Paleis Soestdijk as a
CIRCULAR ESTATE.

By

Julia Kapinga

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Research Team

Main supervisor:	Andy van den Dobbelsteen
Second supervisor:	Nico Tillie
Graduation board member:	Stefan van der Spek
Advisors MeyerBergman:	Rosan Pallada
	Charlotte Uiterwaal
Land agent Paleis Soestdijk:	Hester Lode

Preface

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Dear reader,

In front of you is the final report of my graduation project: ‘*Paleis Soestdijk as a Circular Estate*’. Together with the A3 booklet and the P5 presentation slides, these are the final products of my graduation project. A project that I am on the one hand incredibly proud of, but on the other hand has also cost me a lot of hardship, effort and sleepless nights. During the time that I worked on this project, the world has changed a lot. Working on an individual large project can already be challenging and adding a pandemic on top of that has definitely had some impact on the process I have gone through.

I learned a lot during this project, not just on the topic, but also about myself as a person. This project has taught me more about the difficult design challenges that we face, especially on the level of landscape and how to integrate sustainable solutions that keep our feet dry and minimises our impact on the environment. Climate change is real, and happening perhaps even more rapidly than anticipated. While I am writing this, there have just been large floods in Limburg, Germany and Belgium due to heavy rainfall. Seeing the destruction that such a natural disaster can cause, motivates me even more to continue to work on sustainable solutions that can help with preventing more destruction as well as slow down the process of climate change.

Paleis Soestdijk was a dream to work on. It is a special location of rich historic value and endless potential. Incorporating my gained knowledge on biomass, wastewater management and food production in a circular plan could be difficult at times, but in the end it all came together nicely.

I would like to thank my mentors, Andy and Nico, for their expertise, guidance and patience with me during this project. Charlotte and Rosan from MeyerBergman Erfgoed have been a great help during this project as well. Thanks to their assistance and hospitality, I had all the information that I needed and the possibility to visit the site and palace multiple times.

Enjoy reading the report!

Kind regards,

Julia Kapinga

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1 Introduction

Historically seen the Paleis Soestdijk has been an autarkic estate. Everything that was consumed was harvested from the grounds of the estate. However, over the past 150 years, the estate has become more reliant on outside sources, even though the estate is still rich with possibilities to solve demands locally. This outside sourcing is not limited to Paleis Soestdijk, most people have become more dependent on outside sources and rarely look at what can be used, re-used or shared locally.

Paleis Soestdijk is a former royal residency that has centuries of history. It started as a hunting lodge and has grown into a royal palace that has seen many royals and other important people. After the death of its final residents, former queen Juliana and her husband prince Bernhard, in 2004, the palace and its grounds became accessible for the public. It was the property of the Dutch government and expensive to maintain. Therefore it was put on the market in 2015, and investors and corporations were allowed to send their plans and ambitions for the palace. In 2017 it was announced that the plan 'Made by Holland' of MeyerBergman Erfgoed was approved and they were allowed to buy the property. Their idea is to create a podium for Dutch innovation and design, while respecting and honouring the existing historic values of the palace and the estate.

The ambition of MeyerBergman Erfgoed is for Paleis Soestdijk to become a leader in sustainability and circularity. In 2019, MeyerBergman Erfgoed organised a brainstorm session with renowned people within the world of sustainability to formulate ambitions for the future of Paleis Soestdijk. Their working title: The first energy neutral palace of the world. In figure 1, an infographic of the outcomes of that session can be found. This infographic was also the inspiration to look into the palace as a possible graduation topic and therefore a starting point for this project.

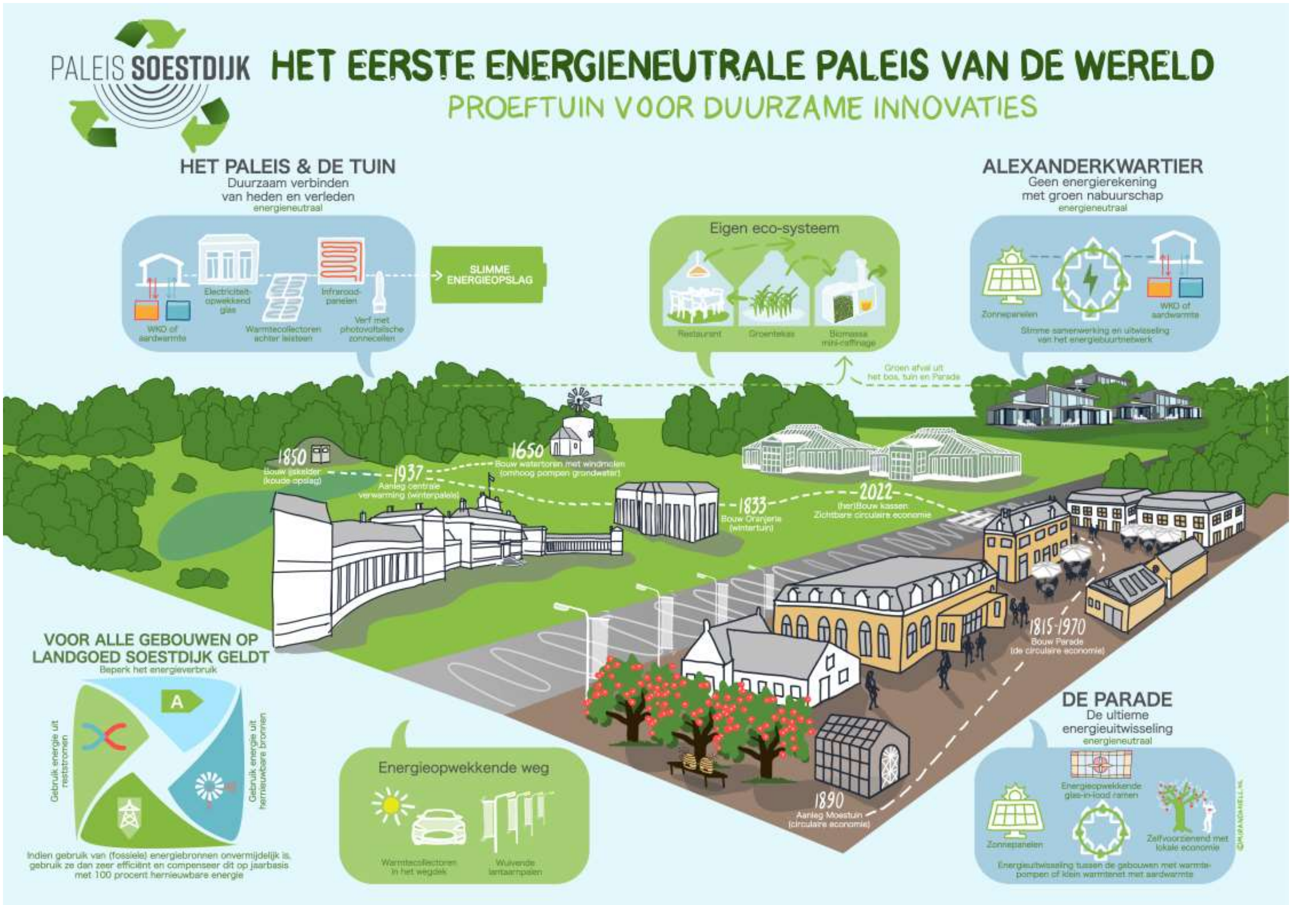

Figure 1: Infographic of sustainable ambitions MeyerBergman Erfgoed (De Groene Grachten, 2019)

The estate of Paleis Soestdijk has developed and evolved over a long period of time. Each period, each contemporary user of the estate has added a layer to the landscape and palace, creating a so-called palimpsest. The circular plan created in this graduation project will add a new layer to this palimpsest, a layer that introduces the innovations of the 21st century while respecting the already existing layers.

In an ideal world, one would like to create a complete plan for Paleis Soestdijk that takes every aspect into regard. However, in a graduation project, one does not have the to fully research all aspects of a plan as well as to design the plan. For this reason the main focus of this graduation project is on the biomass cycle on the estate of Paleis Soestdijk. Finding a circular solution for all biomass streams existing on the estate grounds. Connecting biomass streams where possible, and adding new functions and ways to process biomass to close the loop.

The report starts with some background information and the introduction of the topic and the methodology behind the project. After that it will dive into the literature and explore the topics of biomass, the techniques that can be used in the plan and especially the topic of food production. The next chapter will dive into the history of Paleis Soestdijk, as well as analyse the current situation. The elaboration chapter will explain some aspects of the plan and especially the numerical substantiation of both the plan and the design. The report will end with a conclusion that will discuss the findings during this project as well as the final outcome, and a reflection that will reflect on the process during the graduation project.

2 Research Methodology

2.1 Background

The perspective of this thesis is based on certain defined ideas about sustainability and circularity. In order to give more insight into these topics, the most important background knowledge will be explained.

2.1.1 Sustainability

In order to define the term 'sustainability', it is useful to look at the definition of a sustainable development by the Brundtland Commission. The report, titled 'A common future', states the following: '*A sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*' (Brundtland Commission, 1987)

In other words, this means that sustainability is making sure that the demands of people today can be met without comprising the demands of people in the future. Sustainability depends on three main pillars: the societal, environmental and economic.

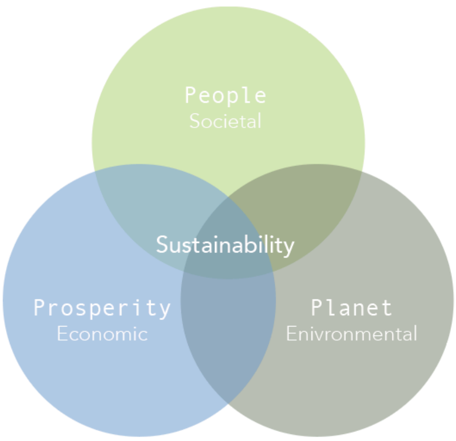

Figure 2: Triple Bottom Line diagram

John Elkington wrote a book in 1994 about sustainability. His theory, called the Triple Bottom line, is that sustainability can only be accomplished if the demands of *People*, *Planet* and *Profit* are in harmony with each other (Elkington, 1998). Two decades later, he changed the term for the economic pillar from *Profit* to *Prosperity*, since economic sustainability does not only concern the financial side, but the overall prosperity of the human population (Kraaijenbrink, 2019).

The perfect situation for societal sustainability (*People*) would be that every human being on earth has access to basic necessities and human rights (McGill University, 2017). That everyone has the ability to take care of their loved ones and that no one is suppressed for who they are, whom they love or what they believe in.

Environmental sustainability (*Planet*) means that the earth's natural resources are consumed at a rate that there is enough time to replenish these sources (McGill University, 2017). Therefore, not assuming that these resources are infinite, but utilising them carefully, so there is also enough for the future.

Economic sustainability (*Prosperity*) derives from the idea that every human being across the world has the ability to acquire what they need and maintain their own financial independence (McGill University, 2017). Which could end the unfair and disproportional difference between poverty and excessive wealth in our current society.

The United Nations have defined in the past years Sustainable Development Goals (SDG's). This serves as an agenda for 2030 and states goals within five domains: *People*, *Planet*, *Prosperity*, *Peace* and *Partnership*. The UN has based its domains on the theory of Elkington, adding two more domains to it. *Peace*, since one of the main goals of the UN is to end war and violence in the entire world. In their objective sustainability can only be reached if there is peace (United Nations, 2015). *Partnership*, because they believe true sustainability can only be achieved when all actors work together, and especially including the third world countries in this as well.

Ensuring that all lives are improved, creating a better world (United Nations, 2015).

This research aims to contribute to the following SDG's:
- Goal 2: 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture.'
- Goal 9: 'Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.'
- Goal 11: 'Make cities and human settlements inclusive, safe, resilient and sustainable.'
- Goal 12: 'Ensure sustainable consumption and production patterns.'
- Goal 13: 'Take urgent action to combat climate change and its impacts.'
- Goal 15: 'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.'

(United Nations, 2021)

In appendix A, an overview of all SDG's can be found.

2.1.2 Circularity

When looking up the term 'circularity' in a dictionary, the following two definitions can be found:

1. 'the fact of constantly returning to the same point or situation'
2. 'the fact of being shaped like a circle'

(Cambridge Dictionary, 2021)

Both of these definitions relate to the definition of circularity in the scope of sustainability, namely solving problems in a cyclic way, ideally closing an infinite circle where waste streams do not exist. When looking at circularity it is important to mention two main topics: Cradle to Cradle and the Circular Economy

The Cradle to Cradle principle was invented by McDonough and Braungart in 2002, and essentially focusses on the life cycle of a material or product. It assumes that this life cycle is not an ending one, but one that anticipates already during the destruction or demounting phase to the next life cycle (van den Dobbelsteen et al., 2012). So from cradle to cradle, instead of from cradle to grave. Creating something new from something that is often regarded as waste.

Circularity is also the basis for a new type of economy: the Circular Economy. The current economic model is linear, focussed on taking (natural) resources, making a product out of this, selling it to someone who will use it for an amount of time and afterwards disposed. This means that a lot of unnecessary resources are wasted in this economic model (Ellen MacArthur Foundation, 2012). There are many reasons to state why this current system is failing. To state a few:

- Loss of value due to high amount of waste. This waste is not just produced when a life cycle of a product is ending, but also already during the manufacturing phase of a product (Ellen MacArthur Foundation, 2012)
- Products are designed in such a way that there is a lot of end-of-life waste (Ellen MacArthur Foundation. 2012). Meaning that the different materials cannot be taken apart after the lifespan of a product and therefore cannot be recycled or reused.
- When a material or product is not recycled or reused, all the remaining residual energy will be lost (Ellen MacArthur Foundation, 2012).
- There is a lot of pressure on our natural environment, leading to for example climate change, loss of biodiversity and ocean pollution.
- More than half of the world's population lives in an urban environment, in cities there is simply not enough space for everyone to have their individual things. It is more practical to share certain amenities.

It is clearly time for a circular model: an economy that is more about sharing and connecting, creating opportunities instead of just discarding a product after its life cycle as waste. According to the Ellen MacArthur Foundation, rests a circular economy on the following three principles:

1. 'Design out waste and pollution'
2. 'Keep products and materials in use.'
3. 'Regenerate natural system.'

(Ellen McArthur Foundation, 2017)

Naturally, a circular economy relies on energy from renewable sources (Ellen MacArthur Foundation, 2012). Next to that, a circular economy heavily relies on concepts such as modularity, versatility and adaptivity, since it increases the resilience of a product or service through diversity (Ellen MacArthur Foundation, 2012). Meaning that a system that can be applied and fit for many different occasions or products is more resilient to outside influences than a system build for efficiency. Thinking in systems, is also a large part of the circular economy. This ensures that one can truly understand how parts have an influence on each other, and what the relationships between the parts and whole product are (Ellen MacArthur Foundation, 2012). Lastly, it is important to keep in mind that waste does not exist in the circular economy. Therefore, waste is food.

Biological materials require a different approach to circularity than technical materials. Therefore the Butterfly diagram (figure 3) created by the Ellen MacArthur Foundation consists of two cycles: the biological (regenerative) cycle and the technical (restorative) cycle.

For the circular economy it is important to not just think of how everything should work as a whole, but also how it can create value (Ellen MacArthur Foundation, 2012). Essentially, there are four ways that ensure circular value creation:

1. The power of the inner circle: a smaller circle results in more saving on costs such as material, labour and energy (Ellen

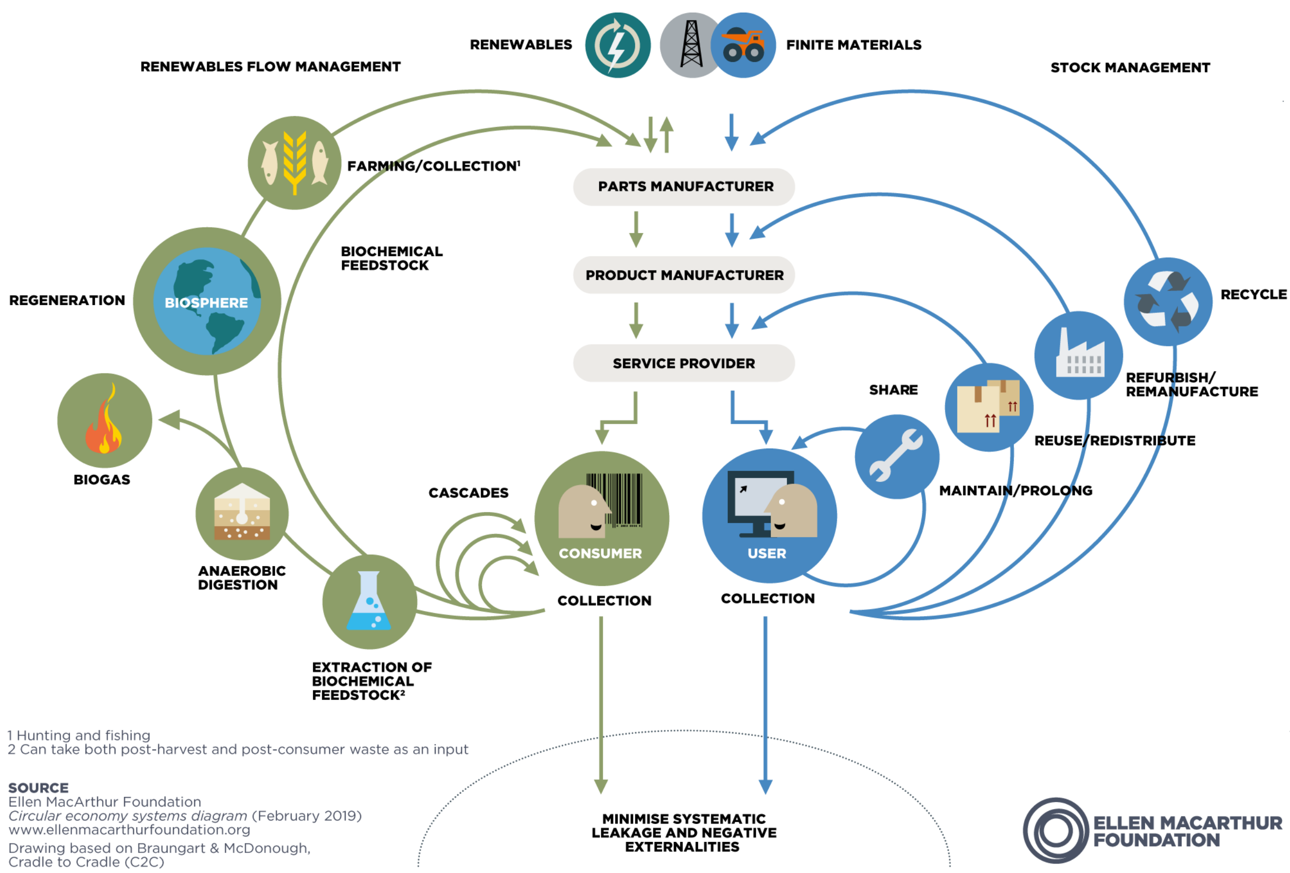

Figure 3: Overview of the Circular Economy (Butterfly diagram) (Ellen MacArthur Foundation, 2019)

MacArthur Foundation, 2012). It is more efficient, and due to the restorative nature of a cycle value remains within the circle.
2. The power of circling longer: the restorative nature of a cyclic process ensures that the usage of a virgin material can be prolonged, the material stays longer in the process, ensuring that less virgin material is needed.
3. The power of cascading: a way to prevent value from being wasted is cascading, which means that a material or (part of) a product is used for another application (Het Groene Brein, n.d.). The cascading material replaces the virgin material in the process. This happens in the biological cycle of the butterfly diagram, organic matter can be easily transformed for a new purpose, creating again and again a product by reusing the value of what is left of the last product.
4. The power of pure, non-toxic and easy-to-separate designs: In order for a circular design to be successful, it is important to work with pure materials or easy to separate components. Ensuring in this way that all materials of a product or design keep their value.

2.2 Problem Statement

In a general perspective, the world currently relies on linear processes in which a product or design is created, utilised until expiration and afterwards disposed of. In this process, a lot of waste is produced, potential material for new purposes. This is not only visible in the things that we consume but also the way we design and operate our built environment and landscape. Therefore, it is important to find solutions to ensure that instead of producing waste, our built environment and landscape become circular, meaning that it will re-use, re-cycle or up-cycle everything that it produces.

Next to that, there is a gap in knowledge on connecting biomass streams on a landscape level, especially in non-urban areas. There is plenty of research on creating circular solutions for urban areas, however connecting domestic and public functions to actual nature as a biomass cycle is still a relatively unexplored topic. Especially linking food production to the cycle of biomass, can lead to interesting outcomes and the ability to simplify the closing of the cycle.

On the level of Paleis Soestdijk, the following problems can be recognised:

2.2.1 Dependency on outside sources

Currently the estate depends on outside sources for energy, food, water , etc. However, the estate itself has many sources that could provide for the estate itself. For biomass, there are many different biomass sources available on the estate, which have no real purpose and there is no plan on how to utilise these biomass sources to its full potential.

2.2.2 Waste disposal problem

The gardens of the estate are under good maintenance; however, the disposal of this gardening waste is a mess. In autumn the leaves are randomly dumped in the forest and the other gardening waste is dumped on the side of the estate, where it looks currently like a large waste disposal. This is not only an aesthetic problem as well as a safety and legal problem. Therefore, it is important to create a strategy for this waste in order to properly deal with it, instead of just ignoring it and putting it aside.

2.3 Objective

The general objective of this graduation project is to create a circular plan for biomass management on the estate of Paleis Soestdijk. This plan will be based on utilising the available biomass sources on the estate and solving the aforementioned problems.

This will result in a plan for the estate of Paleis Soestdijk that will utilise the different biomass sources and the possibility of producing food, by connecting them and converting them to products that can be used for other purposes on the estate. Central in this plan is the creation of two greenhouses around which the processing and conversion of biomass will be designed.

2.4 Research Questions

The aforementioned problems and objective have led to the following question that is central in this graduation project:
How can the cycles of food production and biomass be connected on the estate as part of a wider perspective to create a circular Paleis Soestdijk?

This leads to some additional questions, such as:

- *What biomass streams can be found on the estate of Paleis Soestdijk?*
- *What biomass conversion techniques have potential on the estate of Paleis Soestdijk?*
- *How can the introduction of greenhouses play a role in closing the biomass cycle on the estate of Paleis Soestdijk?*

2.5 Design Brief

As a part of the thesis project, a greenhouse concept will be designed to process the produced biomass on the estate and grow food with it for the restaurant. That restaurant in itself will produce biomass again that can be included in the cycle as well, linking all biomass and food production on the estate. This cycle, consisting of the ways to process biomass and growing food will be visible on the estate, hence also educating visitors on various topics such as circularity, sustainable food production, biomass conversion and so forth.

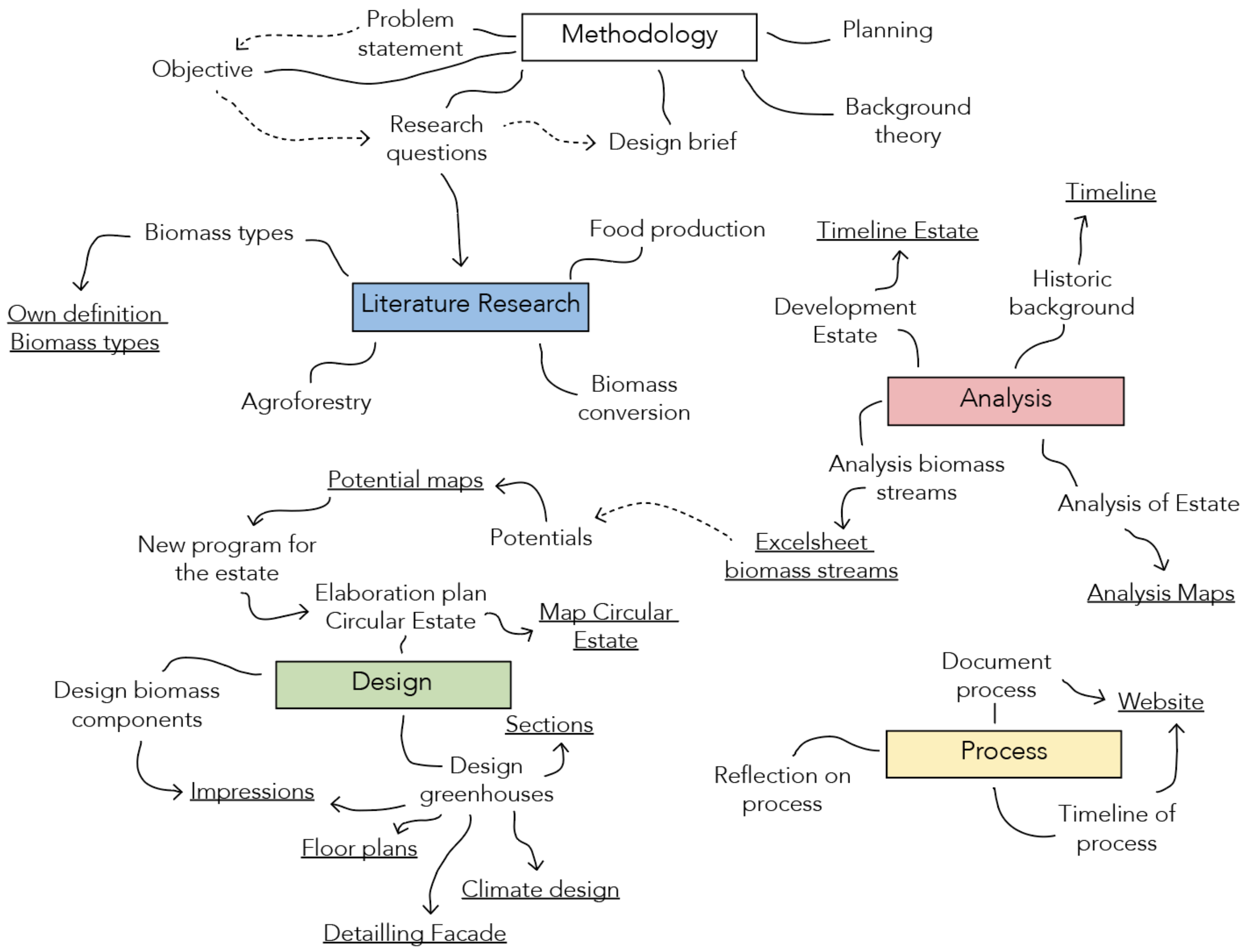

Figure 4: Mind-map of Research

2.6 Methodological Framework

In order to create some structure and give some insight into the process of this research, it is important to create a clear overview of the methodology behind the research.

In figure 4, a mind-map of the entire research can be found. Writing down the different components and what these components entail, made it possible to create a list of products that will eventually form the entire research project in its whole.

2.6.1 Components of the research

In essence, this research consists of four different components, five if one also counts the methodology as a component. Figure 5 shows a schematic overview of all different components. It shows what is researched or designed and to what knowledge or design inputs this will lead. Below the different components are explained.

Literature Research

To fully understand the topic of biomass and its applications, literature needs to be read and reviewed. Without the literature research, those two will be based solely on the designer's perception and knowledge, without any substantiated background on the topic. During the process of the graduation, the topics of research have been carefully chosen and defined to ensure that the gathered knowledge is relevant for the final outcome of this research.

Analysis

To create a fitting strategy and design for the estate, one must know and understand the estate. Therefore, extensive analysis and research into the area are necessary. For this project, there is a focus on the historical context and development of the estate, an analysis of the estate itself and an analysis of the existing and potential biomass streams.

Design

This graduation project will result in an overall plan for the estate that will elaborate on the themes biomass, water and food. The plan will zoom in more on the area around the greenhouses. It will include a preliminary

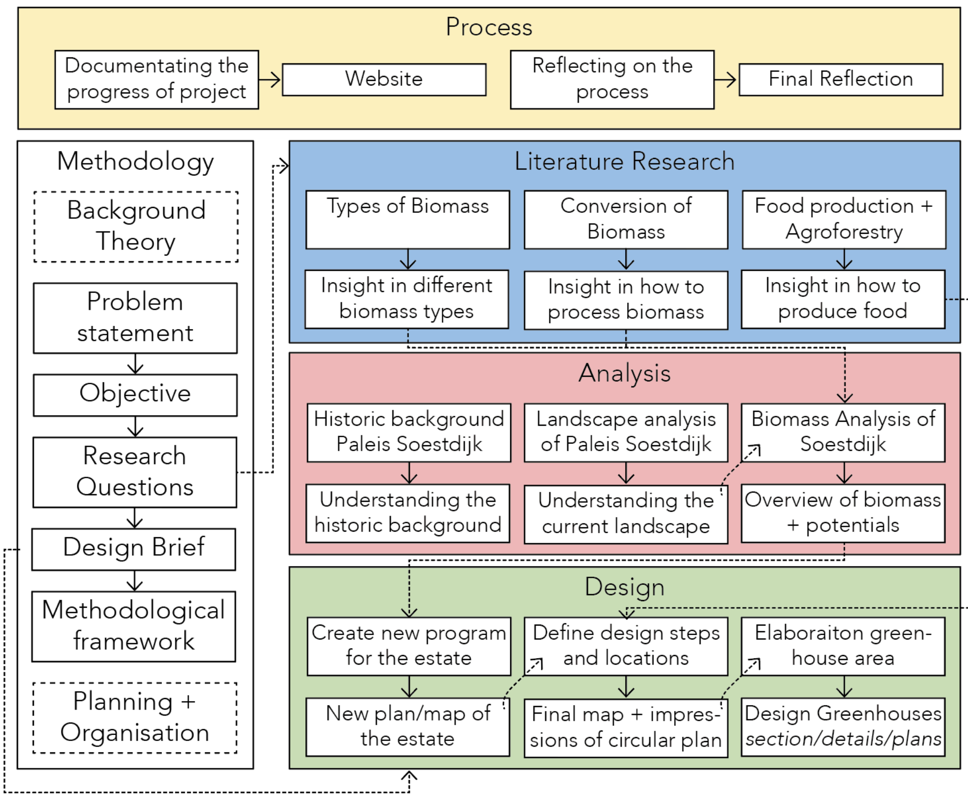

Figure 5: Schematic overview research methodology

design of the collection and processing of biomass and a more detailed design of two greenhouses that will be mostly responsible for the food production on the estate of Paleis Soestdijk.

Process
The process of this graduation project will be reflected on in an elaborate reflection chapter that will dive into the different stages of the project and how the process as a whole has been for me. As can be seen in figures 3 and 4, the plan was to also create a website to document the process and project. However, this turned out to be much more work than intended and therefore was not finished in time.

2.6.2 Outputs of the project
This graduation project will result in three main products: a report, an A3 booklet and a presentation. In table 1, an overview of the products and what these products will include can be found.

2.7 Planning and Organisation

2.7.1 Planning
It is evident in this planning that this graduation project spans over a larger time period than usual. This has, first of all, to do with some personal reasons, that lead to a slower pace in the graduation process. Next to that, the whole COVID19 situation has delayed the process a bit as well.

2.7.2 Organisation
During this graduation project, there was close contact with MeyerBergman group, the owners of Paleis Soestdijk. They provided all the information needed to complete the analysis and also advised on the content. Due to COVID19, there was not a lot of opportunity to visit the estate itself. Fortunately, there had been visits before the COVID measures, as well as a sporadic visit during the pandemic period.

Product	Contains:
Thesis report	Methodological framework
	Literature research - Biomass types > <u>own definition</u> - Biomass processing - Food production - Agroforestry
	Analysis of Paleis Soestdijk - History > <u>Timeline</u> - Development > <u>Timeline</u> - Analysis Estate > <u>Maps</u> - Analysis Biomass > <u>Calculations</u>
	Reflection on the process
A3 booklet	Analysis of Paleis Soestdijk - Analysis maps + drawings
	Circular plan - Plans for the estate - Impressions
	Sketches of the design process

	Design of processing components
	- <u>Impressions</u> + basic plans of:
	  - Collection of biomass
	  - Processing of biomass
	  - Constructed Wetland

	The greenhouse design - <u>Floor plans</u> - <u>Sections</u> - <u>Facade detailing</u> - <u>Climate design</u> - <u>Impressions</u>
Presentation	Story of the project
	Documentation of the project
	Renders + drawings

Table 1: Outputs of the project

3 Literature Research

In literature about circularity and sustainability, especially on a landscape scale, there is a dominant focus on energy production. On the topic of biomass there is literature available, however this is mostly about generating energy. Although the generation of energy is a practical appliance of biomass, other sustainable appliances also have merit on a landscape level (e.g., production of the fertilising compounds). Furthermore, the research on connecting the different biomass types on this level has not yet been researched extensively. Hence this research aims to fill that gap, combining literature research on biomass and its implementation by creating a circular plan to enclose the cycle of biomass on a landscape scale.

The existing literature introduces the idea that a biomass cycle cannot be closed on its own. The cycle needs a secondary purpose to ensure that the loop will continue. Food production could be that secondary purpose, since processed biomass can be used as a fertiliser or produce energy to help plants grow. Additionally, there is the opportunity to turn wastewater, which is essentially liquid organic matter and therefore can be considered as biomass, in clean(er) water for irrigation.

When looking at the definition of biomass, it is evidently clear that the researchers are in agreement. Rentizelas (2013) gives the following definition: 'Biomass is biological material derived from living, or recently living organisms.' The mentioned organisms do not only refer to plants, but also animals and other forms of life, such as micro-organisms (Bos et al., 2019).

This research will serve as a starting point for the design of a circular plan for the estate of Paleis Estate. As a further elaboration of this plan, two greenhouses will be introduced. Therefore this chapter will also shine some light onto the topic of food production inside a greenhouse. Next to that, the topic of agroforestry will be explored, because this type of food production is quite closely linked to biomass.

This chapter will give a display of different literature and the assessment of this literature. This will result in the following:

- An overview of the different types of biomass
- An exploration into the different conversion techniques of biomass
- An introduction to food production inside a greenhouse
- An exploration of the topic of agroforestry

3.1 Types of Biomass

When exploring the topic of biomass and especially what types of biomass there are, one will find that there is quite a wide range of definitions. It was noticeable that most literature just gives a definition of biomass material that can be used for energy production but neglects to classify the material according to what they can become (as in not just for producing heat or electricity). Below, the classifications by several sources are explained and dissected. All definitions are carefully assessed and will form a set of biomass classifications that will be used in this research.

Rentizelas (2013) classifies biomass into five categories:

1. Virgin Wood: the harvest of all forms of wood, including logs, branches, bark and sawdust.
2. Energy crops: biomass that is specifically grown as a fuel source. There are different types, but it mainly revolves around short-rotation crops.
3. Agricultural residues: this mainly refers to the extra biomass produced while producing food. It contains residues from

the harvesting, excess production, animal manure and bedding.
4. Municipal solid waste: the waste that people produce in their daily lives.
5. Industrial waste: the waste of an industry, for instance paper, textile, food, etc.

Rentizelas' article mainly focuses on the conversion of biomass into energy, and therefore his definition of the different biomass types, solely focuses on whether they are suitable for this energy conversion. This is already visible in the way he names and defines the different types.

Bos et al. (2019) divided biomass in the following biomass sources and mention the primary and important secondary products of each biomass source. This is a completely different approach to Rentizelas, especially in the way that it is a lot more objective. It only mentions the products that it produces and not necessarily what one can do with these products. An overview of their definition can be found in table 2.

Next to that, commissioned by the ministry of Economic Affairs and Climate, the RVO (Rijksdienst voor Ondernemend Nederland) has created a classification system for biomass which is included in the document NTA 8003. According to this classification, there are five different categories:
1. Woody biomass from forest management units
2. Woody biomass from forest management unit smaller than 500 ha.
3. Residual biomass from nature and landscape management
4. Agricultural residues
5. Biogenic waste and residue streams

These categories are based on the origin of the biomass and within the first two categories there is not yet a distinction in primary or residual biomass (RVO, 2019). Residual biomass refers to biomass that is produced that was not intended (surplus) or when the product has such a low value that it has little to no market value (RIVM, 2016).

Type of Biomass	Primary products	Secondary products
Trees from forestry	Wood, cork, resin, latex	Foliage, sawdust, bark
Plants, trees and grass from landscape management	Wood, water plants, roadside grass	Pruning waste
Crops:		
- *Grain*	Cereal grain, starch	Straw, bran, chaff
- *Oleaginous crops*	Beans, nuts, oil	Protein-rich scrap, pruning waste
- *Sugar beets*	Sugar	Sugar beet pulp, molasses, beet points, beat leaf
- *Potato's*	Potato's, starch	Potato pulp
- *Oil palm*	Palm oil	Diverse amount of residual flows
- *Vegetables and fruit*	Vegetables and fruit	VF residues
- *Meadow grass*	Grass, hay	Stems, foliage
Microalgae, seaweed	Oil, protein, hydrocolloids	Cell wall residues
Residue streams after usage by consumer and animals (tertiary residue streams)	VFG (vegetable, fruit and garden waste), paper waste, most, waste grease, waste cooking oil, swill, discarded textiles, sewage treatment sludge	

Table 2: Biomass classification (Bos et al., 2019)

3.1.1 Defined Biomass types
The above-mentioned classifications of biomass are in essence quite similar, but they are approached from a different perspective and therefore include a few different aspects. Where Rentizelas focused on classifying biomass for energy conversion, Bos et al. focused more on the different sources and products of biomass. The classification system of the RVO is sort of in the middle of these two. It is a more general overview, that classifies based on the origin of the biomass. For this research, the types of biomass are defined as follows:

1. Woody biomass
2. Residual biomass from plants, trees, and grass
3. Agricultural residues
4. Biogenic waste
5. Other, e.g. algae and seaweed

<u>Woody biomass</u>
This type consists of all wood products, often generated through forest or landscape management. It can be logs, branches, sawdust or bark from woody sources, such as trees.

<u>Residual biomass from plants, trees and grass</u>
This entails all the other residues from forest and landscape management. It is mostly the pruning waste, for example the foliage from the trees and plants.

<u>Agricultural residues</u>
Agriculture produces quite a bit of waste. Besides the edible product, crops also consist of residual material. This residue makes up a large part of the waste produced by agriculture. Also bad crops or excess production end up in this waste pile. It is important to note that food waste from domestic households or CHR (Cafe, Hotel, Restaurant) are not included in this category.

<u>Biogenic waste</u>
This category entails on the one hand the domestic organic waste produced by a household, but also organic waste produced by CHR or industrial companies. It consists of food waste, gardening waste, faeces, animal manure, and other organic waste materials. Under this category it is important to mention that there is a solid variant, but also a liquid variant. This liquid variant is wastewater, which is usually dumped in the sewage system. The wastewater containing organic matter such as faeces is often referred to as blackwater.

<u>Other types of biomass</u>
Next to the aforementioned biomass types, there are a few organic matters and waste streams that do not fit in any of those categories. Two examples of this are algae and seaweed.

3.2 Conversion of Biomass

After identifying what types of biomass there are, one can dive into the matter of how to process and convert this biomass. Especially in how to convert biomass into a new product. In this part, different conversion techniques are introduced.

When looking into the literature, there are several conversion techniques mentioned. In essence there are two main different conversion processes, the biological and the thermochemical. This chapter will start with explaining the biological conversion techniques and afterwards the thermochemical techniques.

3.2.1 Biological conversion techniques

Fermentation
Fermentation is the conversion of organic matter into e.g. alcohol, acids or hydrogen by using micro-organisms (bacteria, yeast, fungi) (Bos et al., 2019).

Fermentation can take place in aerobic (with oxygen) and in anaerobic (without oxygen) situations. The most common is anaerobic digestion, which means that biomass is broken down by micro-organisms in a situation without oxygen (Jarvie, 2018). With this process biogenic waste can be converted into biogas, which can be used for heating, cooking or producing electricity. The most common type of anaerobic digestion takes place inside a biodigester. A biodigester is available in both small and large scale variants that are profitable. Fermentation can also produce biofuels, such as ethanol, butanol, isobutanol or hydrogen. These biofuels are the products of converting biomass with high carbohydrate levels in a fermentation process (Bos et al., 2019). Important for this type of fermentation is to prepare the biomass, that the cell walls are weak enough to start the process of fermenting. An enzyme or other micro-organism is used as a catalyser to start the process. The process of producing biofuels is mostly only profitable on a large scale, since on a small scale it costs more resources, money and energy than it actually produces.

A more domestic type of fermentation is Bokashi. In Japanese, Bokashi literally means fermented organic matter (Vanderlinden, 2019). Instead of producing biogas or other biofuels, this fermentation process is a fertiliser for the soil. It involves layering organic (food) waste with a bokashi inoculant in a bucket, see figure 6 (Vanderlinden, 2019). The inoculant is usually a mixture of sawdust with microorganisms that can start the fermenting process. The bucket has an airtight lid and is open from the bottom so that the produced liquid can be drained off, and used as e.g. fertiliser for plants. The bucket needs to be placed in the sunlight and after about 10 days the fermented waste can be directly buried in the soil where the plants grow (Vanderlinden, 2019).

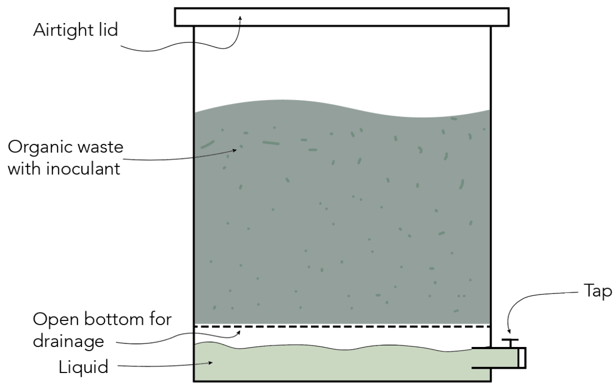

Figure 6: Bokashi bucket

Composting

Composting is a microbiological process in which organic matter is oxidised and broken down to compost by leading air through a heap of porous and solid biomass (Bos et al., 2019).

Composting is one of the most common ways to process biomass, this is mainly due to its flexibility (BVOR, 2014). It can process fluctuating compositions of biomass and still produce something that is usable, without having to alter the process.

Compost, especially from separated domestic biogenic waste, has relatively high amounts of P (Phosphorus) and K (Potassium) (Odlare, 2005). The high amount of P improves the soil and especially K is very important for the growth of the plants. It does however have a low amount of N (Nitrogen), so this needs to be added in another way, if one would like to increase the crop yield (Odlare, 2005). When combining domestic biogenic waste and landscaping waste (woody biomass and residual biomass from plants) the C (Carbon) and N levels will increase in the compost and will improve the nutritional value of the compost (Odlare, 2005).

There are different ways to compost. Composting can process residual plant biomass, agricultural residues and biogenic (domestic or food) waste. On a large scale there are three different types that can be identified:

1. Windrow composting
2. Aerated static pile composting
3. In-vessel composting

Windrow composting
Windrow composting consists of long rows of biomass that are set up and turned regularly (Hyder Consulting, 2012). This type of composting requires a lot of space. The turning is a very important factor. It ensures that the biomass is exposed to all the desired conditions, such as air, light and temperature (Gopikumar et al., 2020). The natural process is already quite successful, however adding a mechanical blower can increase the metabolic activity inside the piles (Gopikumar et al., 2020).

Aerated static pile composting
Aerated static pile composting is the simplest and low-cost option. ASP usually takes place in piles or closed containers. Underneath the piles or on the bottom of the containers there is perforated piping through which air is blown in which controls the aeration. Air can be blown in naturally (more sustainable and cost-effective) or by using a mechanical ventilation system (Gopikumar et al., 2020). ASP is mostly suitable for homogeneous mixtures of biomass (Hyder Consulting, 2012).

In-vessel composting
The name in-vessel composting already gives away that this type of composting happens inside a 'vessel'. This type of vessel can differ, it can be a vertical tower, a horizontal tank, or a circular rotating tank (UNEP DTU Partnership, 2020). There are two different systems. The first one, plug flow, operates according to a first in, first out principle and the ratio between the different particles stays the same during the entire process (UNEP DTU Partnership, 2020). The second system is an agitated bed system in which the composted material is mechanically mixed during the process (UNEP DTU Partnership, 2020). Both systems are designed in such a way that a lot of factors can be controlled and therefore the process does not produce any smelly odours.

On a small scale, for domestic organic waste, there are simpler versions of composting. Most common are the compost barrel or the compost bins.

Compost barrel
The compost barrel is a cylinder-shaped barrel in which domestic organic waste is added on the top and the process of composting goes from top to bottom. The bottom plate needs to be perforated and not directly on the solid ground, to make sure that there is enough ventilation inside the barrel (Geers, 2010). To improve this even further, it is advised to use a special aeration stick to poke around in the biomass or a built in aeration lung as in figure 7. It's best to place a compost barrel on a sunny location, the high temperatures will increase the productivity of the composting process (Geers, 2010).

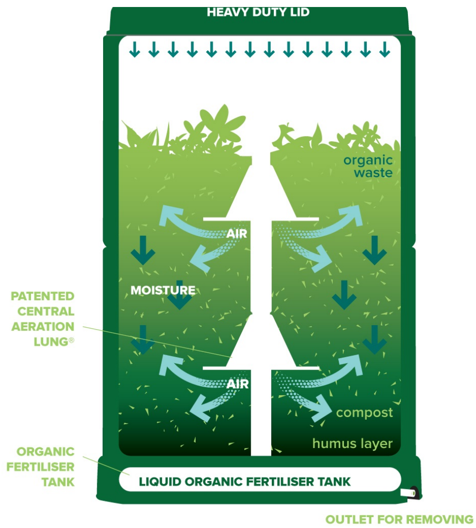

Figure 7: Compost barrel (Maze Products, n.d.)

Compost bins
The compost bins are a system that is a little more complex than the barrel. It consists of three bins, usually constructed from wood or a wire frame. Figure 8 shows a schematic set

up of the compost bins. In the first bin the domestic organic and landscaping waste is added. When the first bin is filled, the content will be moved to the second bin (Vlaco, 2019). Due to the moving of the compost, the micro-organisms are activated, so the temperature will rise inside that bin. The last bin is a closed bin in which the compost from the second bin is put in and stays there till it is finished. The entire process of composting takes usually 6 to 9 months (Vlaco, 2019).

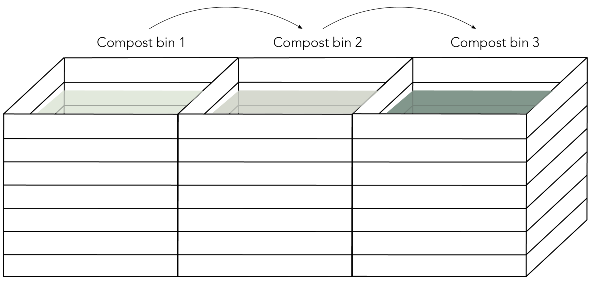

Figure 8: Compost bins

Vermiculture

Vermiculture is a form of composting, it uses worms to process the biomass in a place that allows for enough oxygen (Bos, Groenestijn, Harmsen, 2019). Just as in composting, vermiculture can be used to process residual plant biomass, agricultural residues and biogenic (domestic or food) waste.

A few factors need to be taken into regard concerning vermiculture. First of all, it is important to mention that there are essentially three types of worms. The Anecic, which means 'out of the earth' in Greek, worms that come up at night and drag food deep down to their burrows within the mineral layer of the soil (Munroe, 2007). The second type is the Endogeic, which means 'within the earth' in Greek, worm that has more shallow burrows, but rarely ever gets out of its burrow and feeds from the organic matter inside the soil (Munroe, 2007). The type used for vermiculture is the Epigeic, which means 'upon the earth' in Greek, worm that lives on the surface and feeds on decaying organic matter (Munroe, 2007).

The bedding is adapted to the favourable living conditions for these worms. The bedding needs to have a few characteristics.

First, it needs to be moist, worms breathe through their skin and if it is too dry the worms will dry out and die (Munroe, 2007). Therefore, the moisture levels inside the vermiculture needs to be 70-90% (Munroe, 2007).

Secondly, the bedding needs to be breathable, worms also require oxygen to survive and if the bedding is too dense, they can't take in the oxygen. Since they move the material themselves, they improve the aerating properties (Munroe, 2007). This also means that the material does not need to be turned, the worms will do that.

Last of all, the bedding should have a low protein and nitrogen level, if these levels are too high the degradation speed will increase, and the temperature will rise than as well (Munroe, 2007). If it is too warm inside the bedding, the worms can die as well.

It is important to note that worms eat organic matter, from plant or animal origin (Munroe, 2007). It is also important to not feed them too much at the same time, so this is not a method where all organic waste can just be put in whenever there is organic waste.

There are different types of systems that use vermiculture to process biomass. It can be done on a large scale in composting techniques such as windrow composting. Only extra requirement in that case is increasing the moisture levels inside the windrows. Most common is the flow-through system that can be used on a large and small scale. In this system, which looks a bit like a regular compost bin, there is a top lid from which one can add biomass to the bedding of the worms and from the bottom the vermicompost can be retrieved and used for fertilising (The Daily Gardener, 2020). This technique has been implemented in many ways, but essentially, they all work according to the same principle, see figure 9.

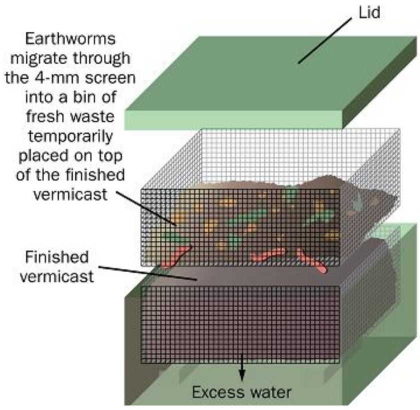

Figure 9: Worm hotel (Chaoui, 2019)

3.2.2 Thermochemical conversion techniques

Combustion

During combustion, biomass reacts with a surplus of oxygen, resulting in the production of CO_2, water, ash, and heat (Bos et al., 2019). This produced heat can be used for multiple purposes, to produce electricity, steam, hot water or just heat.

Biomass that is best suitable for combustion contains barely any water or minerals (Bos et al., 2019). Therefore, especially (dried) woody biomass is perfectly suitable for this type of processing.

There are different ways to combust biomass. On a small, household scale, one could think about a fireplace, a stove, or a furnace. Especially a furnace is quite efficient and can even be combined with a boiler to create a consistent hot water supply.

On a larger scale, there are combustion systems. Most common are the downdraft combustion, the updraft combustion, and the fluidised bed (Sadaka & Johnson, 2010). During the downdraft combustion the flow of gases is downwards, therefore combustion occurs inside the reactor. While during upward combustion the flow of gases is upwards, and the combustion usually takes place above the reactor. Fluidised bed combustion consists of a bed of a non-combustible material such as sand, creating a fluid from it by pumping air from below (Breeze, 2018). The biomass is added to the fluidised bed through a feed system and if needed an additional fuel can be added to aid the combustion of the biomass (Breeze, 2018). In the part about Pyrolysis, the working mechanism of a fluidised bed reactor is explained further.

Incineration

Next to combustion, there is also incineration, which is quite literally burning biomass to produce energy. Organic domestic waste, chicken manure and residue domestic waste (after removing metals, glass, and paper) are incinerated in the Netherlands (Bos et al., 2019). This happens in so-called Waste Incineration Plants (WIP). The main product of incineration is heat, which is converted to electricity. There is also a production of ash, especially ash from incinerated chicken manure is incredibly rich in nutrients and can be reused as a soil enricher. The gasses produced during incineration can be quite toxic, depending on the biomass that was incinerated. Therefore, it is important to have a flue gas cleaning system to ensure that those gasses are not released into the outside air (Bos et al., 2019).

Gasification

Gasification is not a new method of processing biomass. Already in the 19th century, the gasification of wood was used for street lighting (Bos et al., 2019). During the process of gasification, biomass is converted into heat or a synthesis gas under high temperatures (above 600 °C) (Bos et al., 2019). This synthesis gas mainly contains hydrogen, CO_2, and methane, mixed with pollutants depending on the biomass used for gasification (Bos et al. 2019). For gasification it is important that the biomass is extremely dry. Therefore (dried) woody biomass seems to be the most logical option.

During the gasification process either gas for heating can be produced or Syngas. Before they can be used, they do however need to go through a few other conversion processes (Bos et al., 2019). Heating gas can be used for gas engines or turbines to create either electricity or heat. Syngas (hydrogen and CO) is often used to synthesise chemicals, most common is methanisation (Bos et al., 2019). Methanisation is the process of converting hydrogen en CO into a gas with a high methane percentage, this gas is called Synthetic Natural Gas (SNG) (Bos et al., 2019). After purification it can be used in a natural gas grid. The leftover material that is not converted is called biochar, which has the properties of activated carbon and therefore can be used as a soil enricher or as fuel (Bos et al., 2019).

Pyrolysis

Pyrolysis means that biomass is disintegrated under high temperatures in an anaerobic environment (Bos et al., 2019). These temperatures often differ from 400 °C to even 900 °C. The main products created during pyrolysis are bio-oil, biochar and pyrolytic gas.

There are two types of pyrolysis: slow and fast pyrolysis. The slow and fast refer to the heating rate at which the biomass is converted. During slow pyrolysis the heating rate is about 10 °C per minute, therefore the temperature gradually rises, and this process is quite long (Hu & Gholizadeh, 2019). In this process the main focus lies on the creation of biochar. Fast pyrolysis happens at a heating rate of 10 to 200 °C per second, therefore this process is a lot faster (Hu & Gholizadeh, 2019). This type of pyrolysis has the highest yield of bio-oil. There could be a third type recognised, flash pyrolysis, which quite literally only takes half of a second to finish. However, it can be argued that flash pyrolysis is just a form of fast pyrolysis.

As already mentioned, there are three main products from the pyrolysis process. Bio-oil is considered to be the most important product. It is a dark brown liquid that is mainly composed of oxygenated compounds, and therefore can have a high thermal instability (Hu & Gholizadeh, 2019). Due to this and its low heating value, it needs further treatment to be comparable to regular petroleum-based fuels. However, in pure form it is also compatible as a source for bio-chemicals and other renewable compounds (Biogreen, 2021).

The biochar is the solid product of the pyrolysis process. It has a high carbon content, that can range from 53% of the total weight to 96% of the total weight, depending on the biomass composition and the conditions during the pyrolysis process (Hu & Gholizadeh, 2019). Even though biochar has similarities with charcoal, the application is usually very different. Where charcoal is mainly used as a fuel, biochar's main application is as a soil enricher. This is mainly due to its capability to capture carbon in the soil and therefore ensuring that the CO_2 that was captured by the plants and trees is not released back into the atmosphere. During pyrolysis the organic matter is turned into a different type of carbon that is harder to break down and therefore the carbon can be captured inside the soil for a much longer time (Wageningen Universiteit & Research, n.d.). This is a very effective method of storing carbon and keeping the earth's atmosphere cleaner, therefore improving the chances of slowing down climate change.

Next to a liquid and a solid, pyrolysis also produces a gas. This gas is often referred to as pyrolytic gas and can have different compositions, depending on various factors such as temperature, particle size and biomass composition (Hu & Gholizadeh, 2019). Pyrolytic gas can be used as a fuel and is often reused as a fuel to start a new pyrolysis process. During pyrolysis there are different types of reactions happening, these are categorised as primary, secondary and other reactions depending on the process. During the primary reactions the biomass is broken down and that results in the creation of the primary products char, volatiles and gasses. These primary products can still be quite unstable and therefore secondary reactions happen to create more stable outputs. The char produced during the primary reactions can in this process serve as a catalyst (Hu & Gholizadeh, 2019). During the secondary reactions lighter products are created from the primary products due to cracking and recombination of molecules. This will result in heavier products as well as more dense char (Hu & Gholizadeh, 2019). The reactions that happen after the secondary reactions depend on the process. A low heating rate results for instance in a higher production of char, while a fast-heating rate results in more volatile compounds, such as bio-oil (Hu & Gholizadeh, 2019). Bio-oil has a maximum yield between 450 °C and 550 °C, and above 550 °C more gasses are produced. Table 3 shows the different conditions and yields of products (in percentage of the total weight).

Type	Conditions	Bio-oil	Biochar	Gas
Slow	~10 °C /min ~ 400 °C	30 wt%	35 wt%	35 wt%
Fast	10 - 200 °C /s 450 - 550 °C	75 wt%	12 wt%	13 wt%

Table 3: Distribution yields (Hu & Gholizadeh, 2019).

In order for pyrolysis to happen smoothly, it is important that the biomass is suitable for the process. Depending on the desired main product and the process to get the maximum yield of this product it can be important to pretreat the biomass. For instance, a smaller particle size enhances the yield of bio-oil and gasses, while a larger particle size is more favourable for a higher yield of biochar (Hu & Gholizadeh, 2019).

Pyrolysis can be performed in different setups and types of reactors. A few common techniques will be explained below.

A fixed bed reactor is a simple and reliable pyrolysis reactor that has a fixed bed of feedstock in which the biomass is pyrolysed per batch (Guda et al., 2015). Due to the batch process, meaning that it works only in small portions and not ongoing, it is not considered the most economically beneficial reactor type.

In a bubbling fluidised bed reactor the biomass feedstock is placed on a fluidised bed at the bottom of a reactor. The biomass particles travel through heated inorganic particles by using pressurised gas that is pumped into the reactor from the bottom and ensures that the particles become a liquid, the bio-oil (Guda et al., 2015). The name of this type of reactor is mainly due to the bubbling effect of the pressurised gas that is added in the reactor. In order to separate all the products, cyclones are used to separate the char particles from the liquid.

Circulating fluidised bed (CFB) reactors have essentially the same type of operating as bubbling fluidised bed reactors. The main difference is that the CFB is more complex, since it has two fluidised bed reactors working together. In the first fluidised bed the pyrolysis reaction takes place, the produced char in the first bed is then combusted in the second fluidised bed (Guda et al., 2015). The combustion of char is used to heat up the inorganic carrier that is used in the first fluidised bed for the pyrolysis and therefore resulting in a circulating process.

A rotating cone reactor is based on the principle that a heat carrier mixed with biomass particles is injected into the bottom of a rotating cone. The rotation of the cone creates a centrifugal effect and therefore gets the biomass and heat carrier mixture in close contact with the heated surface of the cone, resulting in the pyrolysis reaction (Guda et al., 2015). The centrifugal effect also ensures that the mixture automatically moves to the top of the cone, and there the solids and vaporous parts are separated. The solids, the char and heat carrier, are then combusted in a fluidised bed to heat up the heat carrier after which it can be reused in the process (Guda et al., 2015). The vaporous parts of the pyrolysis are moved to a condenser where the gas and bio-oil are separated.

An ablative pyrolysis reactor works quite different from other techniques. Instead of depending on high heat-transfer rates, it depends on the heat transfer from the hot wall of the reactor to melt the woody biomass particles under pressure (Guda et al., 2015). The pyrolysis happens when the biomass touches the hot wall of the reactor and therefore particle size has no influence on this type of pyrolysis.

An auger reactor consists of a heated tube through with the biomass is fed and pyrolysed while it moves through the tube (Guda et al., 2015). Usually an inert gas is added to the biomass feedstock, to ensure that no oxygen can enter the reactor tube (Guda et al., 2015). At the end of the tube the char is collected on the bottom and there is a vent where the vapours are collected and put through a condenser to separate the gasses from the bio-oil.

Inside an entrained flow reactor the biomass particles are entrained in a carrier gas that helps to separate them so that they can be pyrolysed individually (Guda et al., 2015). The particles are down-fed into a reactor tube that is heated from the outside and contact with the reactor wall and the conductivity of the heat inside the carrier gas introduce the pyrolysis of the particle as they flow down the reactor (Guda et al., 2015). The char can be collected at the bottom due to the miracle works of gravity and the produced vapours are condensed, which separates the gasses from the bio-oil.

Torrefaction

Torrefaction is a slow form of pyrolysis, in which biomass is disintegrated at a temperature between 200-400 °C (Bos et al., 2019). During this process the biomass is dried and turned into solid substances and gasses. The gasses are, again, re-used as an energy supply.

Many different types of biomass are suitable for torrefaction, however using woody biomass is most common. The main product of the torrefaction of woody biomass is biocoal, a coal-like material that can be used for gasification or as a fuel (Bos et al., 2019). Due to the lower temperatures in the reactor, the biomass is not turned into biochar.

Chemical conversion

Chemical conversion is converting biomass into other substances, by letting them react with each other or using a reactant or catalyst to start the conversion (Bos et al., 2019).

Biodiesel is a product that can be created by chemical conversion. Waste oils and fats contain free fatty acids that can be used in combination with methanol to create biodiesel (Biodiesel Amsterdam, n.d.). This process consists of several chemical steps, that eventually lead to the production of biodiesel, bio glycerine (can be used for instance to create soap), bio-heating oil and bio-fertiliser.

Pulping is another form of chemical conversion. The kraft process of pulping is done without the help of mechanical energy. In this process, woody and other biomass with cellulose, are pulped together with chemicals (a solution of sodium hydroxide and sodium sulphide) that dissolve everything but the cellulose parts of the material. This is the main ingredient for creating strong fibre paper and cardboard (Appita, 2015).

There are many more ways of chemical conversion, however this type of conversion is not relevant for the research necessary for the design and therefore not further explored. The examples above give a small indication of what chemical conversion is and what it can create.

3.3 Conversion of wastewater

As mentioned before, biomass can also exist in liquid form: wastewater. There are two categories of wastewater, grey- and blackwater. Greywater is all wastewater produced by sinks, showers, washing machines and other appliances that produce wastewater that has not been in contact with faeces (Lamb, 2020). Rainwater is not necessarily always clean water and can be categorised as grey water due to the similar extent of contamination. Blackwater usually refers to toilet water, wastewater highly contaminated with biogenic matter such faeces and other contaminants. Because blackwater has been contaminated by human solid waste, the risk of it containing harmful bacteria or other matter that can transfer disease is much higher (Lamb, 2020). Therefore, the process of cleaning blackwater is much more extensive than the process of cleaning greywater.

A common technique for cleaning wastewater is using plants that have purifying and cleaning properties. An example of such plants are helophytes that have their roots in wet soil and are often standing partly submerged and partly above the water surface (Coops & Geilen, 1996). The helophyte plants filter the wastewater by absorbing nutrients and degrading toxic compounds (Shahid et al., 2018). Another example is the hydrophyte plant species (hydrophytes are plants that either grow submerged or float on the water surface (Coops & Geilen, 1996) which are used as purifying plants, however these are less effective than the helophytes.

There are different techniques that involve helophytes to clean wastewater. Greywater can often be inserted into the system directly (depending on the level of contamination and type of cleaning technique), while blackwater on the other hand needs pre-treatment as a first step.

3.3.1 Pre-treatment of wastewater

There are multiple ways to pre-treat wastewater, and these often rely on the principle of sedimentation. Sedimentation is the process of solid material in a liquid falling to the bottom and forming a layer (Cambridge Dictionary, 2021a). There are several systems that rely on the principle of sedimentation, two examples of this are a septic tank and an anaerobic filter. A septic tank is a watertight tank made of concrete, fibreglass, plastic or PVC that usually consists of at least two chambers as can be seen in figure 10 (Tilley et al., 2014). As the wastewater flows into the tank it is gradually filtered, the heavy and solid particles will sink to the bottom and the oily and greasy particles will float on the surface. In the second chamber there is an effluent outlet. The separation between the two chambers is designed in such a way that as little as possible sludge (the solid particles) and scum (greasy and oily particles) escape through the effluent outlet (Tilley et al., 2014). A septic tank is an effective pre-treatment of the wastewater, but as a standalone treatment the system is not thorough enough.

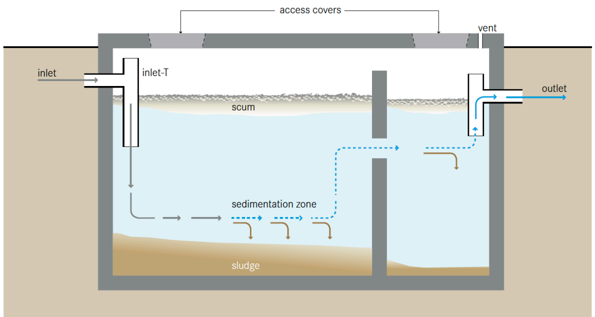

Figure 10: Septic tank (Tilley et al., 2014)

An anaerobic filter looks and works quite similar to a septic tank. This system also has at least two chambers, and the first chamber has the same sedimentation process. Main difference is the second (or more) chamber which is a filtration chamber. A filtration chamber consists of a filter created by gravel, crushed rock, cinder, pumice, or artificially designed pieces with wide enough pores to prevent clogging (Tilley et al., 2014). The connection between the two chambers is also different, in figure 11 one can see that a large pipe serves as the separation between chambers, which lets the wastewater in at the top and lets it out on the bottom of the next chamber. An anaerobic filter is more effective in treating wastewater than a septic tank, however it is still not good enough as a standalone treatment technique because it does not filter out enough small pathogens, such as nitrogen (Tilley et al., 2014).

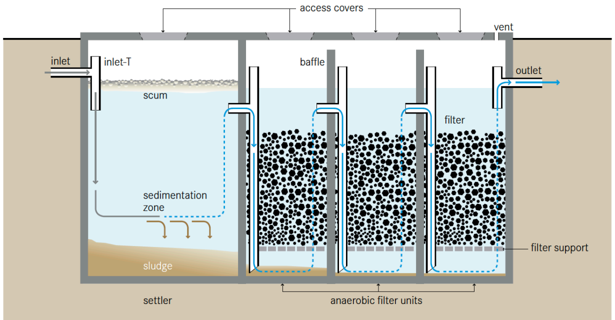

Figure 11: Anaerobic filter (Tilley et al., 2014)

3.3.2 Wastewater treatment techniques

There are several techniques that can be explored. First, there are three natural techniques, the swamp buffer strips, sewage farms, and floating treatment wetlands, which can be quite effective. Additionally, there are more extensive techniques such as the sub-surface flow constructed wetlands and surface flow constructed wetlands.

Swamp buffer strips

Swamp buffer strips were introduced in the 1990s to prevent pesticide residues from farming to leak to the adjacent surface water (STOWA, 2010). The buffer strips consist of plants that filter certain elements of the pesticide residues out of the water. It is most common around farmlands. Although this filter has been proven to be less effective than others, it does improve biodiversity and therefore is still a common used technique.

Sewage farm

A sewage farm is a very simple form of a constructed wetland. It was introduced to filter and clean sewage water, hence the name sewage farm. Essentially, it is an artificial system which consists of shallow ponds or canals in which helophytes are planted (Spoelstra & Truijen, 2010). After the water is subsequently cleaned, the water could be safely disposed back into the groundwater or surrounding surface water.

Floating treatment wetland

In floating treatment wetlands wastewater is collected in a large body of water in which plants float on small artificial islands that purify the wastewater. The helophyte plants float on so-called buoyant mats, which have a structure of low-weight materials, such as polyester sheet, PVC pipes or bamboo (Shahid et al., 2018). The buoyant mats keep the crowns of the plants above the water level, ensuring that the plants can establish roots in deeper zones of the water body (Shahid et al., 2018). This type of treatment can be applied on several types of water bodies, and due to this versatility, it is an interesting solution for purifying wastewater. It should be noted that this method will work best for greywater or pre-treated blackwater, since the wastewater is added to the water body and can get smelly when polluted with highly contaminated water.

Sub-surface flow constructed wetland

A sub-surface flow constructed wetland consists of a sealed basin, which includes a combination of rock, gravel, and soil (Choudhary et al., 2011). The water level remains below the surface, at least 5 – 15 cm (Tilley et al., 2014). This makes it suitable for more contaminated wastewater since the smells will be contained. In a landscape, a sub-surface flow constructed wetland looks like a marsh or a field of reed. This system has two main different types: horizontal flow and vertical flow. The horizontal subsurface flow constructed wetland has an inlet on one side and an effluent outlet on the other side.
This can be seen in figure 12, the water is let in on one side, moves through the bedding of gravel, rock, soil, and the roots of the helophyte plants and is eventually collected on

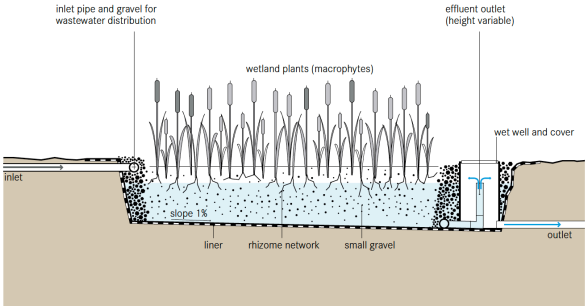

Figure 12: Horizontal sub-surface flow (Tilley et al., 2014)

the other side. The vertical version of this constructed wetland has an air pipe going through the entire system, which ensures that the drainage of the filtered water is on the bottom of the wetland. The inlet is on the top of the surface by using a mechanical dosing system and as the water moves through the filter it is collected by the drainage pipe (Tilley et al., 2014). In figure 13, a section of this type of constructed wetland can be found. In this section it is already visible that this system is more complex than the horizontal variant and next to that requires an electrical source to operate the dosing system. An upside to this method is that it needs less space than the horizontal variant (Tilley et al., 2014).

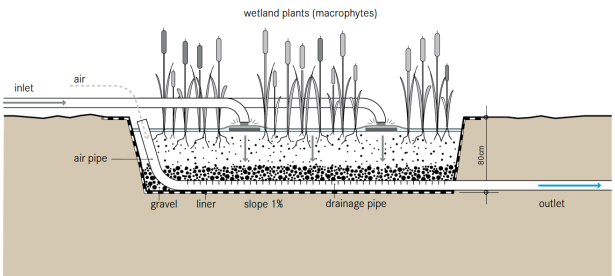

Figure 13: Vertical sub-surface flow (Tilley et al., 2014)

Surface flow constructed wetland

This type of constructed wetland tries to mimic the natural processes happening in natural wetlands, marshes, and swamps (Tilley et al., 2014). The water moves slowly through a shallow basin of less than a meter deep with a layer of soil on the bottom in which the helophyte plants are placed (Choudhary et al., 2011). See figure 14, for a section of a typical surface flow constructed wetland system. While the water moves through the wetland the particles sink to the bottom, the pathogens are removed, and the nutrients are taken up by the roots of the plants. To limit exposure of foul odours, it needs an extensive pre-treatment, depending on the level of contamination of the wastewater. This is an effective technique to get cleaner water that can be used for watering plants or other applications. However, it does take up a lot of land to be effective and takes a long time to be set up and work at full capacity.

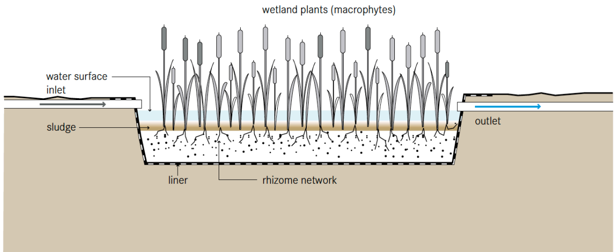

Figure 14: Surface flow CW (Tilley et al., 2014)

3.4 Greenhouse horticulture

One of the main products of this graduation project is the design of two greenhouses. In order to create a fitting and sustainable design for these greenhouses, it is important to learn more about the topic of greenhouses en food production. This section will dive into the topic and give an overview of the possibilities and requirements that need to be taken into account.

3.4.1 Food Production techniques

There are different types of food production that can take place inside a greenhouse. First of all, there is the traditional in soil food production. In greenhouse horticulture this is still a common practice. Next to that, food production according to a soilless culture system is becoming a more standard type of food production. In the traditional growing in soil method the nutrients are supplied to the plants within the soil, whereas the soilless culture uses fertilising irrigation. Food production thus takes place in a different medium, such as artificial soil, air or water.

Hydroponics

The common definition of hydroponics is: "the growing of plants in nutrient solutions with or without an inert medium (such as soil) to provide mechanical support." (Merriam-Webster dictionary, 2021). There are many different types and systems of hydroponics. Next to that there are a lot of substrates that can be used to let the plants grow. Varying from organic to inorganic and synthetic types of substrates. In table 4 below a small overview of common used substrates can be found.

Organic	Inorganic	Synthetic
Peat	Sand	Expanded Polystyrene
Coconut fibre	Pumice	
	Lapillus	Polyurethane Foam
	Vermiculite	
	Perlite	
	Expanded clay	
	Stonewool	
	Zeolites	

Table 4: Common substrates (Maucieri et al., 2019)

According to the research of the Federation and Agriculture Organization of the United Nations (2013), hydroponic systems require higher funding and more technical knowhow than traditional soiling in greenhouses. Their research has however acknowledged that hydroponics could cultivate higher yields of crops. Moreover, traditional problems of soiling, e.g. pathogens within the soil, are absent in the system of hydroponics.

Essentially there are two different systems, the open cycle system and the closed loop system. The open cycle system is quite often a more simple system through which the nutrients run and the surplus nutrients are not recycled in any way (Maucieri et al., 2019). The closed loop system, as the name already suggests, is designed in such a way that all surplus nutrients and water are recirculated through the system. It is an obvious notion that the closed loop system is the more sustainable option, however it also requires a higher investment and a supply of high quality water (Maucieri et al., 2019).

There are different techniques in hydroponics, which differ mostly on the way water and nutrients are supplied to the plants. The most common three are: Deep Flow Technique (DFT), Nutrient Film Technique (NFT) and aeroponics.

Deep Flow Technique

Deep Flow Technique (DFT) is growing plants which are floating or hanging on a support inside a basin filled with a nutrient solution (Maucieri et al., 2019). There are different forms of this type of technique, varying from really simple systems to complex systems that use for instance aeration or pumps. Figure 15 illustrates how a simple DFT system can look like.

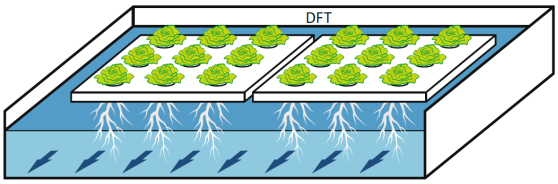

Figure 15: Deep Flow Technique (Maucieri et al., 2019)

Nutrient Film Technique

Nutrient Film Technique (NFT) is the type of hydroponics that people usually envision when picturing a hydroponic system. In this system the nutrients flow inside a small layer of water (1-2 cm) that circulate from plant to plant (Maucieri et al., 2019). There is no substrate used in this system and the main advantage of this system is that it can be fully automated. However, it is also a vulnerable system. It is especially vulnerable to clogging, due to the low water level and the lack of substrate (Maucieri et al., 2019). Therefore new systems that for instance stack the water layers, as can be seen on the illustration on the left in figure 16, can be a solution to this clogging problem.

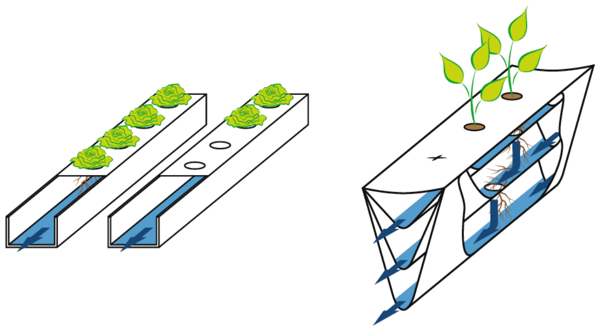

Figure 16: Nutrient Film Technique (Maucieri et al., 2019)

Aeroponics
Aeroponics is a system in which the roots of the plants are suspended in a volume of air that is continuously sprayed with a nutrient solution (Van Os et al., 2019). The plants are hence fed by evaporation of water and nutrients, and the roots of the plant are not placed in any medium other than air. Figure 17 shows an illustration that shows the principle of aeroponics. Aeroponics is usually only used for smaller horticultural species, and is still quite rare due to the high costs of the system (Maucieri et al., 2019).

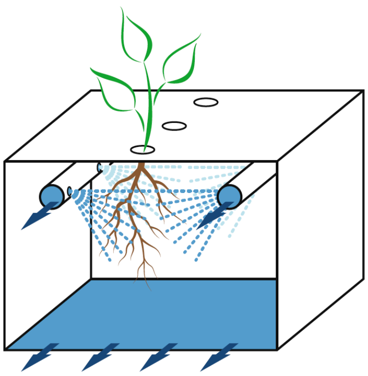

Figure 17: Aeroponics (Maucieri et al., 2019)

Aquaponics
Essentially, an aquaponics system is the combination of hydroponics and aquaculture (Goddek et al., 2019). It combines the production of crops and fish at the same time. The plants are supplied with nutrients that derive from the waste that the fish produce and excrete in the water. Aquaponics has evolved from the ancient old practices in South East Asia that would integrate fish culture with the production of rice, however this was rarely actually put to practice (Lennard & Goddek, 2019). Both technologies of hydroponics and aquaculture have been proven to be very effective, however, in order for aquaponics to be viable it should be able to compete with the two separate technologies. Otherwise the disadvantages and high costs will outweigh the advantages of aquaponics.

One of the main advantages of aquaponics is the possibility to produce both fish and crops on a relatively small area. It therefore also reduces the amount of kilometres that the food needs to travel to the consumer (Hakkesteegt, 2017). The main disadvantage of the system is mainly due to fish. The fish produced in aquaponics are often really expensive and therefore cannot compete with normal fish production farms. Therefore it is important to realise that aquaponics in its current form is only viable on a small scale.

3.4.2 Requirements of a greenhouse
In a nutshell, a greenhouse is a structure with a translucent cladding that shelters and fosters the growth of crops. Next to that, the orientation and shape of the greenhouse are also factors that need to be considered when designing a greenhouse.

The orientation of a greenhouse is mainly important in relation to light. The amount of light that the crops receive should be uniform and adequate (Ponce et al., 2014). It is therefore important that there are not too many high structures or vegetation around the greenhouse from especially the sides from which the sun can shine on the facade. There are areas in which it is also important to look at the prevailing wind, since this can have influence on the structure and shape of the building.

It is imperative that there is enough space inside the greenhouse. The shape of the building, however, can vary, depending on the location, orientation, type of food production and other factors. There are, however, some basic designs that are often implemented. In figure 18, an overview of the different types can be found. When it comes to free-standing greenhouses, the arch shape and standard peak are the most common (Ponce et al., 2014). For larger structures, for instance large-scale crop production, the basic shapes can be combined as a multi span.

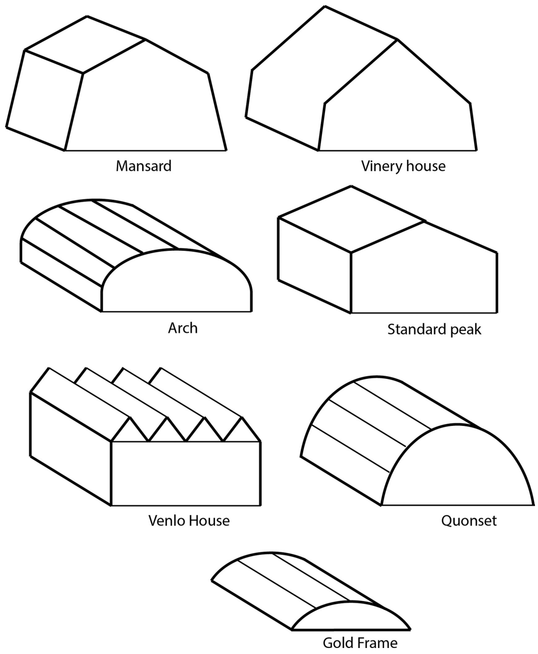

Figure 18: Basic shapes greenhouses (Ponce et al., 2014)

Translucency is often a requirement for a greenhouse. It allows the plants to use natural daylight as a source and limits the energy use necessary for artificial lighting. There are different types of materials that can be used that have this translucent property. Most common are cladding made from glass, polyethylene, PVC, vinyl sheet, FRP or acrylic sheet. Glass is the most traditional type, it is attractive, transparent, but also relatively expensive compared to the other types.

To make sure that the crops can flourish, the environment inside the greenhouse needs to be controlled on the temperature, the amount of ventilation, the amount of moisture, the amount of natural or artificial lighting and irrigation. Even though there is a lot of knowledge on the regulation of a greenhouses environment, there is a lack of knowledge on the optimum climate conditions for crops to grow (Kubota, 2019). Especially on the level of the combination of all different factors involved in the greenhouse climate there is a missing gap.

There are a few things certain. For the growth of crops it is vital that there are not too many fluctuations in temperature. Therefore temperature needs to be regulated inside the greenhouse. This can be done passively by for instance using the advantage of the sunlight heating up the facade or ventilating more to cool the space down. Practically it usually comes down to the installation of a heating unit and often also a cooling unit. There are different ways to heat or cool a greenhouse.

Another vital factor for the growth of plants is light intensity. Especially the PAR, Photosynthetically Active Radiation, factor affects the rate at which a plant grows and develops (Kubota, 2019). The PAR has a wavelength of 400 to 700 nm (Fondriest Staff, 2014). It is a parameter that shows whether there is enough light intensity for the plants to perform photosynthesis. There are days that the daylight contains enough PAR, however there are especially in the Netherlands also many days that this level is too low.

Irrigation is also an important factor that needs to be taken into account when designing a greenhouse. Water is of vital importance for the crops. Water ensures that the crops can take up the nutrients, it ensures the turgor of the plant (meaning that there is pressure on the cell membranes and therefore ensuring the rigidity of the plant tissue) and the transpiration of the plant through the leaves can cool down the plant (Ponce et al., 2014).

3.5 Agroforestry

When looking into forest biomass, the topic of agroforestry came to light as well. Agroforestry can be defined as a type of agriculture that combines forest grounds with the management of agricultural crops and/or animals (FAO, 2015). Another condition is that there should be sufficient interaction between the woody and non-woody components (Dagar & Tewari, 2017). The relationship should be beneficial to both sides and not hold back one or the other. There are three different types of agroforestry systems:

1. Agrisilvicultural: a system that combines trees and crops (FAO, 2015).
2. Silvopastoral: a system that combines forestry with graze areas for domesticated animals (e.g. cows, sheep, pigs) (FAO, 2015).
3. Agrosylvopastoral: a system that combines all three elements of trees, crops and grazing animals (FAO, 2015).

There are different ways to achieve the practices explained in the different agroforestry systems. Dagar and Tewari (2017) published a book on agroforestry, and in one of the chapters there is a large overview of all the different practices explained and categorised. In table 5 a summary of this overview can be found.

System	Practices	Explanation
Agrisilvicultural	Improved fallows	During this process shrubs and crops are planted together to improve soil fertility (in time of soil replenishment)
	Relay intercropping	Shrubs and crops are planted together every year
	Trees on crop land	Scattered trees on agricultural land
	Plantation crops combination	Shade trees are combines with crops that are shade-tolerant
	Homegardens	Layering of trees, food producing shrubs and crops on the soil level
	Alley cropping	Hedgerow intercropping with woody species
	Boundary planting	Trees on the boundaries of agricultural fields
	Strip planting	Plantations with corridor farming to control the rise in water
	Shelterbelt	Plantations to shelter crops from wind
	Farming in forests	Cultivation of crops in natural forests
Silvopastoral	Trees on rangeland	Scattered trees on grazing land
	Perennial crops with pasture	Plantations of e.g. fruit trees on pasture land
	Boundary plantation	Trees on the boundaries of pasture lands
	Shelterbelts	Trees to shelter pastures and animals from wind
Agrosilvopastoral	Homegardens with animals	Layering of trees, food producing shrubs and crops on the soil level, combined with animals grazing on the land
	Compound farms	Food crops are grown with food trees, and animals
	Parkland system	Trees are cultivated along with staple cereals and free roaming animals

Table 5: Agroforestry typologies (Dagar & Tewari, 2017)

4 Paleis Soestdijk

4.1 Historic Background

4.1.1 Historic timeline

In order to give an overview of the rich history that the estate of Paleis Soestdijk has, a timeline has been constructed. The most important dates and happenings on the estate are stated below.

1638 Cornelis de Graeff (mayor of Amsterdam) buys the grounds on which later the estate of Soestdijk will be situated
1674 The estate of Soestdijk is sold to stadholder Willem III
1795 The Netherland is invaded by the French and Louis Napoleon becomes the owner of Soestdijk
1815 Soestdijk gets Dutch owners again and is gifted to then crown prince Willem II and his wife Anna Paulowna
1820 Placement of the remembrance needle for the Prince of Orange (Willem II)
1893 Start of modernisation of the palace by queen Emma
1937 The palace is renovated to become the residential home for then crown princess Juliana and her husband Bernhard.
2004 Both Juliana and Bernhard pass away
2006 The palace and part of the estate become open for the public
2017 The estate is bought by MeyerBergman Erfgoed

4.1.2 Development of the estate

Essentially the development of the estate of Paleis Soestdijk can be divided into different periods. The most significant periods that had the most influence on the development of the estate will be illustrated and explained in this chapter.

Development before 1638

In figure 19, a reconstruction map of the developments before 1638 can be found. Around 1565 the paamgracht was dug out in order to reclaim the peatland (indicated by the light blue on the map) (Stichting in Arcadie, 2019). The large black arrow is the former Soester dijk, which is now the Amsterdamsestraatweg.

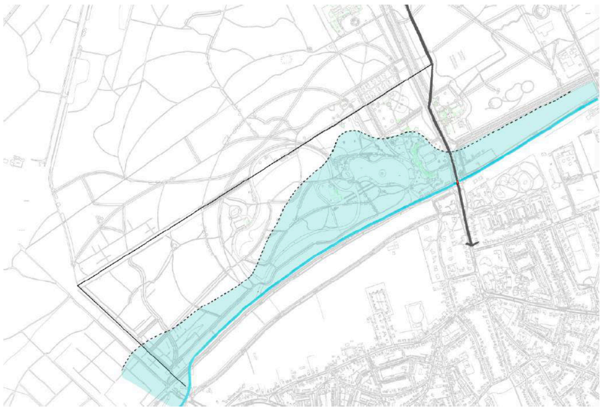

Figure 19: Reconstruction of landscape before 1638 (Stichting in Arcadie, 2019)

The beginning of Soestdijk

The first player on the estate of Paleis Soestdijk is Cornelis de Graeff. He becomes owner of the grounds that later become the estate of Soestdijk in 1638. Around 1650 the first building is built on top of these grounds by the Graeff,.named 'den Soestdijck' (Stichting in Arcadie, 2019). There is a painting by Jacob van Ruisdael that reportedly shows de Graeff in front of the house that he built on the estate, see figure 20.

Figure 20: Aankomst op Soestdijk van Cornelis de Graeff met zijn echtgenote en zonen (Van Ruisdael, 1660)

Willem III's hunting lodge

In 1674 the heirs of Cornelis de Graeff sold the estate to stadholder Willem III. During that year the estate is also expanded, when the estate of Eyckendael is bought as well (Stichting in Arcadie, 2019). The architect, Maurits Post is hired to create plans for a more modern and luxurious hunting estate. Artist Gerard Valck has perpetuated the views of the estate during the late 17th century in a series of engravings. Figure 21 shows the front view of the house and figure 22 shows the water tower that is nowadays still present at the estate grounds.

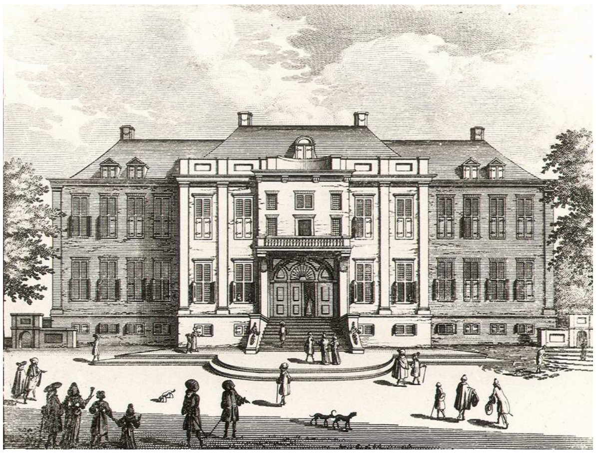

Figure 21: Front view of House (Valck, 1695)

Figure 22: Water tower (Valck, 1695)

The design of the gardens can be labeled as a formal garden, which was at that time considered ‘fashionable’. The design contained a lot of symmetry, squared geometric borders and the introduction of avenues throughout the entire layout of the estate. Some of these avenues are still visible in the currently existing landscape of the estate.

Palace for crown prince Willem II

After the recapture of the Netherlands from the French, the estate of Soestdijk was in bad shape. In 1815, Soestdijk is gifted to the then crown-prince Willem II and his wife Anna Paulowna and from that year onwards the house is transformed into a palace led by architect Jan van Cleef (Stichting in Arcadie, 2019). An impression of the new palace can be seen in figure 23. Here the Russian influences of Anna Paulowna can be seen in the arched wings and the symmetry of the building.

Figure 23: Design Paleis Soestdijk (Goetghebuer, 1820)

At the same time, a plan to transform the estate grounds into a landscape style garden were created by J.D. Zocher (Stichting in Arcadie, 2019). His son will later on execute the plans due to the passing of Zocher.

On the estate nowadays the signature features of a Zocher garden are still recognisable. The large pond, the park-like structure of paths that form a route along the estate grounds that open and close, hence creating unique views throughout the walk. This so-called ‘hide and reveal’ principle is especially a signature feature of gardens designed by Zocher jr., where the main eyecatcher is always the house (in this case the palace) (Stichting in Arcadie, 2019). One of those viewpoints was perpetuated by Bierweiler in around 1830 (see figure 24).

Figure 24: View of Soestdijk (Bierweiler, 1830)

Juliana and Bernhard
Until 1937 there had never been a permanent inhabitant of Paleis Soestdijk. This changed when crown-princess Juliana and her husband Bernhard decided to move permanently to Soestdijk after their marriage in 1937 (Jansen et al., 2011). The transformation and furnishing of the new home for the young and growing family was gifted as a wedding present to the royal couple by the Dutch population. Juliana and Bernhard lived in a truly 'Dutch home', donated by the Dutch subjects (Jansen et al., 2011). During WWII, the family resided overseas, and when they returned the palace was almost completely still intact. When Juliana became queen, Paleis Soestdijk was established as the official royal residency, therefore it was not just the home of the family but also the place of work for Juliana and Bernhard. Many famous and important people have visited the palace over the years that Juliana was queen. From 1949, Juliana would celebrate her birthday (Koninginnedag) with a large parade and the opportunity for the Dutch people to personally congratulate her. It was always a huge happening, as can be seen in figure 25.

Figure 25:'Koninginnedag' 1949 (RTL Nieuws, n.d.)

As mentioned, the palace and the estate were transformed into a permanent residency. For the palace itself this meant e.g. the addition of a cinema, indoor swimming pool, extra terraces and offices for Juliana and Bernhard (see figure 26). On the estate itself extra functions were added, such as the sport facility and the housing of the Military police.

Figure 25: Juliana in her office (Paleis Soestdijk, n.d.)

Paleis Soestdijk as a public domain
After the deaths of Juliana and Bernhard in 2004, the estate became empty and without function. The idea arises to open the palace and the palace grounds for the public, and in 2006 the first visitors are welcomed on the estate (ANP, 2006). At first it was meant to only open for 3 years, but due to the success it was extended. The palace was at that time in ownership of the government of the Netherlands and was quite expensive to maintain. Therefore it was decided to sell the estate of Paleis Soestdijk. Potential buyers were allowed to send in their plans for the estate and the government would choose which one was allowed to buy the estate and realise their plans. Eventually, in 2017, the news broke that MeyerBergman Erfgoed group had bought the estate with their plan called ' Made by Holland' (Weesies, 2017).

4.2 Analysis of the Estate
Analysis material that requires the reading of large maps and figures can be found in the A3 booklet.

4.2.1 Context
Paleis Soestdijk is situated in the centre of the Netherlands, in the province of Utrecht. The estate of Soestdijk is part of the twenty estates that are situated on the East side of the Utrechtse Heuvelrug. It is situated

between the higher grounds of the Heuvelrug and the valley grounds of the Eemvallei. It is therefore indirectly connected with two large green structures and has in typology a mixture of the hilly nature of the Heuvelrug and the valley properties of the Eemvallei. The name Soestdijk derives from the situation of the estate next to a former dike, called 'Soestdijk', which is the foundation for the nowadays Amsterdamsestraatweg (Paleis Soestdijk, 2019).

In the past, the estate of Paleis Soestdijk was a lot larger than it is today. Currently the estate spans over an impressive 165 hectares, on the map in appendix B one can see that the estate used to be twice as big.

4.2.2 Soil

Archeologically speaking, the estate of Paleis Soestdijk does not have a significant history. There is only one small part on the North-West side of the estate that is built on so-called drifting dunes ('stuifduinen' in Dutch) which is part of the primordial landscape (Paleis Soestdijk, 2019). The rest of the estate is completely man-made.

The soil on the estate of Soestdijk can mostly be identified as field podzols with fine sand that contains little to no loam (van den Bijtel, 2014). The other two type of soil existent on the estate are holtpodzols with coarse sand and dune soils with coarse sand (van den Bijtel, 2014).

In 2014 research into the quality of the soil was implemented, and the results were quite positive. It concluded that there is a small amount of mercury, zinc and PCB contamination sporadically around the terrain (Paleis Soestdijk, 2019). In 2015, further research established that on the places where there are small contaminations, it should be taken into account when re-developing or any excavation work.

4.2.3 Elevation

For this analysis, the database of AHN (Actueel Hoogtebestand Nederland) has been consulted to determine the height differences on the estate. Appendix C shows the data from the AHN website. In essence, one can see that the North part, especially the part near the old Marechaussee grounds, is the highest (roughly 8 meters). While the South side of the estate is the lowest (roughly 2,5 meters), especially

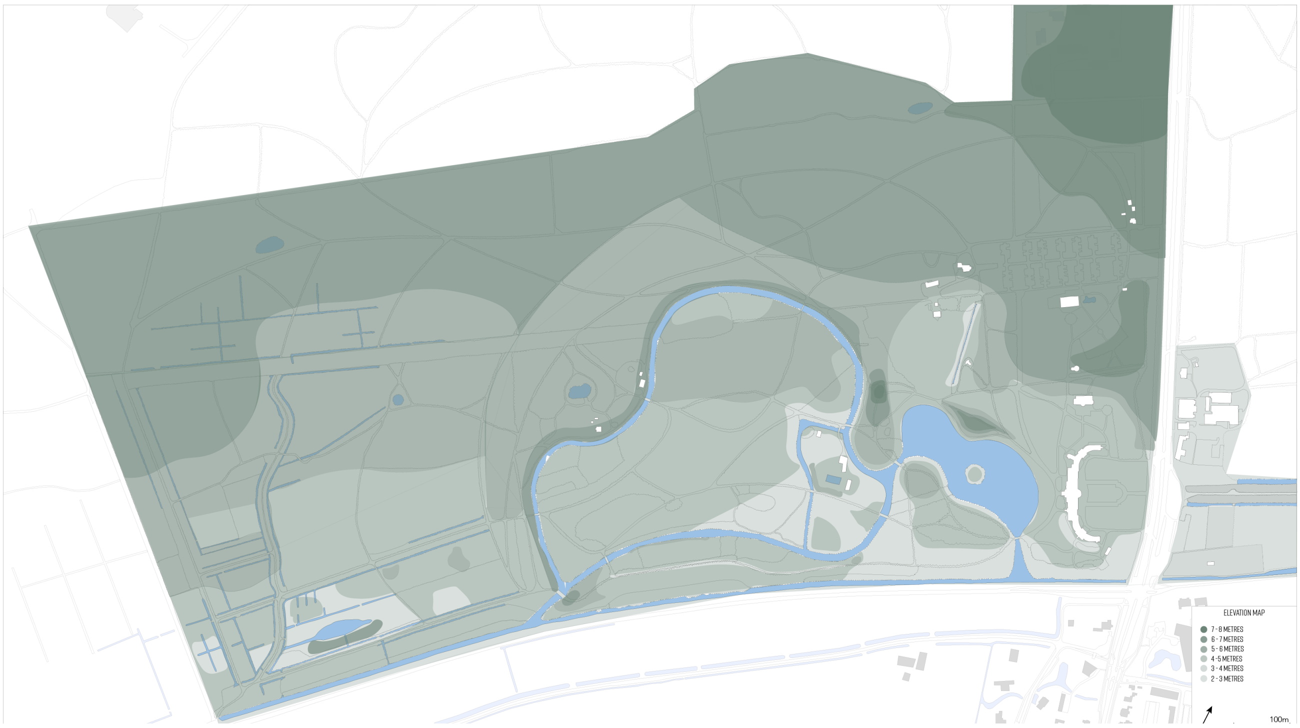

Figure 27: Elevation map of the Estate

around the pond and the praamgracht. In figure 27, a map of the estate with the elevation levels can be found. The darker the colour green is, the higher the elevation.

4.2.4 Water

As showed in the map in figure 27, due to the elevation, the water naturally flows to the paamgracht and the South side of the pond. Currently there are some problems with water management on the estate. In dry summers, especially the higher parts of the forest do not get enough water. There are also some problems with the pond, when there is not enough water added naturally, the pond needs to be kept up to level by pumping in water from the grid. This is done by pumping clean drinking water into the pond. This is mainly also due to the quays, which might collapse if the water level gets too low.

4.2.5 Forest

The existing landscape of the estate is distinguished by its broad diversity in species. For instance, in trees, the variety spans from deciduous trees, such as the beech, pedunculate oak, American oak and linden, to conifers, such as the pine tree, spar and larch (Paleis Soestdijk, 2019). The Northside of the estate is characterised by the conifers, while the Palace side of the estate only consists of a mixture of deciduous trees. Between these two zones, there is an intermediate zone which contains a mixture of deciduous trees and conifers.

In 2019 an extensive inventory of the forest was performed by Boomtotaalzorg, an independent consultancy firm for trees and green structures. In appendix D, a map of the health situation of the forest per forest section can be found.

In the report the consultancy firm has recognised two types of forest on the estate: 'Dry forest with production' and 'Pine, Oak and Beech forest'. The first one scores an 8, so is therefore considered as a healthy forest (Debruyne & Corbet, 2019). The 'Pine, Oak and Beech forest' is rated with a 5, and therefore scores mediocre (Debruyne & Corbet, 2019). When looking at the individual forest sections, it can be seen that there are even some sections that score incredibly low (see appendix D). The main issues in these sections are connected to the lack of layering and mix of species.

4.2.6 Protected Flora and Fauna

There are in total 366 different types of plants present on the estate grounds of Paleis Soestdijk (van den Bijtel, 2014). Van den Bijtel made an inventory of the species that are protected or vulnerable, in total there are five protected species on the estate. These are:

1. 'Akkerklokje'
2. 'Brede wespenorchis'
3. 'Kleine maagdenpalm'
4. 'Koningsvaren'
5. 'Prachtklokje'

In appendix E, a map with the location of the protected species can be found. The 'Prachtklokje' is the most endangered species, and is therefore the main priority when looking at preservation and cultivation of plants.

Next to these protected species, there are also two plant species present at the estate that are considered special. These are the 'Stomp fonteinkruid' and 'Vlottend bies' (van den Bijtel, 2014).

The estate of Soestdijk is also rich in other types of vegetation, there are 63 types of leaf moss, 11 types of liverworts, 50 types of lichen and 385 different types of mushrooms (van den Bijtel, 2014).

When looking at the fauna present at the estate, it can be stated that there are in total 23 different types of mammals present at Paleis Soestdijk. An overview of these mammals can be found in appendix E. All eight different bat species are protected under the Flora & Fauna legislation (van den Bijtel, 2014). Other protected species include squirrels, badgers.

and pine martens. It is therefore important that their living conditions are maintained or perhaps even improved on the estate.

When looking at the feathered species, there are more than 50 species present at the estate. Four of these species are protected, which are the 'Grauwe vliegenvanger' (Sooty Flycatcher), 'Groene Specht' (Green Woodpecker), 'Raaf' (Raven) and 'Wielewaal' (Oriole) (van den Bijtel, 2014). There are also three types of birds that build their nests often on the estate of Soestdijk, which are the 'Ransuil' (Long-eared owl), the 'Buizerd' (Buzzard) and the 'Havik' (Hawk). The nests of these birds are to be protected.

On the estate there are three types of reptiles: the 'ringslang' (grass snake), the 'levendbarende hagedis' (viviparous lizard) and the 'hazel worm' (slow worm) (van den Bijtel, 2014). All of these species are protected. There are also six different types of amphibians, of which the 'Heikikker' and 'Poelkikker' are protected.

There are about 20 different types of butterflies on the estate of which one, the 'Groot dikkopje' is a protected species (van den Bijtel, 2014). Next to that there are 32 different types of damselflies and dragonflies. There are also 52 different types of wild bees present at the estate (van den Bijtel, 2014).

The report concludes that the estate of Paleis Soestdijk has a significant nature value, with approximately 90 protected species (see appendix E). Therefore it is important to take these values and protected species into account when designing the new functions.

4.2.7 Landscape

The landscape of the estate is what one would call palimpsest, which means that multiple layers of (relevant) time are visible. The landscape was mainly designed during the 17th, 18th and 19th century, and many of these parts are still visible nowadays.

The garden and landscape design of Soestdijk have a 'rijksmonument' (national monument) status and are therefore highly valued and protected (Paleis Soestdijk, 2019).

The estate of Soestdijk has a formal style which combines classicist avenue structures with scenic routes. The main spatial structure is mainly formed by the orthogonal layout of the avenues, which were implemented in the 18th century. The trees planted to create these avenues are over 200 years old and this means that an entire ecosystem has appeared around these trees.

Secondary to the main structure is the large pond with the curved avenues around it, which was designed by the Zocher family. The large pond is designed with the 'hide and reveal' principle, which means that from each side of the pond a new perspective arises, and new corners of the estate can be discovered. It is a tool often used by landscape architects to frame a view and was often noticeable due to the placement of a bench or small arbour. The landscape is mainly distinguished by the sight axes, which also connects the landscape architecture with the architecture of the palace and other dwellings and monuments.

On the map in figure 28, the important sight axes on the estate are displayed. One of the most important and oldest ones is the sightline from the entrance of the palace to the remembrance needle of Willem II.

4.2.8 Program

The entire estate is divided into four different zones; the Paleistuin (Palace Garden), the Paleisbos (Palace forest), the Alexanderkwartier (new to build neighbourhood) and the Parade. On the map in figure 28, the different zones are indicated.

Currently the program of the estate is quite simple. There is the palace, which serves

Figure 28: Map of estate with the important sight axes

sometimes as a museum or filming location. This will be closed soon, due to restoration and transformation of the palace. The orangery is a restaurant and furthermore there are offices for the employees of MeyerBergman at the Parade. There are a few small housed with tenants, but apart from that the palace estate is currently not a residential area.

In appendix F, a plan for the new Paleis Soestdijk can be found. The palace will get a more educational purpose, that will also connect different parts of the professional world together. New purposes will be added on the estate, such as greenhouses, a hotel at the parade and art works. The old Marechaussee terrain will be transformed into a neighbourhood.

4.3 Analysis of biomass streams

In order to make a good plan for biomass processing and food production on the estate, it is important to know which biomass streams are available on the estate. Furthermore, quantifying the streams can help with creating a fitting and realistic solution.

There is a map with an inventory of the different biomass streams on the estate, however this map is unreadable in this format. Therefore it can be found in the A3 booklet. The recognised available biomass streams are:

- Woody biomass from the forest and park
- Residual (woody) biomass from landscaping from the park and gardens
- Agricultural biomass from the orchard at the parade
- Biogenic waste from the Orangery (food waste) and wastewater (from the lavatories)

The calculations to give some numbers to the biomass streams can be found below. These numbers are based on sources and calculations, as well as given information and estimations by Paleis Soestdijk itself. It should be noted that the Parade on the other side of the Amsterdamsestraatweg is not included in these calculations.

4.3.1 Woody biomass calculations

In order to give an indication of how much woody biomass can be harvested from the estate, literature has been consulted. The following equation has been found in literature:

P = A x E x C x R x N (Tolkamp et al., 2006)

P =	The amount of dry matter
A =	Additional growth of the forest
E =	Expansion factor of branch biomass (BEF Biomass Expansion Factor)
C =	Conversion of fresh wood to dry matter
R =	Reduction factor for the harvestable woody biomass
N =	Amount of hectares

The thinning of the forest is not taken into account. On average grows a forest in the Netherlands with 7.1 m3 per ha per year (Tolkamp et al., 2006). The BEF is generally speaking 1.35 (average deciduous and conifer) (Tolkamp et al., 2006). The conversion of volume fresh wood to dry matter is 0.46 (Tolkamp et al., 2006). The reduction factor can be considered 1.

On the estate there is about 136 hectares of park and forest. This leads to the following estimation of the amount of woody biomass:

P = 7.1 x 1.35 x 0.46 x 1 x 136 = 599.6376 m3

This means that the current forest produces about ~ 600 m3 of dry woody biomass per year, which equals about 150.000 kg of dry woody biomass per year.

4.3.2 Landscaping waste estimations
The amount of landscaping waste per year is an estimation based on information provided by employees of Paleis Soestdijk.

Based on the large piles of gardening waste that has been growing on a blind side of the estate, an estimation of how much m3 biomass is produced from this waste per year. The estimation is that the estate produces approximately 400 m3 of landscaping waste per year. This is based on the pile that has been growing for over 15 years which is about 6000 m3 by now. The specific weight of landscaping waste is 300 kg/m3 (Stichting Stimular, 2020). This specific weight does not take into account the conversion to dry biomass, but for instance for composting or vermiculture this is not needed. Only if the biomass is needed for the pyrolysis, it will need to be dried. The conversion factor for this is taken from the calculations of the woody biomass and is therefore 0,46. Table 6 shows the calculations of both wet and dry biomass.

Type of biomass	Volume (m3)	Weight (kg)
Wet biomass	400	120000
Dry biomass	184	55200

Table 6: Calculation landscaping waste biomass

4.3.3 Amount of wastewater from existing buildings
In order to give an overview of the amount of wastewater that the estate generates or can possibly store, the amounts of black, grey and rain water have been calculated (Table 7). For black water the toilets in the Orangery and for the grey water the wastewater coming from the sinks have been considered. The rainwater on the roofs of the palace and orangery are calculated for the amount of the rainwater. It can be argued that there are more sources that can be explored, however these are impossible to estimate.

On average per year there is about 650 litres of rainwater per m2 roof (Mijn Waterfabriek, 2019). This means for the roof of the Palace, which is approximately 2000 m2, 1,3 million litres of rain water per year. The roof of the orangery is about 330 m2, and therefore it collects 214.500 litres per year.

For grey water, the sinks in the orangery have been calculated. On average uses a person 4 litres of water to wash their hands (Waternet, n.d.), so to calculate how much grey water this produces it should be known how many visitors Paleis Soestdijk has in average. On average 400.000 people visit Soestdijk per year. If every single person would wash their hands, this would mean that this would produce 1,6 million litres of grey water.

When calculating the amount of black water, the toilets are the main source. On average we produce 1,5 litres of urine and faeces a day and we drain that as black water with an extra 35 litres (Saniwijzer, n.d.). This is per day, but on average we go five times a day to the toilet (Waternet, n.d.). This means that we produce 7,3 litres of black water per toilet use. If we go back to the same assumption as with the grey water calculation, and we say that the toilet is used 400.000 times a year. That will mean that the toilets produce 2,92 million litres of black water per year.

Type of wastewater	Location	Amount (L)
Rain water	Roof palace	1300000
	Roof orangery	214500
	Total:	1514500
Grey water	Sinks orangery	1600000
Black water	Toilets in orangery	2920000

Table 7: Calculation wastewater

4.3.4 Amount of food waste in Orangery
According to a report by the OVAM (Openbare Vlaamse Afvalstoffenmaatschappij) produces a small restaurant 21 kg of food waste per day (AVOM, 2011). At the moment the opening days of the Orangery are sporadic, due to the changing opening and closing of the estate. Therefore, for this calculation, the situation of normal opening days for a restaurant are considered. On average is a restaurant 246 days open a year (Van Dullemen, 2021).

This means that the Orangery will produce 5166 kg of food waste per year.

5 Elaboration

5.1 The Circular Plan

The circular plan for Paleis Soestdijk has a main focus on connecting the biomass streams, combined with wastewater and food production to fully close the loop. Further elaboration on the plan and certain design choices can be found in the A3 Booklet.

5.1.1 Biomass

On the estate of Paleis Soestdijk there are different biomass streams available. Figure 29 shows a diagram of all different biomass types on the estate, where they come from, what they can produce and how everything is connected. On the estate biomass is converted to heat and nutrients for plants. The first happens in a pyrolysis oven in which dried (woody) biomass is heated and produces bio-oil, biochar and gas that can be repurposed inside the pyrolysis reactor. The nutrients for the plants are created by the composting and vermiculture units. There is a large compost bin system and there are a few worm hotels present on the estate grounds. Part of the landscaping waste together with the agricultural and biogenic (food) waste is converted to nutrients for the crops that grow inside the greenhouses.

In section 4.3, different types of biomass have been quantified. In table 8, a summary of those numbers can be found. From the woody biomass an estimation is made that about half of the material can be re-purposed elsewhere, so therefore 75.000 kg of dry biomass can be used for heat production. The landscaping waste is divided into a part for the biological conversion and for heat production, for which a

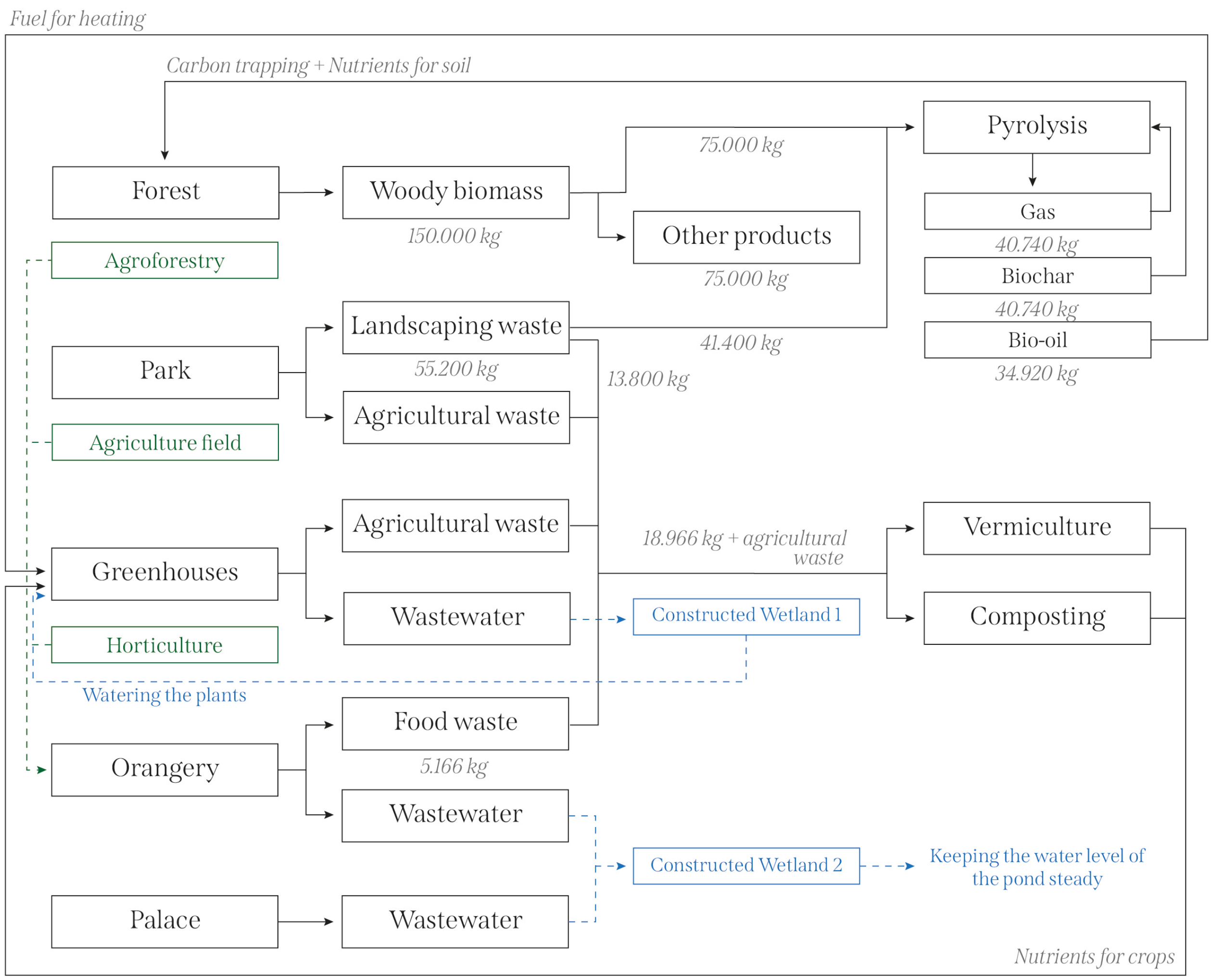

Figure 29: Schematic overview circular plan on the estate.

fourth is for composting and the rest for heat production. This would mean that 13.800 kg would go to the biological conversion and 41.400 kg to the heat production. These estimations are not based on any data, since no good examples or source were found, and therefore are mere guesses.

Type of biomass	Volume (m3)	Weight (kg)
Woody biomass (dry)	600	150000
Landscaping waste	400 (wet)	120000
	184 (dry)	55200
Agricultural	-	-
Biogenic waste	-	5166

Table 8: Quantification of biomass streams

For the production of heat there is 75.000 + 41.400 = 116.400 kg of dry biomass. As can be seen in table 4 on page 22, the wt% of the products of pyrolysis are as follows: 30 wt% bio-oil, 35 wt% biochar and 35 wt% gas. This means that there is a yield of 40.740 kg of biochar, that can be used to enrich the soil of the forest and carbon trapping. There is also a yield of 40.740 kg of gas, which is re-used inside the reactor to keep it running. This leaves 34.920 kg of bio-oil that can be used to heat up a boiler and provide the greenhouses with heat.

In order to calculate how much heat can be produced from this bio-oil, it is important to know the calorific value. The calorific value of bio-oil is ~30 MJ/kg (Kit Ling et al., 2015). This would mean that the amount of bio-oil would be (30 * 34.920 =) 1.047.600 MJ_{fuel}. The efficiency of the boiler can be estimated as 80%, and therefore the bio-oil can produce (0,8 * 1.047.600 =) 838.080 $MJ_{thermal}$. So the woody biomass from the estate and landscaping waste equals 838.080 MJ of heat per year that can be used for the greenhouses.

5.1.2 Wastewater

As can be concluded from section 4.3.3 there are several sources of wastewater on the estate. When adding the greenhouses and the biomass conversion buildings a few extra sources of wastewater (especially rainwater from the roofs) can be added. Therefore, table 9 contains the updated amounts of wastewater.

Type of wastewater	Location	Amount (L)
Rain water	Roof palace	1300000
	Roof orangery	214500
	Roof greenhouses	585000
	Roof pyrolysis	41600
	Roof drying sheds	260000
	Total:	2401100
Grey water	Sinks orangery	1600000
Black water	Toilets in orangery	2920000
	Wastewater from greenhouses	18270
	Total:	2938270

Table 9: Calculation wastewater (updated)

The wastewater from the food production inside the greenhouses is hard to define as specifically grey or black water, but is in this case determined as black water due to the level of contamination compared to grey water. The amount of wastewater is estimated based on the fact that on average a greenhouse produces 203 m3/ha/year of wastewater (Balendonck et al., 2012). This would mean that for a greenhouse surface of 900 m2, there is a wastewater stream of 18,27 m3 per year, equal to 18.270 litres per year.

Essentially there can be two different purposes of filtering wastewater. First of all to create clean water for growth of crops in the greenhouses and secondly to maintain the level of water in the pond. As mentioned in section 4.2.4, the quays might collapse if the water level is not maintained. Next to that it might be interesting to see if the excess water can be used to fill the small creeks in the forest part.

The choice was made to reserve two places for wastewater treatment. The first treatment area will be around the greenhouses and the second one close to the orangery and the pond. They have been respectively named constructed wetland 1 (CW1) and constructed wetland 2 (CW2). Further elaboration on the constructed wetlands can be found in the A3 booklet.

5.1.3 Food production

As can be seen in figure 29, the plan does not only add the greenhouses as a form of food production. In the forest a form of agroforestry is added and in the park a former field is reinstated. The agroforestry type that is implemented in the forests is a low-key and simple form of agrisilvopastoral agroforestry. In the case of the estate this means that fruit and nuts are produced inside the forest as part of the aim to improve the layering and mix of species in the forest. The amounts of food and agricultural waste are impossible to estimate and therefore excluded from the quantification.

5.2 The Greenhouses

In the 19th century, two greenhouses arise on the estate of Paleis Soestdijk. In figure 30, a photograph of one of these greenhouses in 1879 can be found. Unfortunately these greenhouses were prematurely broken down and later on, in Juliana's period, a simpler greenhouse was built on the original location. From photographs it is clear that these greenhouses were incredibly majestic and fitting for a royal estate. It is a shame that these greenhouses were broken down. This is not just a conclusion of my own, but also MeyerBergman Erfgoed has included the reintroduction of the greenhouses in their vision for the future (see number 17 on the map in Appendix F).

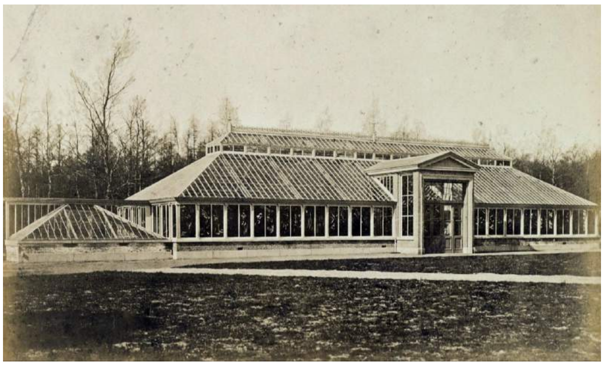

Figure 30: The greenhouse (Collectie Eemland, 1879)

The greenhouses form a central function in the circular plan for Paleis Soestdijk. The entrance to the estate will move between the two greenhouses and therefore the structures will figuratively serve as the opening act for the visitors. Next to that, as can already be read in the last section, they are also important for the biomass cycle on the estate.

The purpose of the greenhouses is not only to produce food that can be used to serve the visitors of the estate. It will also have an educational purpose. The two greenhouses will display different types of food production and the layout will be adapted in such a way that tours can be held through the greenhouses. The first greenhouse will display a more traditional in-soil food production, which can then be compared to the second greenhouse which will house more modern and experimental food production technologies. These technologies will be different types of hydroponics, aeroponics and aquaponics. At the end of the visit, the visitor will not only have learned about the different types of food production inside a greenhouse, but also about growing plants and especially on how to create nutrients from their own organic waste.

Full documentation and impressions of the greenhouses can be found in the A3 booklet.

5.2.1 Materialisation

For the materialisation it was important to look at circularity and sustainability as well. If the facade and structure are created by bio-based,

recycled or at least recyclable materials as well it will fit in the whole story of the estate.
The greenhouses are quite large structures and therefore require a solid building structure. Most large greenhouses in the Netherlands have a steel structure, which is not the most sustainable material. Research into the possibility of re-using steel from former greenhouses or other structures was done, however finding out if that is possible seemed impossible to find. Next to that, steel is often perceived as a cold material that is, especially next to a glass facade, not very warm and welcoming. The greenhouses are meant to be the entrance of Paleis Soestdijk and therefore deserve to look warm and welcoming.
Therefore, research was done into creating a wooden structure.

Due to the large span of the buildings, there were not a lot of options there. Wood is a strong material, but it has its limits. One of the options that allowed the span of the greenhouses, is CLT. Cross Laminated Timber (CLT) is a material that consists of layers of planks glued together. It mainly gets its strength due to the fact that every layer is oriented perpendicular to the previous layer. This ensures that the structure has both tensile and compressive strength (Souza, 2018). There are a lot of advantages to CLT structures, however there are also disadvantages. One of them being that the wood is glued together, therefore after the life span of the building it cannot be fully taken apart. However, one could argue that the structure as a whole could be re-used and there is also more and more research into bio-based glues that could change the sustainability of CLT as well. An example of a greenhouse with a CLT structure can be found in figure 31.

For the infill of the facade of the greenhouse one of the main criteria was translucency, but at the same time also keeping the sustainable and circular aspect in mind. The re-use of existing typical greenhouse facades was considered, but discarded due to the rigidity

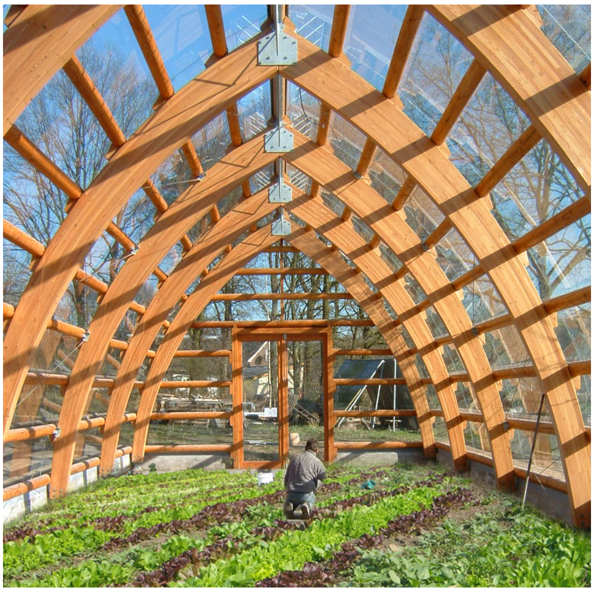
Figure 31: CLT structure (GLASStube, 2018)

and look of the facade system. Also translucent materials made from bioplastic or other bio-based material were considered, but discarded due to the unreliability and uncertainty of lifespan of the material. This left the option of glass, and therefore the possibility for recycled glass were researched. There are a lot of companies and research groups that have developed glass that is created from waste glass and is even fully recyclable again, one of these companies is MAGNA Glaskeramik (figure 32). The downside is that it is in practice not fully transparent yet. Another way to improve sustainability of the glass facade is to make sure that the facade can be reused, for example by choosing mostly standard sizes of glass panes or creating a flexible system that can be adapted to other dwellings. This allows the glass to be re-used in another project, after the lifespan of the current project. This last option was chosen for the facade of the two


Figure 32: Recycled glass (MAGNA Glaskeramik, 2019)

greenhouses, also due to the fact that on two sides of the greenhouses BIPV will be installed, and therefore the choice for transparent standard sizing glazing was chosen.
As mentioned, the facade will include BIPV (Building Integrated PhotoVoltaics) to produce electricity for the functions inside the greenhouses. When looking at the different options, there are also a few options that have a bit of translucency. These options are often available in multiple colours or prints.

Kameleon Solar is one of the companies that produces high-quality BIPV panels, and two of their products are interesting for the facade of the greenhouses. The first one is the Mystica colored solar modules that contain colored polycrystalline solar cells, and is available in multiple colours. From these colours, the colour 'Endless Pines' seems to be the perfect fit for the greenhouses. Due to the fact that it represents the colour of the forest that it surrounds. Figure 33 shows an example of the colour and look of the BIPV.

Figure 33: Mystica BIPV in Endless Pines (Kameleon Solar, 2021)

Another type of BIPV from Kameleon Solar that fits the design of the greenhouses, is the Royal Glam PV panels. Which is also created by coloured polycrystalline solar cells, but in a pattern. Especially the Emerald Green version is very fitting, which seems to look like a leaf pattern (Figure 34).

In the end the choice between the two types of panels is trivial. It depends on personal preference. The only slight difference between

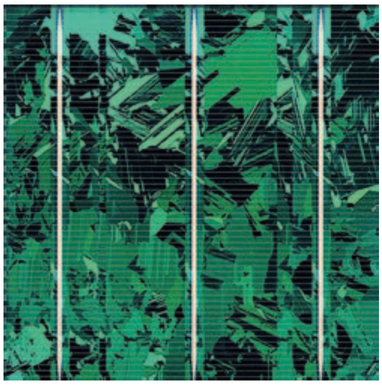

Figure 34: Royal Glam BIPV in Emerald Green (Kameleon Solar, 2021)

the two is that the Endless Pines panel has a yield of 129 WP per m2 and the Emerald Green panel has a yield of 136 WP per m2. A small difference that can hardly be seen as a deciding factor. In the booklet the facade studies with both panels can be found. In which one can see that the main difference is in the vividness and liveliness of the facade. As for the detailing, both panels can be almost identical and are mounted the same way, so there is no visible difference there.

Whereas the CLT structure is the main structural layer, secondary to that structure there is the facade structure. In this case the structure on which the glass panels and the BIPV panels are mounted on. The inside structure of the facade is made out of wood and connected to the primary structure. Both the glass and the BIPV are mounted in a combination of galvanised steel profiles with a bio-based polycarbonate cover on the outside. The look of these profiles is quite chic due to the slimness of it.

The final detailing and design of the facade can be found in the A3 booklet.

5.2.2 Climate design
This section will contain the elaboration and calculations of the climate design choices that were made. For further information on the climate design, go to the A3 booklet.

Ventilation
The greenhouse needs to be ventilated. Normally one would just look up what the

desired ventilation rate inside a greenhouse should be. However, in the case of the greenhouses at Paleis Soestdijk there are also visitors coming every day. Therefore the ventilation rate of 2 was chosen. The total ventilation flow inside one greenhouse is therefore approximately 4000 m3/h. When looking at ventilation units, the choice was made for the Zehnder CVF unit with a maximum ventilation flow of 4400 m3/h (Zehnder, n.d.). This unit is about 710 mm by 710 mm by 710 mm and has a duct opening with a diameter of 450 mm.

The unit consumes about 1,1 kWe and over 8000 hours a year it consumes about 8800 kWh of electrical energy. Since there are two greenhouses, the total amount of electrical energy that is needed for ventilation is 17600 kWh. The calculations for the ventilation can be found below in table 10.

	Amount	Unit
Ventilation rate	2	m3/h per m3 GH
Volume GH	2000	m3
Ventilation flow	4000	m3/h
Electric power	1,1	kWe
Effective usage per year	8000	h
Power consumption	8800	kWh
2 GH, therefore:	17600	kWh

Table 10: Ventilation calculations

Heating

The surface area of both greenhouses is in total 900 m2 which needs to be heated. In order to find out what to expect when heating a greenhouse, the average heating demand per m2 of greenhouses was researched. According to a report by Van der Velden and Smit from 2018, the average heating demand of a greenhouse is 0,9 GJ/m2 per year. This means that the greenhouse requires 900 MJ/m2 per year. The calculations for the heating demand can be found in table 11.

	Amount	Unit
Surface area	900	m2
Average heating demand	900	MJ/m2 per year
Total heating demand	810000	MJ per year

Table 11: Heating calculations

These calculations estimate that the greenhouses have a total heat demand of 810.000 MJ per year. According to the pyrolysis output calculations it seems that the yearly produced bio-oil, which can produce 838.080 MJ of heat per year, is more than enough to heat the two greenhouses.

The greenhouses will be heated by floor heating which is supplied by an oil fired boiler. This boiler needs to have the capacity of 115 kW. This would mean a medium sized oil fired boiler will suffice, like e.g. the Viessmann VITORADIAL 300-T with a capacity of 101 to 305 kW (Viessmann, 2019).

Cooling

During summer the greenhouses will in the first place be cooled down passively. There are large openable windows on the roof and part of the facade can be opened, this will ensure cross ventilation and the loss of most of the heat. In more extreme situation a water vapour system can be used around the plants to at least ensure that the plants do not overheat and die.

Lighting

In order for the plants to grow, it is important that they get enough light. Since there will most definitely not be enough daylight ever day, LED fixtures are installed. The calculations in table 12 are based on the information from a company that sells LED fixtures for greenhouses.

	Amount	Unit
LED fixtures	32	W/fixture
Amount	0,2	Fixture/m2
Effective surface plants	600	m2
Electric power	3,84	kWe
Effective usage per year	4000	h
Power consumption	15360	kWh

Table 12: Lighting calculations

Energy production (electricity)
As mentioned, the facade is partially built up with Building Integrated PhotoVoltaics (BIPV). The amount of facade covered in BIPV is the estimation of the South facade and slanted roof. For this calculation the minimum WP per m2 was chosen from the Kameleon Solar panels, see table 13. This is estimated to an amount of 64.500 WP of power production and when multiplied by an efficiency of 0,88 it results in the production of 56.760 kWh.

	Amount	Unit
Surface area facade	500	m2
Power production per m2	129	WP/m2
Power production	64500	WP
Conversion to kWh	56760	kWh

Table 13: Electriciity calculations

When adding up the known consumers of electricity inside the greenhouses, it can be checked if this amount of BIPV is enough to cover at least the needs electricity for the greenhouses. In table 14 the amounts are added up and it can be seen that only using the South side of the building for electricity production is already more than enough. There is still about 20.000 kWh excess, from which also other functions, such as the boiler, the watering system and other appliances need to be fed. It can be concluded that there might even be enough electricity production to also serve other functions on the estate, especially when more of the facade is covered in BIPV.

	Amount	Unit
Ventilation	17600	kWh
Lighting	15360	kWh
Total electricity demand	32960	kWh

Table 14: Known electricity demands

6 Conclusion

This graduation project focused on the following question:
How can the cycles of food production and biomass be connected on the estate as part of a wider perspective to create a circular Paleis Soestdijk?

The central question is directly connected to the main objective of this graduation project, which states that the aim of the circular plan is to utilise the available biomass sources on the estate and therefore get a step closer to an autarkic estate.

To answer the main question, there were three sub-questions formulated. The first one is as follows: *What biomass streams can be found on the estate of Paleis Soestdijk?* During the analysis of the estate, it became clear that there are several biomass streams available. These biomass streams, as defined according to the literature research, are woody biomass, residual biomass from landscaping, agricultural residues, and biogenic waste. Most of these biomass streams were quantified by either using sources or estimations. Recognising these streams and knowing the quantities helped with finding the right techniques and design choices for the circular plan for Paleis Soestdijk.

This leads to the second sub-question: *What biomass conversion techniques have potential on the estate of Paleis Soestdijk?* In order to answer this question, it was important to start with identifying the possible conversion techniques and for this extensive literature research was conducted. According to the literature, there are two different conversion techniques: biological and thermochemical techniques. The biological conversion techniques rely on the natural processes and examples of these techniques are fermentation, composting or vermiculture. In thermochemical conversion techniques the biomass is converted by using different types of reactions. Reaction created by for example combustion, incineration, gasification, or pyrolysis. For the plan, the biological techniques composting and vermiculture were chosen to create nutrients for the crops in the greenhouses. The chosen thermochemical technique is pyrolysis, because it can create biochar, which is a type of carbon trapping and a very good nutrient for the soil. There was also some research on the conversion of wastewater, a type of biogenic waste. For the plan different techniques were chosen to deal with the different types of wastewater and the purpose of the filtered water.

The last sub-question that was needed to answer the main question is: *How can the introduction of greenhouses play a role in closing the biomass cycle on the estate of Paleis Soestdijk?* Already while researching the topic of biomass and how to process biomass, there seemed to be a gap between the production of nutrients for plants and biogenic waste (which includes food waste). This led to the conclusion that to further close the cycle of biomass on the estate a form of food production was necessary. Especially when the plan came fully together it became even more clear that the greenhouses play a central role on the estate itself as well as in the circular strategy. To fully understand the working of a greenhouse and especially the types of food production that can take place inside a greenhouse, a section in the literature research chapter was dedicated to that. This research led to the conclusion that there is the traditional in-soil food production and the more modern techniques, such as hydroponics, aeroponics and aquaponics. Next to that, there was also some research on agroforestry, a possible solution for the forest, which currently mainly has problem concerning the layering and mix of species within forest sections. These problems can possibly be solved by adding food producing shrubs and trees to the forest sections.

All in all, it can be concluded that there is not one right solution or answer to the main question. That is also not the intent of the question, it was meant more as an inventory into a possible solution for the estate of Paleis Soestdijk. The possible solution is presented in this report, the A3 booklet and the presentation as a circular plan that has recognised the different types of biomass on the estate, found a fitting purpose for those biomass streams and combined them with food production to fully close the biomass cycle. This has resulted in a diagram, see figure 29, that shows how all streams connect to each other. From this diagram it can be concluded that essentially the loop is almost fully closed.

Limitations

As already mentioned, there is not one solution to the main question of this graduation project. This is due to a few reasons. First of all, there is the personal perspective of the researcher and designer, which is in the case of this research the same person. Therefore, also the interests of both research and design were aligned. This is not necessarily a wrong thing, but it can cloud the objectivity in the interpretation of literature, or in the translation of the research to the design. Next to that, every individual has their own focuses and preferences, and especially when designing a plan this can have an influence. If another person would have designed a plan for Paleis Soestdijk would have probably had a completely different solution and design. Last of all, it should also be considered that perhaps there are multiple good solutions and that there is never just one perfect answer or solution. This is especially true for design since this is a subjective science. There are countless possibilities, some are considered better than others, but that also depends on whom you ask.

Another limitation to this research is the quantification of the biomass streams and the plan. These are estimations based on sources or an educated guess. If one would have exactly measured and calculated the numbers, there would have perhaps been very different results. However, it was in the context of this graduation project just simply not possible to work in such an exact way.

Recommendations

When looking back at the project, there are still countless of possibilities and questions that could be explored. When working on a plan for such a multifaceted estate, it is inevitable that not every angle of research or design is explored. That would perhaps require a large team, and even then one could argue that there will probably still be other possibilities.

For future research, there are the following suggestions:

- Looking more in depth into the large scale implementation of agroforestry as part of the biomass cycle on a large estate
- Research into circular and demountable greenhouse structures with a focus on using bio-based or fully recyclable materials.
- More extensive research into landscape management and especially the potentials of the waste streams that are produced.

7 Reflection

Reflecting on a period of 1,5 years can be difficult. When I look back at the graduation plan that I wrote in January 2020, a lot has changed. Where in essence my graduation project still revolves around the same, it has also been narrowed down and formed by the knowledge that I gained. In January 2020, I presented the idea to create a circular strategy for the estate of Paleis Soestdijk on all levels. Energy, water, food, biomass and materials were all included in the plan and would be elaborated on in detail in the form of creating two greenhouses. The main critique of my mentors was that this was far too extensive and impossible to do during a master thesis. This resulted in a change of perspective, instead of tackling all of these topics, I would put a main focus on biomass. My choice for biomass was based on two arguments. First of all, the topic of circularity connected to biomass had been researched before, however not on the level of for instance energy or water. Next to that, I saw a lot of opportunities on the estate of Soestdijk, opportunities like the forest, mixed-use functions and the maintenance of the gardens and park.

This change in topic, did have an effect on my process. The topic of energy, but also water or materials, I had had much more knowledge on due to the courses I followed for the master track Building Technology. I did know a few things about biomass, but soon realised that there was far more to discover than I thought. This caused a little bump in my process, because being curious by nature did not help during this period. Every time I would read something and learn about a new technique or theory of knowledge, I wanted to understand it completely. However, I did not have the background to always understand these topics. This resulted in me trying to figure it out by diving deeper and deeper into the matter until I would understand it. I was unable to write it down properly and had only written down chaotic notes on the topics. It was a mess, and a very hard one to clean up. The information was all in my head and my notes, but not in a concrete and organised report. Later on, when I started to work on the design for the estate itself, this happened again. I explored every in my mind and notebook every option that there was, but still not able to put it in actual words and drawings. This slowed down the process a lot and made me realise that this was a large problem. Still, till this moment, I have difficulty capturing my knowledges, ideas and designs on paper. I am currently working on that with a professional, but it is not an easy problem that can be solved in a short period of time. Right now, this results in a slow process in which I try to write and draw all the things that are in my head and notebooks.

The methodological framework, as presented in the graduation plan, has been changed and tweaked in the past year. That was mainly, because the methodology that I had written at that time was quite basic and did not really propose a clear plan. It was based on the idea that the project consisted of three phases: the research, a strategy and a design. During the research phase, literature and experts would be consulted in order to create a good theoretical basis for the plan and design. Next to that the location would be analysed and documented. The strategy phase would mainly consist of creating criteria and scenarios for the estate. The final phase, design, would consist of creating the greenhouses, a place where all parts of the plan would come together. In some ways, I did follow this methodology, however the methodology that can now be read at the beginning of my report is more extensive than the one I proposed in January 2020. One could say that it was actually quite the

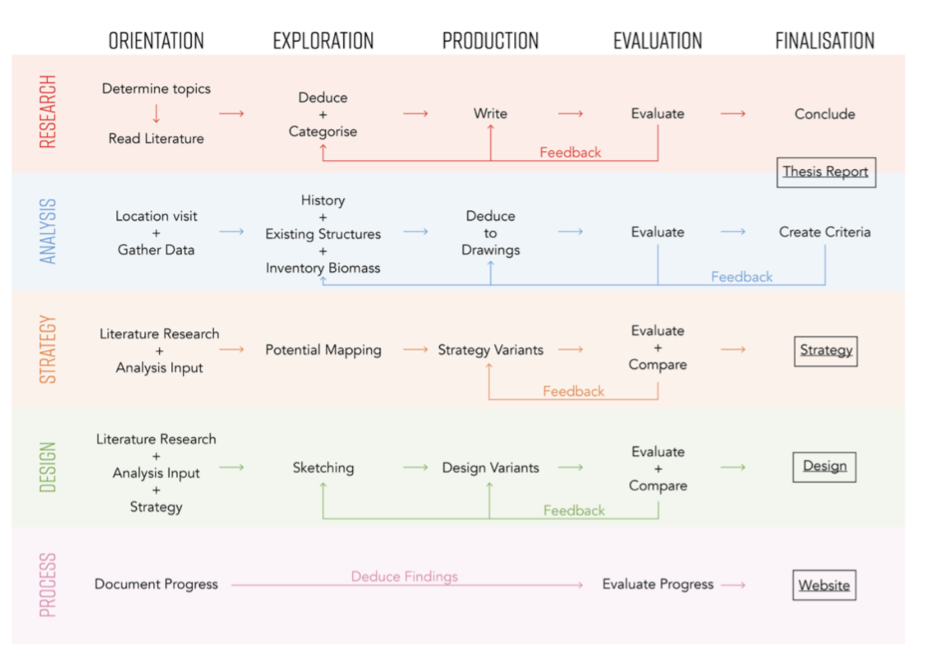

Figure 35: Schematic overview research methodology (OLD version)

journey, there have been multiple versions of my methodology. Partially because I felt it was not good enough, but also because my process was ever-changing. In figure 35, a schematic overview of one of these versions of the methodology can be found. In this version, I had divided the research in five different topics: Research, Analysis, Strategy, Design and Process. These were dissected over several stages, from orientation to finalisation.

Whereas this was a more extensive methodology, which explained more about the different aspects of the project and where they would lead, it was not the way I was working. Upon realising this, I created a new version of this methodology. This version would not necessarily be divided into stages, but more on realising what outcomes were desired and how to get to these outcomes. It resulted in a messy mind map in my notebook, that I translated to figure 3 (see Methodology). I wrote down the products that I needed to create the circular plan that I wanted to create for Paleis Soestdijk. By ordering them and writing down the things that I needed, I was able to link them to different facets of the project. These facets were Methodology, Literature Research, Analysis, Design and Process. After creating this diagram, it all made a lot more sense. Where before I felt I had no idea what I was doing, it now made sense to me. It resulted in the diagram in figure 4 (see Methodology). A clearer diagram that shows the relationships within the facets and among the facets. This last methodology has really helped me structuring the research that I had already done. The report is also divided into the different chapters that all reflect the facets explained in the methodology.

The most important thing that I learned during this research is the necessity of a good and realistic plan and organising the knowledge that you gain during the entire process. My process was chaotic and seemed to lack a good sense of organisation and planning. I made attempts to create these, but always ended up doing it differently than the plan that I had created. During the first part of the project, I did not really have a clear approach. It took me a long time to create a method that made sense and by that time I was already lost. I gained it back a little bit by trying to follow the method that I had created. However, it did feel like sailing against the wind and felt often quite disorientating.

From the beginning, I had, unconsciously, adapted the approach of Research for design. Therefore, doing research (literature and analysis) beforehand, from which the conclusions would be starting points for creating a design. However, during the process of designing, I have also explored options and compared them to each other. Thus, touching also on the approach of Research through design, although not in the full extent.

The topic of this research project does not necessarily feel connected to the master track of Building Technology (BT). However the way of creating a circular plan, is part of the curriculum of BT. I have had more than one course on the topic of creating a plan focused on circular principles, the main difference with this project is that it is not in an urban area and revolves around the topic of biomass. In those courses the main focus was on energy. This research project was more focused on a landscape level, and the introduction to this has grasped my interest. Therefore I have also started a second degree in landscape architecture at the Wageningen University and Research. I have followed a few courses, next to this project, which was in the beginning really fruitful. I learned new approaches and gained knowledge on the landscape scale, which reflects in my plan for the estate of Paleis Soestdijk. I did try to do a more extensive course earlier this year, however this made me realise that I should for now just focus on finishing this graduation project. In that period my concentration and ability to write down my ideas got even worse. Looking back, I don't think it was a mistake to start the second degree, however I should have just only done a few small courses. Next educational year I will continue there, learning even more about landscape and implementing everything that I have learned during this project and the rest of my studies. In my opinion, the knowledge that I have gained on climate design, materials, detailing and other building technological topics can really contribute on making changes on the level of landscape design. The unique combination of being able to design in the smallest detail to creating large-scale plans, could be the start of a whole new approach to sustainability.

In my opinion, the methodology used in this project could be used for any case study. It was not specifically tailored for Paleis Soestdijk and could be applicable in many other situations. I think that the main requirements for a case study would be to have a substantial amount of land, with several functions and space to implement new functions to process the biomass or to produce food. It would mean that the analysis should have to be specifically tailored for the case study and it could lead to different choices for the design.

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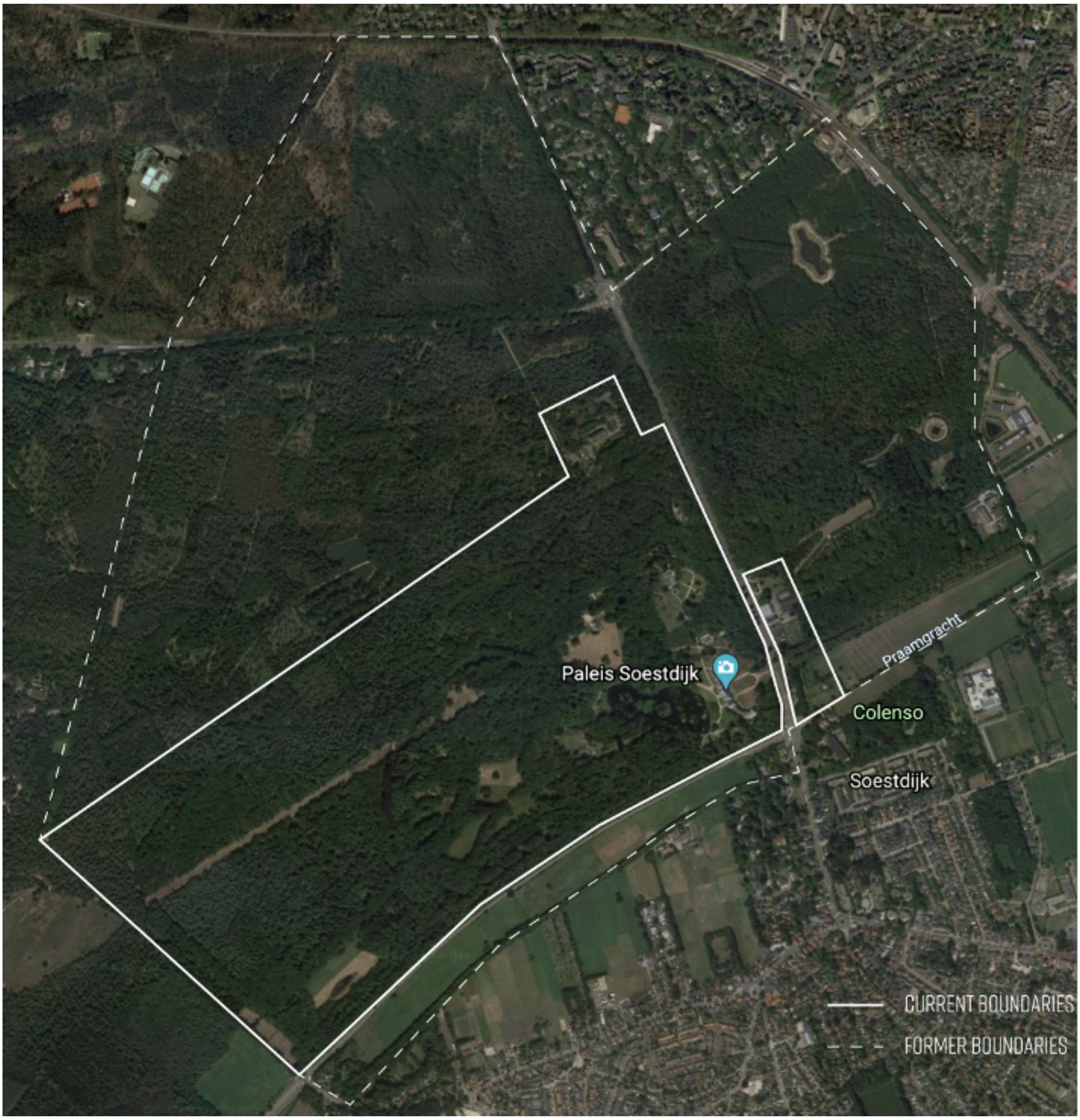
Appendix A

Overview of the Sustainable Development goals by the United Nations*

* source: https://www.un.org/sustainabledevelopment/news/communications-material/

Appendix B

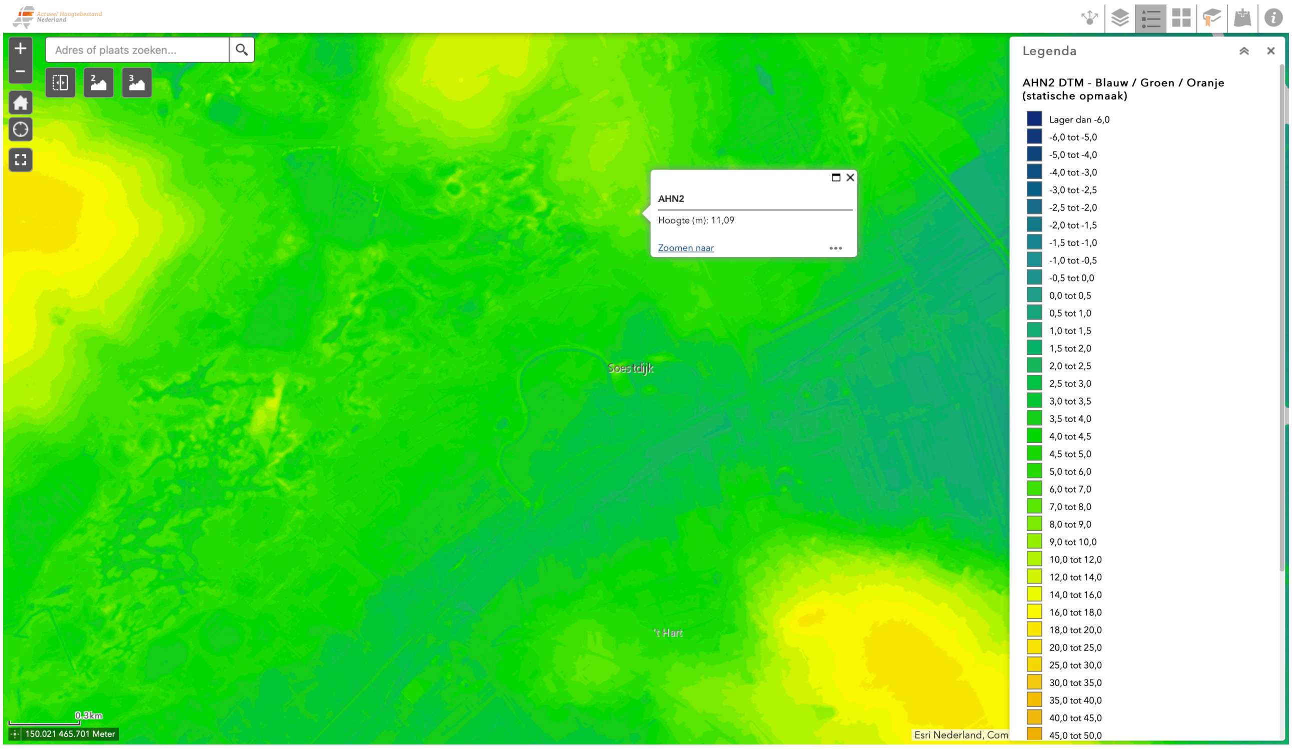
Map with the current and former boundaries of the estate.



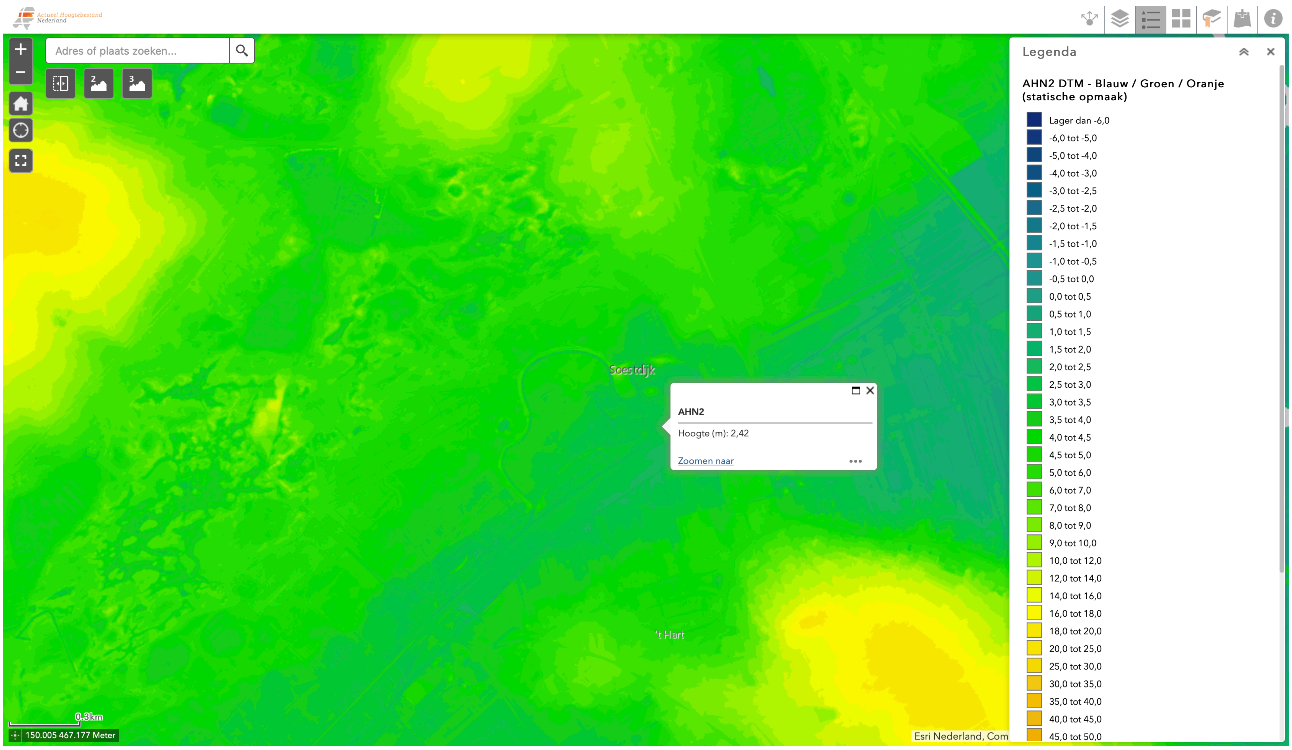
* source of the underlying map: https://earth.google.com/web/search/soestdijk/@52.1959206,5.27653402,9.82274928a,6734.61083948d,35y,-0h,0t,0r/data=CigiJgokCcG9r5b2-j5AEcK9r5b2-j7AGVv4fdIat0ZAIcdqUexN1lDA

Appendix C

Map from the Actueel Hoogtebestand Nederland (AHN)*



Highest point on the estate

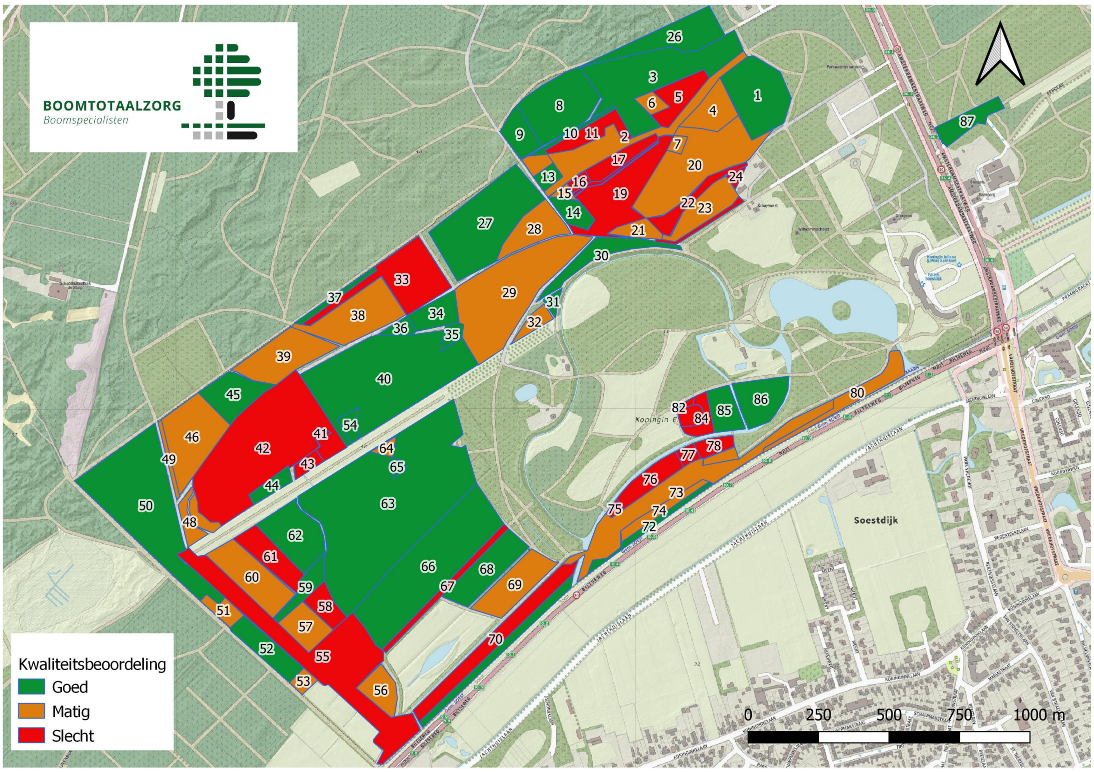


Lowest point on the estate

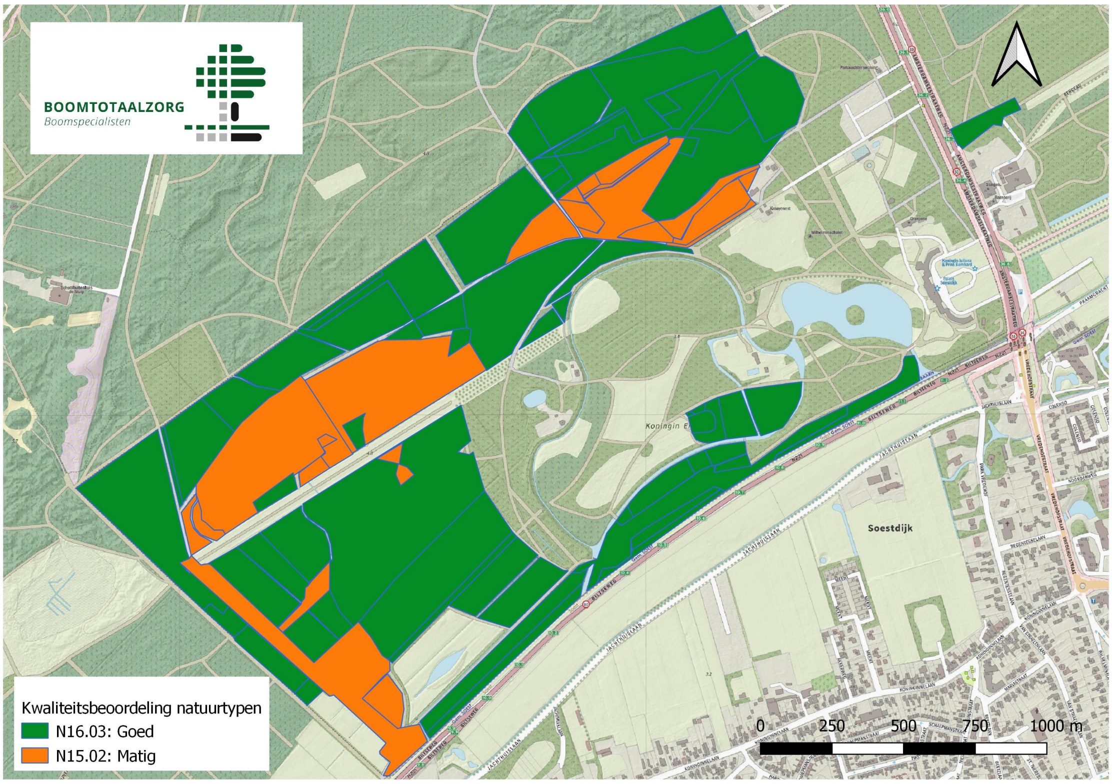
*source: https://ahn.arcgisonline.nl/ahnviewer/

Appendix D

Information on the health of the forest at Paleis Soestdijk*



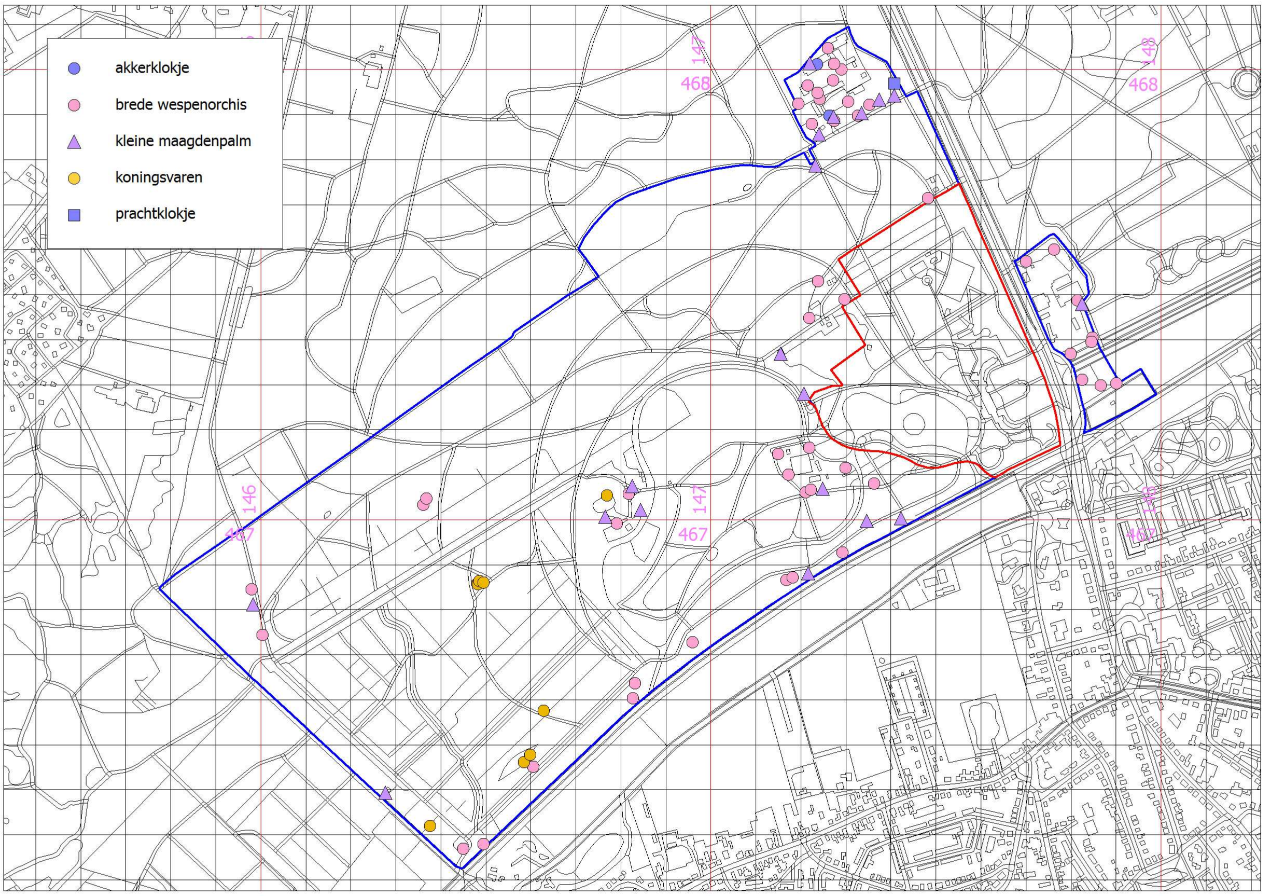
Map conditions per forest section
Map conditions per forest typology



* from the report of Boomtotaalzorg (Debruyne, M., & Corbet, K. (2019). *Inventarisatierapportage: Paleis Soestdijk -Kwaliteitsbeoordeling Natuurtypen.* Boomtotaalzorg.)

Appendix E

Information on the status of the flora and fauna at Paleis Soestdijk*



Map of location of protected plant species

Nederlandse naam	Wetenschappelijke naam	Rode Lijst	Oranje Lijst	F&F
Egel	Erinaceus europaeus			1
Gewone/tweekl. bosspitsmuis	Sorex araneus/S. coronatus			1
Dwergspitsmuis	Sorex minutus			1
Mol	Talpa europaea			1
Gewone baardvleermuis	Myotis mystacinus		4	3-IV
Franjestaart	Myotis nattereri		4	3-IV
Watervleermuis	Myotis daubentonii			3-IV
Ruige dwergvleermuis	Pipistrellus nathusii			3-IV
Gewone dwergvleermuis	Pipistrellus pipistrellus			3-IV
Rosse vleermuis	Nyctalus noctula	KW	4	3-IV
Laatvlieger	Eptesicus serotinus	KW		3-IV
Gewone grootoorvleermuis	Plecotus auritus			3-IV
Haas	Lepus europaeus			1
Konijn	Oryctolagus cuniculus			1
Eekhoorn	Sciurus vulgaris			2
Rosse woelmuis	Clethrionomys glareolus			1
Aardmuis	Microtus agrestis			1
Bosmuis	Apodemus sylvaticus			1
Huismuis	Mus domesticus			
Vos	Vulpes vulpes			1
Boommarter	Martes martes	KW	4	3-I
Das	Meles meles		3	3-I
Ree	Capreolus capreolus			1

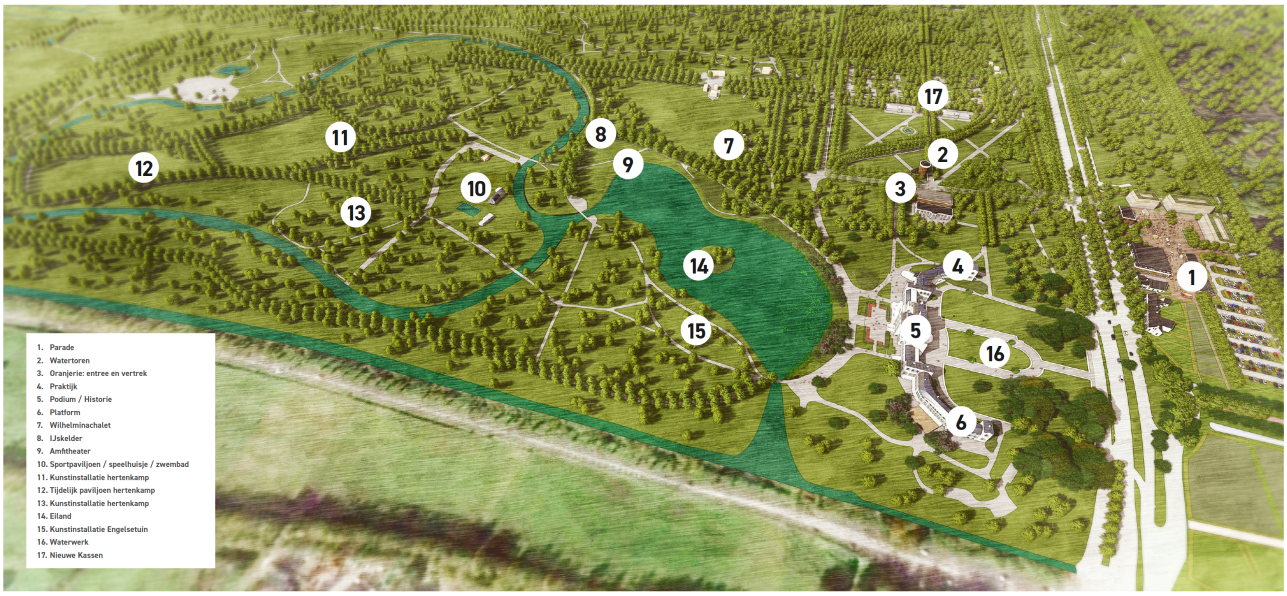
	Aantal soorten	Beschermd	Habitatrichtlijn	Rode Lijst	Oranje Lijst
Planten	366	5		7	41
Blad- en levermossen	74			4	
Korstmossen	50			2	
Paddenstoelen	385			52	
Zoogdieren	22	22	8	3	5
Broedvogels	53	3 (53)		5	2
Reptielen	3	3		2	3
Amfibieën	6	6	2		2
Dagvlinders	20			1	
Libellen	32	1	1	6	10
Sprinkhanen	17			1	1
Wilde bijen	52			4	

Overview of all different mammals that live on the estate grounds
Overview of the amount of endangered and protected species on the estate of Paleis Soestdijk

* Van den Bijtel, H. J. V. (2014). *Paleis Soestdijk: Flora en fauna van het bos en park.* van den Bijtel Ecologisch Onderzoek.

Appendix F

New plans for Paleis Soestdijk by MeyerBergman Erfgoed.*



1. Parade
2. Watertoren
3. Oranjerie: entree en vertrek
4. Praktijk
5. Podium / Historie
6. Platform
7. Wilhelminachalet
8. IJskelder
9. Amfitheater
10. Sportpaviljoen / speelhuisje / zwembad
11. Kunstinstallatie hertenkamp
12. Tijdelijk paviljoen hertenkamp
13. Kunstinstallatie hertenkamp
14. Eiland
15. Kunstinstallatie Engelsetuin
16. Waterwerk
17.Nieuwe Kassen

* https://www.paleissoestdijk.nl/transitie/madebyholland/