transplantation preparation, a total of 35 trees have been relocated to the Schouwburgplein.

Specifically, 10 trees have been imported and exported between the Josphstraat, Gaffelstraat, and the Schouwburgplein. This exchange involves replacing them with adaptive forestry solutions. This transition allows for the conversion of these streets into nurseries where trees can thrive until their canopies have reached maximum proportions suitable for their street dimensions. Subsequently, they can be relocated to other locations, such as the Handelsplein.

Tree exportation:
Certain streets in Rotterdam are in dire need of trees to improve liveability in these areas. One such street is the Fransjonkerstraat, where trees are entirely absent due to underground facilities, street dimensions, and the presence of tramlines. By introducing adaptive forestry solutions, even these challenging locations can be enriched with the addition of greenery. As a step towards this enhancement, 5 S2 trees have been exported to this specific location, as indicated on the map.

Fig 102, Large scale design strategy year 7

Fig 103, Schouwburgplein development year 7

Urban tree nursery year 10

After a decade, the Schouwburgplein now boasts an impressive count of 90 trees. Given the square's need for periodic reorganization to accommodate events, this number of trees is pushing the limits of available space. Notably, three specific trees have grown to sizes necessitating transplantation into S3 containers. These containers, measuring 250x250x150, have reached the maximum size permitted for transport by truck. These trees serve as evidence of the nursery's effectiveness and the arborist's diligent work. As an option, these trees can be permanently planted in the open soil on the square or in nearby parks.

The square has realized its full forest potential, creating various intriguing spaces where people can relax and enjoy the atmosphere.

Tree Importation:
Over the course of a decade, a total of 130 trees have been imported to the square. Trees that have reached their maximum proportions in the Volmarijnstraat, Van der Poelstraat, and Zwartjanstraat are meticulously transplanted to the Schouwburgplein nursery, where they can continue their growth and contribute to improving the livability of the city centre of Rotterdam.

Tree exportation:
After a decade, a total of 40 trees have been transformed into adaptive forestry solutions, enabling their easy and flexible integration into the urban environment. During this specific period, 15 trees are exported to areas in Rotterdam that encounter significant challenges in establishing green infrastructure in their streets.

Of these, 10 S1 trees will find their home in Zaagmolenstraat, where they can be positioned between buildings and tram cables. Particular tree species with a natural upright growth direction have been selected to accommodate the available space.

Five S1 trees are exported back to the neighborhood of Oude Westen to revitalize the areas from which the trees were initially extracted to be transformed into adaptive forestry solutions.

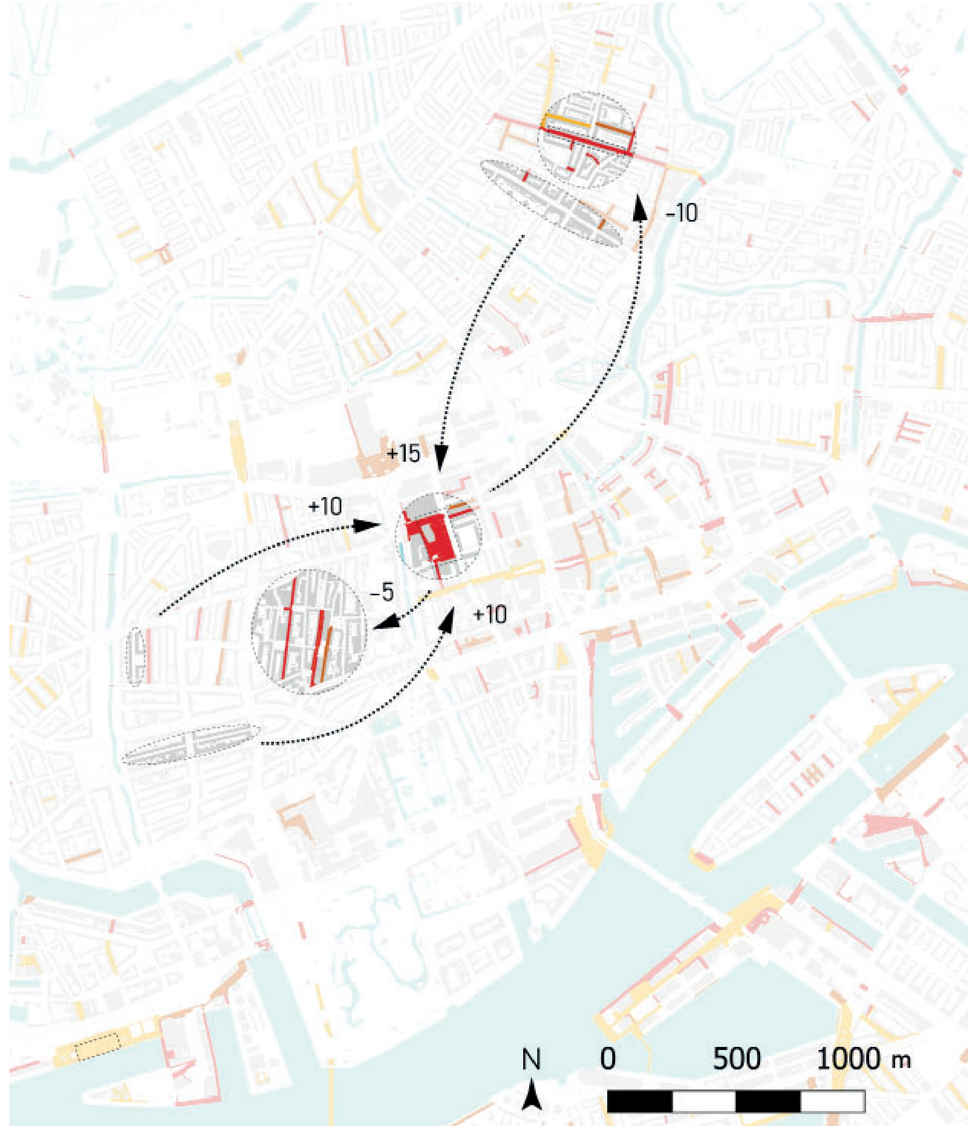

Fig 104, Large scale design strategy year 10

Fig 105, Schouwburgplein development year 10

Conclusion | 10.05

The implementation of adaptive forestry solutions to transform the Schouwburgplein into a tree nursery has provided valuable insights into the potential of adaptive forestry. As an illustrative exploration, the plan on the next page demonstrates how the adaptive forest can be integrated with events that need to occupy the center of the square. While this is one possibility, there are numerous configurations in which the adaptive forest and events can be combined. This experimentation can involve input from local residents or event organizers.

Over the course of 10 years, the neighborhoods of Oude Westen, Oude Noorden, and Stadsdriehoek have all been transformed into adaptive forestry solutions. These areas, now on their own terms, can play an important role in the production of transplantable trees as street nurseries. If this process is continued, one could envision the city center of Rotterdam as one vast tree nursery.

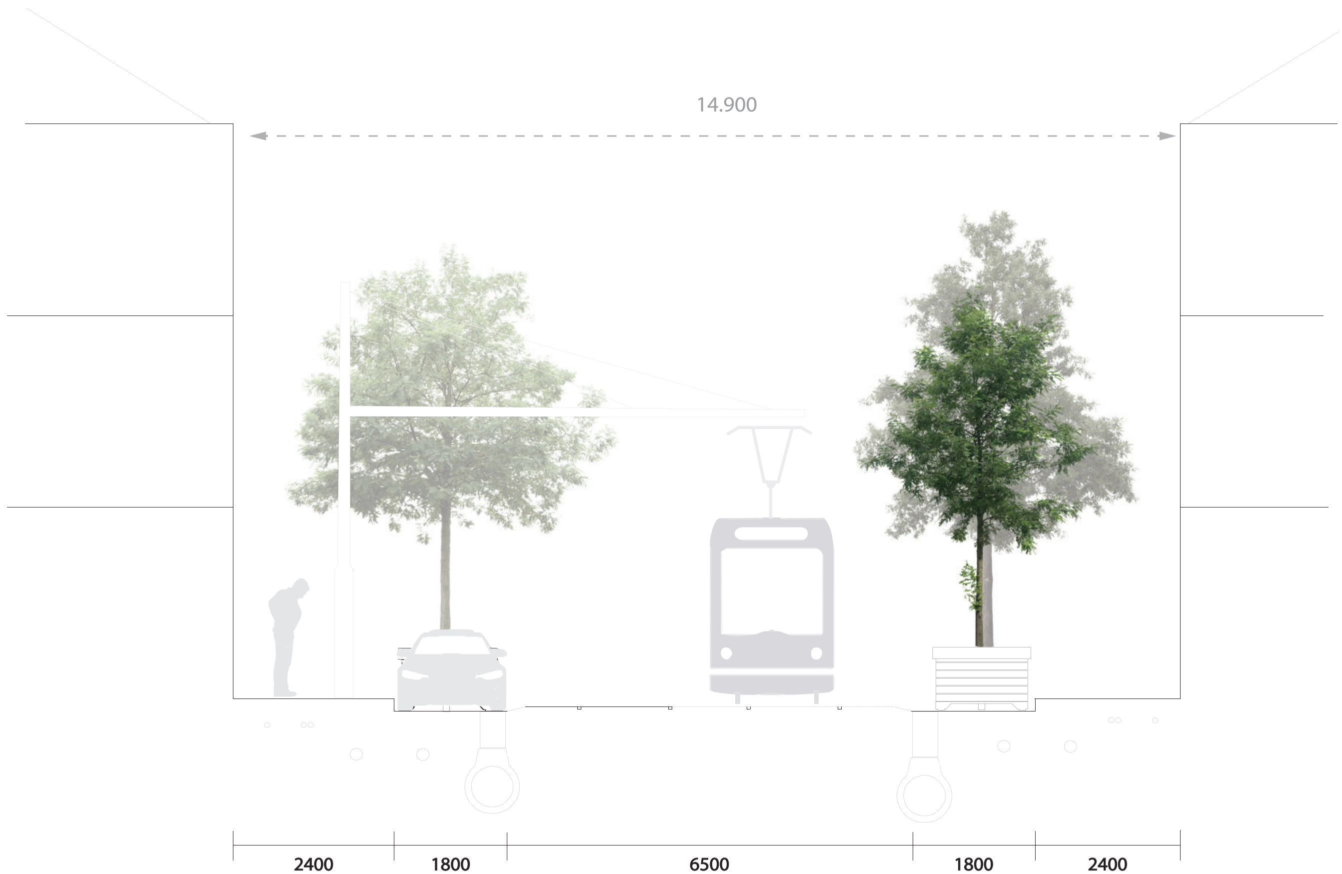

Fig. 106, Design section Zaagmolenstraat

Fig. 107, Schouwburgplein event arrangement.

11 Discussion

In preparation for a comprehensive conclusion of the research question in the subsequent chapter, the present chapter focuses on delving into a critical discussion and reflection derived from the analysis and the large scale design implementation for Rotterdam. Here, the four distinct domains of the methodology are reintroduced to examine the potentials and constraints regarding tree transplantation to enhance urban forest resilience and longevity.

Each of the four domains will critically assess the feasibility of various implementation aspects of Adaptive forestry by drawing insights from the design implementation in Rotterdam. These assessments will not only raise questions about the practical implementation of Adaptive forestry but will also lead to the formulation of several future research recommendations in the reflection. These recommendations are essential to contextualize and position the potential and constrains of Adaptive forestry within the current knowledge domain of the urban forestry discipline.

This chapter will reflect on the conclusions from the analysis and design implementations using the 4 perspectives on Adaptive forestry Methodology.

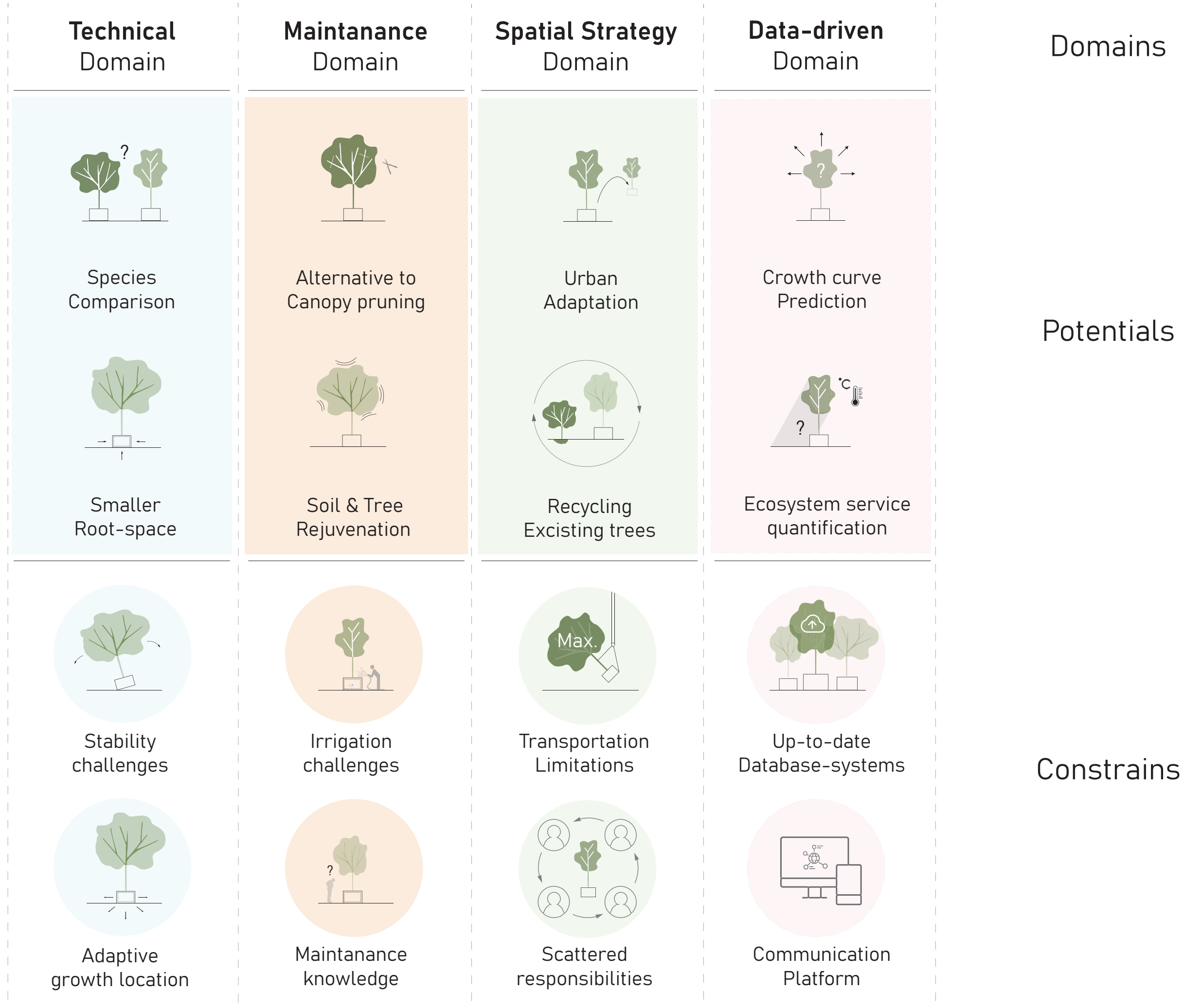

Fig 108, Adaptive forestry Methodology

Technical insecurities | 11.01

This paragraph critically evaluates the technical uncertainties on indivudual trees designs in adaptive forestry by reviewing the large-scale design implementation in Rotterdam. It emphasizes the examination of the four technical aspects described in the adaptive forestry methodology highlighting the potentials and constrains inherent in the technical sphere.

Species comparison
Trees growing in constrained environments with carefully managed root systems will invariably exhibit distinct growth patterns compared to trees growing in open soil. Due to the challenge of accurately assessing the root surface area of trees in open soil, making precise comparisons or estimations of their growth performance still remains inacurate. Having trees grown in constrained environments gives the posibility to compare different tree species since their root vollume in known. This holds great potential for selecting the right tree species related to its desired location and purpose.

Smaller root-space
In constrained environments, trees often require artificial watering and fertilization, offering the potential to cultivate trees within smaller root spaces. This presents a significant opportunity for planting trees in locations with limited available space, such as metropolitan city centers.

However, while this appears promising, the practice of artificial watering and fertilization demands a sustainable, circular approach for long-term, large-scale implementations in metropolitan city centers. This necessitates a thoughtful strategy that considers the environmental impact and sustainability of these practices for continued growth and maintenance in urban settings.

Stability
Trees grown in constrained environments lack the capacity to extend their roots extensively, rendering their stability entirely reliant on external support measures. While numerous methods exist for providing external stability, such as cables, supports, or tension wraps around the rootball, a careful assessment of stability demands considerable caution. On a positive note, the implementation of external stability measures significantly diminishes the risk of trees toppling during storms. In urban environments, falling trees often result from underdeveloped root systems that tree management teams may not have been aware of. Nonetheless, as a tree's architecture evolves over time, its stability requirements should be continually reassessed to ensure the safety and stability of urban greenery.

Adaptive growth location
One of the most intriguing challenges in the technical design of individual tree growth locations is the dynamic and evolving nature of a tree's architecture. As a tree continues to grow, the design of the growth location must adapt to accommodate these changes. Failure to do so can lead to a significant imbalance, potentially resulting in damage to either the tree or the growth location itself.

This challenge is not limited to underground growth locations but also extends to above-ground growth locations, as seen in large-scale design implementations for Rotterdam.

Fig 109, Prototype design

Maintanance feasibility | 11.02

Caring for trees in restricted environments stands in stark contrast to traditional urban forestry methods. This paragraph explores the viability of maintaining trees in these alternative settings by emphasizing the following four aspects derived from the analysis and large-scale design implementation in Rotterdam.

Alternative to canopy pruning
The implementation of adaptive forestry methodologies offers the potential to reduce the frequency of canopy pruning in two significant ways. Firstly, trees can be relocated when consistent structural pruning becomes necessary due to urban context constraints, mitigating the need for excessive canopy pruning. Secondly, by strategicly limiting root space, the growth rate of trees can be intentionally slowed down, thereby reducing the demand for structural pruning.

These approaches potentially contribute to more sustainable tree maintenance within urban environments. However, it's important to acknowledge that the effectiveness of root space confinement for individual tree species within the Adaptive forestry methodology is not yet fully understood.

As a result, there are critical gaps in our knowledge regarding how different trees respond to these practices. To establish the feasibility of this alternative maintenance approach, further experimentation and research are imperative. Gaining deeper insights into the specific impacts on various tree species will be essential for refining and optimizing the Adaptive forestry methodology for urban forestry applications.

Soil & Tree rejuvenation
In natural forest ecosystems, soil undergoes a constant process of rejuvenation. This process involves the decomposition of various organic materials, such as leaves, seeds, and other plant matter, facilitated by fungi, insects, and bacteria. This decomposition contributes to the availability of nutrients to trees. However, in the case of trees grown in restricted environments where resources are limited, the addition of nutrients through fertilization becomes necessary.

To establish a sustainable methodology for fertilizing adaptive forests, there is potential in collecting dead plant material directly from the trees themselves. This collected material, including leaves, seeds, flowers, and fruits, can be added to the soil and decomposed by fungi, insects, and bacteria, potentially supporting the sustainability of the Adaptive forestry methodology.

Nonetheless, the exact quantities of fertilizers required for each tree species and the extent to which their own organic material can contribute to nutrient cycling are not yet fully understood. Therefore, ongoing research and experimentation will be essential in evaluating the feasibility and effectiveness of this methodology over time.

Irrigation
The limited soil volume in restricted environments necessitates more frequent watering, and while automatic watering systems offer the potential for increased irrigation frequency in Mobile trees, they come with a trade-off. The installation of automatic watering systems significantly reduces the flexibility of the trees in terms of relocating them during events or maintenance activities.

As an alternative approach, especially during hot seasons, manual watering using a portable tank becomes an option. This method allows for more precise control over watering while maintaining the mobility of the trees. It's important to strike a balance between efficient irrigation and the need to move trees when required, depending on the specific circumstances and goals of the Adaptive forestry methodology.

In the design and implementation of Schouwburgplein, a balanced approach has been adopted to address the irrigation needs of trees. Permanent trees are equipped with automatic watering systems to ensure a consistent water supply. In contrast, transplantable trees are watered using portable tanks. This strategy optimizes both efficiency and flexibility, allowing for the care of trees while accommodating their mobility as needed within the urban space.

limited maintanance knowledge
One of the major constrains regarding the management of trees in restricted environments is the limited availeble knowledge of the required maintanance. This resolves around two main principles, the firs being that each tree species requires different management, since the body of knowledge is not related to trees artificialy growing in confined growth locations there is a large knowledge gab. the second constrains resolves around outsourcing to different contractors resulting in a fragmentation of the maintanance knowledge.

Spatial strategic posibilities | 11.03

This paragraph evaluates the spatial uncertainties of strategicely transplanting trees in metropolitan city centres by reviewing the large-scale design implementation in Rotterdam. It emphasizes the examination of the four spatial aspects described in the adaptive forestry methodology highlighting the potentials and constrains inherent in the technical sphere.

Urban adaptation
The implementation of the Adaptive forestry methodology holds significant potential for the preservation and strategic replacement of existing trees. This methodology facilitates the transplantation of trees to secure their survival during specific phases of urban development. These trees, often characterized by their larger canopy proportions, can then be strategically relocated to different areas. In doing so, this approach effectively conserves valuable urban greenery while maximizing the utility of trees as valuable assets within the ever-evolving context of urban landscapes.

Recycling excisting trees
The transplantation and preservation of existing trees in urban environments hold the potential to significantly reduce the loss of trees during various urban development projects. For example, when underground facilities need renewal or restoration, trees are often removed if there isn't enough available space for the maintenance of these facilities without disrupting the trees. However, by adopting practices that prioritize the preservation and relocation of these trees, urban areas can mitigate the unnecessary loss of valuable green assets and maintain their ecological and aesthetic benefits.

Urban canopy cover policies
The implementation of the Adaptive forestry methodology introduces a range of new possibilities for spatial and strategic urban greenery development. These possibilities can have a profound impact on the urban canopy cover policies initiated by municipalities aiming to enhance the livability of their cities. One potential policy change could involve obligating housing development companies to preserve all existing trees on their properties, allowing them the flexibility to relocate these trees to new locations within the same property. While the exact policies that may emerge in response to this methodology are challenging to predict, the option of transplanting trees has the potential to dramatically reshape policies in various ways and over different time frames. These changes could have far-reaching effects on urban greenery preservation and expansion efforts, ultimately contributing to more sustainable and liveable urban environments.

Transplantation limitations
The transplantation of trees holds significant promise in addressing various challenges associated with urban densification and climate change. However, the feasibility of transplanting various tree species is not yet fully understood. Some tree species may react to transplantation in a stressful manner, while others might exhibit greater resilience and adaptability to the procedure.

The size and proportions of trees play a crucial role in the feasibility of transplantation, particularly in densely populated urban areas. As trees grow larger, their ability to be maneuvered through narrow streets becomes increasingly challenging. To address this, partial trunk pruning can be employed to facilitate navigation through tight spaces. Nevertheless, the length of the trunk remains a limiting factor, especially when considering horizontal transportation, which is often necessary due to the prevalence of bridges and tunnels in urban landscapes.

Transplanting existing trees within urban environments presents a wide array of challenges. While the Schouwburgplein served as a storage location for the trees in this specific design experiment, it's important to recognize that other urban tree transplantation projects may encounter difficulties in finding suitable temporary storage spaces. Given the unique characteristics of each urban development project, the quest for adequate space required for these tree transplantation procedures should be thoroughly investigated and planned before such initiatives are executed. This proactive approach is essential to overcome potential hurdles and ensure the successful transplantation and preservation of existing urban trees during periods of development and change.

Scattered responsibilities
The transplantation of trees in densely populated urban environments requires a close collaboration between landscape architects, urban planners, municipal bodies, arborists, and tree care professionals. However, due to differences in expertise and roles among these entities, the execution of tree transplantation in current practices remains limited. The establishment of an open-source, interactive communication platform among these organizations is crucial to enhance successful cooperation and the transplantation of existing trees. The feasibility and potential benefits of introducing such a communication platform will be discussed in the following chapter.

Data-driven managmenent | 11.04

The management of urban forests places significant responsibility on municipalities. This responsibility can sometimes appear daunting, leading municipalities to view their trees as costs rather than assets. Given that the management of Adaptive forestry implementations introduces even greater management and maintenance responsibilities, the adoption of data-driven management practices becomes imperative for the feasibility of this approach.

For the discussion on the design implementation of Schouwburgplein it is essential to consider the perspective of data-driven Adaptive forestry management. This approach involves leveraging data and analytics to make informed decisions regarding tree health, maintenance, and relocation. By collecting and analyzing data on tree growth, environmental conditions, and other relevant factors, municipalities can optimize their management strategies, ensuring that trees are viewed as valuable assets rather than burdens. For the discussion on data-driven management the methodology, analysis and the design implementation of the schouwburglein is used highlighting the 4 following subjects:

Growth curve prediction
The implementation of data-driven management methods has the potential to significantly enhance decision-making regarding urban design. In the case of Schouwburgplein, the integration of data could provide valuable insights to arborists, allowing them to identify trees that have exhibited rapid growth and therefore require different maintance. This information could lead to more strategic tree placement, including relocating trees closer to maintenance areas for easier care.

Another intriguing aspect of data-driven management is the ability to make accurate predictions based on data collected over time. This enables the establishment of growth curves for trees, facilitating calculations regarding the mitigation of heat in the context of climate change. Additionally, it allows for assessing the required tree planting density in specific areas to achieve desired cooling and climate mitigation effects. Predictive modeling based on data-driven insights empowers urban planners and policymakers to make informed decisions for a more sustainable and resilient urban environment.

Maintance monitoring
The implementation of data-driven tree monitoring plays a crucial role in maintaining the demanding Adaptive forest. One approach involves the installation of soil quality measuring devices around the rootball to monitor moisture levels and other relevant factors over time. This data-driven monitoring can trigger various maintenance tasks for arborists, ensuring that the trees receive the care they need.

What's particularly intriguing about Adaptive forestry is that individual trees growing in confined root spaces, in conjunction with data-driven monitoring, allow for a meaningful comparison of the specific requirements among different tree species. When data is collected over an extended period, it can yield an immense amount of information about the performance of various tree species. This scientific approach to data collection enables municipalities and arborists to make informed decisions about tree species selection, placement, and long-term maintenance, contributing to the success and sustainability of Adaptive forestry initiatives.

Ecosystem service quantification
Data-driven approaches for quantifying the benefits of trees are gaining increasing popularity. With individual trees in confined growth locations offering a scientifically comparable basis, quantifying the benefits per tree species holds significant potential. This allows for the calculation of the long-term effects of trees, aiding in decision-making for large-scale urban design projects. Accurate quantification of the benefits, such as air quality improvement and carbon sequestration, per tree species provides valuable insights into the overall impact of urban greenery.

Furthermore, a data-driven approach within the design phase could aid in the selection of the most suitable tree species for specific locations. This could involve analyzing data on urban conditions and considering available tree species and proportions for transplantation within the city. By using data to inform tree selection and placement, municipalities can optimize their urban greenery, making more informed decisions that contribute to the overall health and sustainability of their urban landscapes.

Up-to-date database systems

A crucial aspect of using data-driven management for Adaptive forestry is the heavy reliance on accurate and up-to-date data. Effective decision-making in this approach hinges on the consistent collection and proper storage of data.

Data collection can be executed through automated systems or manual efforts by humans. Regardless of the method, there is always a possibility of slight errors creeping into the data, rendering it unreliable and potentially leading to incorrect decisions. Moreover, considering the potentially extensive scale of urban forests, collecting data on individual trees continuously may prove to be logistically challenging.

As a potential solution to these challenges, predictive modeling based on existing data can offer a way to achieve large-scale data collection objectives. This approach allows for the creation of accurate databases by continuously checking and updating data over extended periods. Ensuring data accuracy is paramount to the success of data-driven decision-making in Adaptive forestry and maintaining the health and sustainability of urban greenery.

communication platform

The effective and appropriate use of data-driven management relies not only on accurate and reliable data but also on making this data accessible to individuals beyond data specialists. A well-designed open-source communication platform that allows various organizations to extract and import their data is essential for the comprehensive use of this information.

Currently, in the absence of such a communication platform, only specialized data experts can access and interpret the available data. This limited accessibility reduces the collaborative interaction and communication required for decision-making in the tree transplantation process within urban environments. This highlights the critical need for the development of a comprehensive communication platform.

Fig 110, Canary Wharf, London (2023)

12 Conclusion

This master's thesis undertook a comprehensive examination of the potentials and constraints involved in transplanting trees within hardscaped city centers to enhance the resilience and longevity of urban forests. Using a four-step assessment the research question has been adressed.

In the initial sections of this thesis, the problem statement has been introduced which encompassed both site-specific challenges and broader issues such as urban densification and climate change, both critical to the urban forest domain.

In the second part the methodology is introduced, discribing the four essential domains for understanding the challenges and oppertunaties across various time frames and scales. Each of these domains contains verious sub-questions that have been thouroghly discussed in the main theory body of this thesis. After each chapter an conclusion and alternative strategy or aproach was introduced leading up to the large scale design implementaion.

After the data-driven analysis of Rotterdam various area's in the city have been highlighter to be addressed with the large-scale design implementation. The schouwburgplein was used as an interactive example to gain deeper understanding in the various potentials and constrains.

This led to an in-depth discussion in the preceding chapter, where the potentials and constraints arising from both the analysis and the large-scale design implementation were examined utilizing the four overarching domains specified in the methodology.

While the iterative approach of integrating literature and interview insights into a methodology and design process appears to be a valid means to approach the research question from multiple perspectives, a more confident and substantive answer can only be derived through reflection and learning from real-life projects in diverse locations over an extended period. Nonetheless, the conclusive remarks of this master thesis can be found on the subsequent page.

Fig 111, Shukeien Bonsai museum, Tokyo (2023)

What are the potentials and constrains of transplanting trees in hard scaped city centres for improving the urban forest resilience and longevity?

Thesis conclusion | 12.01

The ever changing nature of both trees and the urban environment inevitable asks for an adaptive aprouch in which changes and adjustments to both the trees and their context can effectively be made. Since the theoratical lifespan of trees often exceeds the temporal scope of urban development in hardscaped city centres, transplanting trees to new locations can significantly enlongate the lifespan of metropolitan trees.

The successful transplantation of metropolitan trees, regardless of the method chosen, allows for the growth of the right tree in the right location for the desired period. This adaptive approach offers numerous advantages that could significantly influence the formulation of comprehensive policies for the design, maintenance, and management of the urban forest.

For example, it enables the prolonged accumulation of tree benefits over an extended period, the effective assertion of their benefits in the desired location, reduction in the loss of valuable trees due to urban developments, and provides designers with the opportunity to recycle existing trees into transformation, renovation, and new projects. Having more trees with respectively canopy proportions in the urban environment increases the overall benefits that the urban forest can provide. This forms a solid foundation to advocate for the potential of transplanting trees in hard scaped city centres.

However, the successful transplantation of large trees is not always guaranteed and often necessitates time consuming preparation. The process relies significantly on timing, available space, and arboricultural expertise. To implement tree transplantation on the scale of the urban forest, an integrated strategy that incorporates transplantation procedures into the management, maintenance, and technical design of the trees' growth locations should be initiated as a stating point of the public space design.

Another approach for effectively transplanting trees in the urban environment involves the placement of trees in mobile containerized environments as illustrated in the large scale design implementation in this thesis. Although this method doesn't demand time-consuming transplantation preparations, the maintenance of containerized trees calls for an entirely different approach. The long term viability of managing dynamic trees can only be advocated for if their maintenance is conducted in a sustainable, circular manner.

With the responsibility of the management and design of current day urban forests being already being scattered over various organisations, the implementation of transplanting trees in metropolitan city centres as an integrative strategy for improving the urban forest reselience and longevity still nesesates many development steps. Before successful incorporation of this strategy into the overall management of the urban forest, all involved organizations should be well aware of the potentials and constraints. Not only does this require an open-source approach in the sharing of information and knowledge related to the maintenance and management of the urban forest, but it also entails that the initiation and argumentation for tree transplantation should be well-informed and discussed from an overarching body of knowledge.

One of the conclusions drawn from this master's thesis is that successful management of the urban forest through strategic tree transplantation can only be achieved by implementing data-driven decision-making. The dynamic nature of trees and the urban environment, coupled with the vast scale of metropolitan urban forests and their complex management, necessitate data-driven management platforms easy accessible to all involved organizations.

Given the absence of data-driven management platforms, their application for enhancing urban forest resilience and longevity through tree transplantation can be considered both a potential and a constrain. On the one a data-driven aproach has a significant potential to make well-informed design, maintanance and manamgement descisions. This not only involves the monitoring of the urban forest but it also has a potential to involve analysis of the urban environment fascilitating a proactive attitude towards the future management and design of the urban forest. Furthermore, the comprehensive collection of extensive datasets regarding the growth and health of trees over an extended period enables researchers and analysts to quantitatively predict the future benefits that the urban forest can provide. This data allows municipalities to make well-informed financial decisions concerning the management and investment in their urban forests.

Although this approach may appear promising, a critical aspect of using data-driven management lies in its heavy dependence on accurate and up-to-date data. Effective decision-making in this approach relies on the consistent collection and proper storage of data by various organizations. Considering the extensive scale of urban forests, collecting data on individual trees continuously may prove to be logistically challenging and potentially leading to incorrect decisions.

Although this thesis has highlighted many potential benefits of tree transplantation for enhancing the resilience and longevity of urban forests, a data-driven decision-making approach is crucial for its success. This underscores the significant necessity for new developments and further research in the adaptive management of urban forests within hardscaped city centers to enhance livability for future generations.

13 Reflection

Throughout the development of this graduation thesis both the research and design process have undergone continuous iterations. Inspiration has been drawn from various sources, including the art of bonsai, interviews, and desk research, all of which have significantly influenced the development and implementation of the adaptive forestry concept. The excursion to Japan and the exposure to numerous projects and interviews there have had a profound impact on the thinking process, sparking ideas and shaping their execution and visualization. All these ideas, concepts, interviews, and lessons learn are documented in a pocket notebook. This notebook, organized chronologically, serves as a vital resource for reflecting on the master's thesis process. In this reflection the development of the thesis is discussed by highlighting the previous research questions and their effect on the proces and final outcome of this masters thesis.

Research development | 13.01

During this master's thesis, numerous research questions have been explored and addressed. In this process, my focus has extended beyond the potential of transplanting trees to improve the resilience and health of the urban forest. I've been also intrigued by the broader prospect of enhancing the overall livability for all life forms within the urban environment through this process.

My research questions, initially focusing on the intrinsic value of trees in enhancing the livability of metropolitan city centers and progressing towards exploring their potential in addressing challenges posed by climate change and urban densification. These concepts were collected into the research questions in the diagram.

The concept of mobile forestry, encompassing the extensive transplantation of trees as an integral strategy for urban forestry management, has been the central fascination throughout my thesis. Despite dedicating significant effort to this research question, the availability of substantial scientific information has been limited. Nonetheless, in the upcoming section of this reflection, I aim to emphasize the conclusions drawn from this exploration. Specifically, I will reflect on the large-scale design implementation of Rotterdam through the perspectives of urban densification, climate change, and enhancing liveability.

Chronological Research Question development

How can we improve and maintain the future livability of metropolitan city centers in moderate climate zones by implementing trees?

How can we improve and maintain the future liveability of metropolitan city centres in temperate climate zones by implementing Mobile trees?

What is the potential of Mobile Forestry in relation to climate change and urban densification?

How could Mobile Forestry be implemented, maintained and analysed in the city centre of Rotterdam?

What is the potential of Mobile Forestry in relation to climate change and urban densification for improving the liveability in hardscaped city centres like rotterdam.

What are the potentials and constrains of transplanting trees in hard scaped city centres for improving the urban forest resilience and longevity?

Urban densification | 13.02

As city centres experience increasing population density and the urban environment undergoes various transformations, the urban forest also undergoes changes. Introducing flexibility through Adaptive forestry solutions can provide municipalities and designers with the means to adapt.
The potential of adaptive forestry in relation to urban densification is in this paragraph is discussed, utilizing various spatial typologies from the design implementation in Rotterdam as examples.

Narrow streets
For instance, in existing historical urban areas like the highlighted streets in Oude Noorden and Oude Westen, there is a growing intensity of use, which necessitates the incorporation of green infrastructure to meet the rising demand for green spaces.

These narrow streets are unlikely to change significantly in their above-ground dimensions. The periodic maintenance of underground facilities, such as sewage systems and plumbing, is requiring the removal of many trees. Due to the limited space available and the proximity of buildings to the potential location of trees drastically reduces their lifespan potential.

Introducing adaptive forestry solutions to these specific streets could offer a practical approach to address the issue. This approach would involve temporarily relocating the trees during the periodic underground maintenance and construction activities. Once these maintenance and construction tasks are completed, medium-sized trees could be reintroduced to restore the greenery and maintain the urban forest's presence in the area. This strategy not only safeguards the trees but also ensures the continued integration of green elements in the urban environment, contributing to the overall liveability of the neighborhood.

Dynamic urban area's
Another notable application of adaptive forestry solutions pertains to densely used squares and shopping streets such as Schouwburgplein or Lijnbaan. These areas experience constant transformation due to weekly markets, temporary events, and festivals. Typically, these areas show significant absence of trees due to their ever changing utility of the space.

The integration of adaptive forestry solutions presents several opportunities to meet the dynamic and temporary demands of these spaces. For example, mobile planters or tree containers could be strategically placed in these areas to provide greenery during events or festivals. When the event is over the trees can be and easily repositioned into various configurations. This adaptability allows city planners and event organizers to maintain a balance between urban greenery and open space flexibility, ensuring that these public areas remain versatile and accommodating to various activities and functions while enhancing their overall liveability.

New neighbourhoods
Due to the growing demand for housing, urban densification sometimes requires the redevelopment of buildings in challenging areas of the city. Often, a more cost-effective solution involves demolishing existing structures and constructing new housing or public buildings. In this process, the existing green infrastructure and trees are also affected. The loss of these medium-sized trees is unfortunate and should be prevented.

The introduction of Adaptive forestry solutions in these areas could facilitate the transplantation of existing trees and the reintroduction of large, mature trees to strategic locations once the urban development has finished.

From the initial stages of the design process, the placement of these large, mature trees should play a central role in securing long-term liveability goals. By preserving and relocating mature trees, the urban landscape can maintain a connection to its natural heritage, offering shade, biodiversity, and aesthetic benefits in newly developed areas.

Climate change | 13.03

The impacts of climate change are undeniably altering the habitats for both humans and the urban forest. Since most tree species have specific climate preferences, such as humidity and temperature, even slight variations in climate can significantly affect their health. In addition to the challenges posed by changing climate conditions, the urban forest must also adapt to meet various benefits demands that trees need to provide to their surroundings. Due to these changing conditions placing “the right tree at the right location becomes a challenge”

The right tree at the right location
Adaptive forestry solutions offer a valuable means to experiment with different tree species in various locations. For instance, if a tree species in a specific urban area experiences declining health due to increasing temperatures and sun exposure, Adaptive forestry solutions can be implemented, involving transplanting the struggling tree to a more shaded location while reintroducing a mature tree species that are better suited to withstand the evolving climatic conditions of the sunny location.

This adaptive approach not only ensures the continued presence of trees but also promotes the resilience and vitality of the urban forest in the face of climate change. It allows city planners and arborists to proactively manage the urban environment, optimizing the benefits that trees provide while enhancing the overall liveability of the city.

Drought & short periods of heavy rainfall
Another significant effect of climate change is the increasing frequency of prolonged droughts followed by intense rainfall, which poses significant challenges to newly planted trees. These conditions can lead to high tree mortality rates during the initial stages of newly planted trees since their root system are not yet developed.
Adaptive forestry solutions offer a means to address this problem. By incorporating root ramification techniques and adaptive irrigation systems, these solutions can significantly improve the survival rates of newly planted trees. Root ramification methods encourage the development of a dense and robust root system, allowing trees to better absorb water and nutrients, especially in the initial phase when they are re-planted.

The adaptive irrigation systems can respond to changing weather conditions. During drought periods, these systems can provide more frequent and targeted watering to trees that are at risk. Additionally, if trees are struggling to survive due to severe drought stress, the adaptive forestry approach allows for the option of temporarily relocating them to a nursery where they can receive specialized care and attention to restore their health.

This proactive and adaptive approach not only enhances the resilience of urban trees but also contributes to urban greenery’s long-term viability in the face of the challenging climate conditions associated with climate change.

limitations on Climate change effects of mobile trees
Adaptive forestry solutions have the capability to grow trees in area’s with both limited above and underground space. Due to their Mobility they can adept to various challenges that trees can face in the urban landscape.

However it is necessary to acknowledge that due to their confined root space and their maximum canopy proportions for transplantation we could argue their effectiveness in preventing climate change. The ability for a tree to sequestrate carbon dioxide is directly related to its growth curves and proportions.

On the other hand, one could argue that the implementation of trees in urban environment do not need to absorb carbon dioxide but that their efforts for cooling, providing clean are and enhancing liveability to their local climate is enough reason to implement adaptive forestry solutions to urban city centres.

Liveability | 13.04

The concept of liveability in hardscaped city centers can be approached from various angles. On one hand, it can be assessed through physical aspects like air quality, temperatures, walkability, and the overall maintenance of pavements, roads, and public spaces. On the other hand, liveability of urban area's can also be evaluated based on psychological factors such as stress reduction, nearby parks, noise management and the sense of safety.

The site analysis based on QGIS has revealed several areas within Rotterdam facing challenges in terms of liveability, specifically concerning thermal comfort, available green spaces, and the increasing demands resulting from population density. The absence of adequate green infrastructure in these areas has underscored the need for alternative adaptive forestry solutions.

The potential impact of trees on liveability can be interpreted differently for distinct neighborhoods, such as Oude Westen and Oude Noorden, in comparison to the more commercial areas like the squares and shopping streets in Rotterdam's city centre. Each of these areas has its unique characteristics and liveability considerations.

Residential Neighbourhood Areas
Adaptive forestry solutions can be used to strategically plant and manage trees for improving both the physical and psychological liveability in residential neighbourhoods such as Oude Noorde in Rotterdam.

While the neighborhood areas may not experience rapidly changing demands for trees in the short term, the implementation of adaptive forestry solutions could significantly enhance the liveability in these areas where trees face difficulties to grown. These Adaptive forestry solutions can improve thermal comfort by providing shade, increase greenery, and meet the demands of residents for accessible green spaces. Additionally, they can address the specific needs of the community, such as creating safe and pleasant spaces for outdoor activities.

City Center and Commercial Areas:
In the city centre, where public spaces like squares and shopping streets play a vital role in the urban experience, adaptive forestry solutions can be used to ensure that these areas remain adaptable to various events and functions. Adaptive forestry solutions can be used to strategically plant and manage trees in these every changing urban environments. The changing context and use of space also asks for different types of trees in these spaces.

For instance, mobile trees can be introduced to provide temporary shade during outdoor events or festivals, enhancing the comfort and appeal of these spaces. After these events have concluded, the arrangement or configuration of the trees in these places can be altered to address other demands, such as creating beautiful green spaces that are inviting for relaxation and leisure.

In both cases, adaptive forestry solutions offer a dynamic and flexible approach to urban greenery management, responding to the unique liveability needs of each area. Whether it's the creation of lasting green oases in neighborhoods or the adaptability of urban centers, these solutions can contribute to making Rotterdam a more liveable and resilient city for its residents and visitors.

Due to the limited size of mobile trees, one might question the extent to which adaptive forestry solutions can effectively address various physical demands, such as improving air quality and mitigating temperature. On the other hand, there is limited knowledge regarding the specific proportions of trees required to address psychological demands, such as reducing stress.

Thesis reflection | 13.05

Throughout this thesis, the research and design process have undergone continuous iterations. Inspiration has been drawn from various sources, including the art of bonsai, interviews, and desk research, all of which have significantly influenced the development and implementation of the adaptive forestry concept. It is essential to emphasize that Adaptive forestry solutions should not be seen as the sole objective in tackling urban forestry challenges. There will be situations where the conventional method of planting trees still remains a more suitable solution for a particular area than containerized trees.

However, the key takeaway from this thesis work is that implementing Adaptive forestry solutions in highly urbanized and dynamic environments can be a viable approach. It not only contributes to increasing urban canopy covers in such areas but also has the potential to enhance both the physical and psychological aspects of livability. By strategically transplanting and preserving trees, Adaptive forestry offers a promising strategy for creating more sustainable, resilient, and enjoyable urban environments in the face of climate change and urban intensification.

Societal impact

When considering Adaptive forestry as a strategy to enhance the livability of hardscape city centers, it is essential to recognize the potential for gentrification. To mitigate the societal impacts, urban planners and policymakers should adopt inclusive and equitable approaches. These approaches may encompass the implementation of measures to provide affordable housing, the protection of existing communities, and the active engagement of residents in decision-making processes related to neighborhood development, particularly concerning the green spaces in their vicinity. By involving local residents in these discussions, not only can an understanding of the importance of urban greenery be fostered, but it can also serve as a foundation for co-caring initiatives where the community plays an active role in maintaining the Adaptive forest.

Research Recommendation

Due to the limited time available for this master's thesis, it was not possible to address all aspects of the Adaptive forestry concept and its feasibility. Existing knowledge gaps still require further investigation to gain a better understanding of the potentials and constrains of transplanting trees in metropolitan city cnetres.

A unified, open-source communication platform that consolidates information is crucial for the continuous advancement of research in tree transplantation and urban forest management. This accessible platform ensures that all organizations involved in these fields can easily access and contribute to the collective knowledge base, fostering steady research development. The continues input of data over a long period of time will allow researchers and experts to better understand growth curves, maintanance and management patters ultimately contributing to a pro-active aprouch in which various developments can be quantified and predicted.

Besides comprehending the growth patterns of these trees, there's a need for research to delve into their management, maintenance, and ability to be transplanted. Given the limited knowledge available about containerized trees and their adaptability to transplantation, the ongoing collaboration between academic studies and real-life implementation is crucial. This collaboration is key to expanding the knowledge base. Only through such comprehensive research efforts can we effectively evaluate how these trees perform in diverse urban environments, each presenting distinct challenges and opportunities that adaptive forestry can potentially address.

To further the understanding of the potential of adaptive forestry, I aspire to dedicate my efforts, hopefully alongside many other researchers who may be inspired by this thesis report, to address these knowledge gaps and advance the field and potential of adaptive forestry.

Fig 112, Former bonsai tree at Ritsurin garden Takamatsu (2023)

Epilogue | 13.06

Within this master thesis the art of bonsai has been a guidance and inpiration from the beginning until the end. It has shed light on both the technical, maintanance and strategic manamgenet of the urban forest. As a last remark of inspiration I would highlight the softer, spiritual side of bonsai and it's intricate relation to the humans that give shape to them. Not only does this give us the opertunity to learn more about inmense value and beauty of the trees that seround us but it also gives us understanding of our own easthethic preferences and positioning regarding our biophilia.

With gratitude for the interviews and conversations I had with Bonsai master Kunio Koboyashi, Seji Morimae, and Teunis Jan Klein, as well as the invaluable guidance and advice from Professor Erik de Jong about our biophilia, I am inspired to conclude this thesis with a hopeful note.

Fig 113, Kunio Kobayashi & author, Tokyo (2023)

The Teachings of Bonsai

"It happened to be that the ancient bonsai tree became a part of our life. We humans have placed the bonsai in a cage. There is no other way for the bonsai than to accept its fate. Now, it is our responsibility to take care of this tree that is imprisoned within its pot. Some trees have been cared for, for more than hundreds of years, solely for the purpose of appreciating their visual and spiritual beauty. Their presence in today's life is a testament to the consistency and loyalty of many generations. Without human care, in one day the tree might get sick, and within one week, the tree might die. The bonsai's fate is within our hands, and there is only acceptance and trust left for the tree in this situation.

From this point of view, it can be interpreted that the bonsai tree and the artist are entangled in a very interesting long-term relationship; they are married across multiple generations. Without human care, the bonsai would not survive; they form a symbiotic relationship that helps us understand not only how the bonsai lives but also how the artist feels and their personal preferences for beauty.

Given the right attention and state of mind, this symbiotic relationship between humans and trees is also present in many people's living environments in metropolitan city centers. Especially there, in densely populated concrete city centers, this symbiotic relationship is profoundly evident. Trees and humans need each other to thrive, stay healthy, and survive. A single tree can become a symbol for all natural phenomena, including the earth, its climate, and our collective biophilia.

If we want our future generations to have a healthy, resilient, and sustainable living environment, we should start planting, planning, and caring for our trees now. Let us enhance and sustain the beauty of trees in the city by applying bonsai techniques, traditions, concepts, and poetry to showcase to everyday people, governments, and politicians the complex, spiritual, and profound value of trees. With the right attention and care, all that remains for us is to appreciate their beauty and welcome their wonderful presence in our lives."

14 References

This reference list is containing all references made within this thesis report, The references to pictures can be found in the Image bibliography

A

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