FROM AMBITIONS TO REALITY

UNDERSTANDING AND QUANTIFYING THE RELATIONS BETWEEN FOOD, ENERGY & WATER FOR A NEIGHBORHOOD SUSTAINABILITY HUB, THE GREEN TOWER IN AMSTERDAM

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METROPOLITAN ANALYSIS, DESIGN & ENGINEERING

Master's Thesis

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Understanding and quantifying the relations between food, energy & water for a neighborhood sustainability hub, the Green Tower in Amsterdam

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Moreover, the process of creating the FEW Sustainability Hub Tool has sparked such enthusiasm in me, that I consider continuing the development of this tool. Therefore, this thesis might really be a 'version 0.1' of a FEW Sustainability Hub Tool that will be used in planning neighborhoods of the future.

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Abstract

Sustainable food, energy, and water (FEW) provisions are essential to creating sustainable urban communities. However, there are only few examples of decentralized systems that support the generation, distribution, and recycling of FEW at a neighborhood level. Let alone, examples of a neighborhood sustainability hub that processes all three at one location. Motived by the Green Tower in the Bajeskwartier, a tower with the intention to become the 'sustainable heart of the neighborhood', this thesis aims to improve the understanding of the interrelations in FEW for neighborhood sustainability hubs. In this, emphasis is placed on creating a flexible and interactive tool that helps improve this understanding to help designers and developers in the initiation phase of designing the hub. The Green Tower is used as case study for this research and the designers as test group for the tool. Design thinking was applied as overarching methodological approach and the FEW Nexus used as theoretical basis for creating this tool. First, a stakeholder analysis and power relation mapping helped identify the types of involvement of the main stakeholders. Then, a literature study and a series of SWOT analyses helped understand the preliminary design of the Green Tower and the strengths and weaknesses of its planned systems from a FEW Nexus approach. Afterwards, a system diagram and theoretical model were created to visualize the planned and potential relations in FEW among the Green Tower's systems. By means of prototyping, an interactive quantitative model was made in Excel that calculates the FEW balances of the sustainability hub based on a scalable floor plan. Last, the outcomes of the model were tested in a focus group with representatives of the main stakeholders involved in designing the Green Tower. The tool created in this thesis exists of the visualization method and quantitative model. The results of the quantitative model showed that the current program of the Green Tower has a negative energy balance, limited availability in food supply and a lack of water treatments systems from a FEW Nexus perspective. The design team of the Green Tower positively received the tool and results. An elaborate set of recommendation for operationalizing the tool have been documented.

Contents

1. Introduction

1.1 Overview

A former prison site located in the South-East of Amsterdam will be redeveloped into the 'healthiest neighborhood of the Netherlands'; the Bajeskwartier. Two main goals can be identified from the masterplan, the Bajeskwartier will: (1) be climate neutral and (2) support its citizens living a healthy life (Bajes Kwartier Ontwikkeling, 2020, June). An important element of the masterplan in achieving these goals is the transformation of a former prison tower to the sustainable heart of the neighborhood: The Green Tower. This tower aims to become a place where sustainability is both measurable and perceptible. Organic waste will be processed, food will be produced, energy generated, stored, and distributed, and rainwater reused. The exact program of the building has not yet been decided upon and a shortcoming in the focus on the relations between food, energy, and water systems is observed in the building's current program. Moreover, there is little to no knowledge available on the creation of a multi-faceted sustainability hub that generates, distributes, and recycles food, energy, and water flows. Combine this with offering valuable experiences on healthy and sustainable living, and you have a completely new and unexplored concept.

By creating a tool that visualizes and quantifies the food, energy, and water flows of the Green Tower, this thesis aims to improve the understanding of the relations between food, energy, and water in a sustainability hub in general, to help the design team of the Green Tower specifically. The tool consists of two components: (1) a system diagram that visualizes the food, energy, and water systems of the sustainability hub and their realized and unrealized relations, (2) a quantitative model that calculates the food, energy, and water balances of the sustainability hub based on a scalable spatial program. The tool instantly shows the effect of adding, deleting, or changing the size of systems and technologies planned for the Green Tower, on its food, energy, and water resource balances. This makes the tool suitable to use in dialogues where the preconditions for the sustainability hub's design are set. The tool is based on a thorough analysis of the design of the Green Tower in Amsterdam, and the team of designers and researchers of the tower will function as subjects for testing the tool.

1.2 Context: Urban Metabolism & Nexus Thinking

By 2030 about 5 billion people, more than half of the world's population, will live in cities (Avgoustaki & Xydis, 2020, -a; UN, 2018). Cities can be held accountable for consuming 75% of the global energy supply and producing of over 75% of global greenhouse gas emissions (UNEP, 2011). The consumption density of resources in cities requires vast production in- and transportation from hinterlands polluting local ecosystems and emitting greenhouse gasses. With the Paris Agreement aiming to reduce greenhouse gas emissions by 80% in 2050 (Rogelj et al., 2016), cities will have to play a vital role in this reduction.

Linear urban metabolism, the situation where cities only consume resources and produce waste, creates negative impacts for the global rural 'hinterland' that feeds the city and takes it waste (Brunner, 2007). While services can be provided more efficiently in metropolitan areas than in rural areas, urban living promotes more resource intensive lifestyles which leads to overconsumption and centralized waste production (Hoff, 2011). The absence of productive landscapes within these metropolitan areas, has created a dependence on their hinterlands for the processing of waste and the provision of food, energy, and water (Hoff, 2011). Concurrently, freshwater resources, fossil fuels and arable land in these hinterlands are becoming increasingly scarce (Lehmann, 2018). As a result of the linear nature of processes in society, concerns arise that critical thresholds within the capacity at all scales of our ecosystem services will be crossed (Hoff, 2011). Eventually this will force us to a point where we exceed our planetary limits and we can no longer meet our demand in food, energy, and water (Steffen et al., 2015). Establishing a circular urban metabolism and associated sustainable FEW systems is essential to sustain our way of living within metropolitan areas and elsewhere (Lehmann, 2018). Yet even in developed countries, governments and urban utility sectors are in a constant battle with nature to keep providing food, energy, and water in a way that is sustainable, stable and of high-quality (Romero-Lankao et al., 2017). Nexus thinking enables me to think across sectors and thus provides an approach that can reduce trade-offs and build synergies in food, energy, and water systems (Hoff, 2011). The aim of the food, energy, and water Nexus is to "improve system efficiency, pursue sustainability and increase system performance through a holistic understanding and management of resources" (Cai et al., 2018 p.6).

Amsterdam is a city with great potential for adopting sustainable practices within its urban fabric, due to its innovative character and ambitious sustainability goals. In their circular strategy, the municipality of Amsterdam describes there aim to halve the use of raw materials by 2030 and achieve a full circular economy by 2050 (Circle Economy & City of Amsterdam, 2020). In the South-East of Amsterdam, a former prison site will be redeveloped into a neighborhood with sustainability, health, and happiness as core values. The Bajeskwartier, as it is named, aims to be an exemplary neighborhood for healthy and happy living. Moreover, a strong focus on circular economy principles can be identified from its masterplan. Circular material use, zero-waste and smart energy systems are three of its seven design pillars (Bajes Kwartier Ontwikkeling, 2020, June).

1.3 Problem Statement

Secure and sustainable food, energy, and water provisions are essential for creating sustainable urban communities. However, resource scarcity, changing climates and unsustainable consumptive practices jeopardize food, energy, and water security. Local production and sustainable production of food, energy, and water resources can be part of the solution for regaining this security. The Green Tower in Amsterdam offers the opportunity to become a sustainability hub that can improve food, energy, and water security for its neighborhood. However, the shortcomings in the design from a FEW Nexus perspective, can be accounted for by the lack of knowledge available on creating a sustainability hub tackling all three food, energy, and water resources in general. This lack of understanding will potentially result in a sub-optimal design for the Green Tower. This study will aim to improve this understanding, to help the designers of the Green Tower, and possibly the design of other sustainability hubs in the future.

1.4 Research Objective

The objective of this thesis is to ***"create a tool that helps designers make more informed choices regarding the food, energy, and water systems in the concept phase of designing a sustainability hub, such as the Green Tower in Amsterdam***". The reason for this tool to be created is the lack knowledge on how food, energy, and water systems in sustainability hubs operate and relate to one another. The tool consists of two components: (1) a system diagram that visualizes the food, energy, and water systems of the sustainability hub and their realized and unrealized relations, (2) a quantitative model that calculates the food, energy, and water balances of the sustainability hub based on a scalable spatial program.

The objective has led to the formulation of the following main research question:

> **MRQ**: How can we make the relations between food, energy, and water systems of a sustainability hub easier to understand for designers?

For this main research question to be answered, four sub research questions have been formulated:

> **RQ1**: What are the strengths and weaknesses of the current design of the Green Tower from a FEW-Nexus perspective, and who designed it?
>
> **RQ2**: How can the food, energy, and water ecosystem and the interrelations of its components of the Green Tower be best displayed?
>
> **RQ3**: How can food, energy, and water flows be captured in a quantitative model for a sustainability hub?
>
> **RQ4**: How do the outcomes of the created tool influence the decision making of stakeholders in the Green Tower project?

1.5 Context: Bajeskwartier and Green Tower

From Bijlmer Bajes to Bajeskwartier

In 2017, the consortium of AM, AT Capital and Cairn commissioned the architectural firms FABRICations, OMA, and LOLA Landscape to create a Masterplan for the 7,5-hectare former prison grounds (Ritzen, 2016). The central theme of the Masterplan is the 'healthy urbanism' framework (Bajes Kwartier Ontwikkeling, 2020, June). The Healthy Urbanism framework advocates the need to see health and sustainability as interrelated concepts in urban development and planning. Sustainability, equity, and inclusiveness are the three core principles of healthy urbanism (Pineo, 2020).

The prison grounds are located one-kilometer South-East of one of Amsterdam's largest train station, the Amstel Station. The Bajeskwartier's location has a rich cultural heritage, as the neighborhood will be built on the grounds of the former 'Bijlmer Bajes' prison. The prison was one of the most notorious prisons of the Netherlands, where many infamous criminals had been imprisoned. The prison was operable between 1978 and 2016. After it closed, the Municipality of Amsterdam repurposed the area to be transformed into a residential area. The municipality of Amsterdam set out a closed tender for the redevelopment of this area. The location was 7,5 hectares and offered space for 135.000 m2 floor area, of which at least 70% should become housing. Five plans were submitted, all included a strong focus on mixed housing, green space, and sustainability, were car-free, and reused the main building of the Bijlmer Bajes (Rijksvastgoedbedrijf, 2020). The tender was a closed tender, meaning that the municipality pre-selected parties which were allowed to bring out a plan and bid. For these types of tenders, the selection procedure is often not made public. Therefore, the criteria on which the Bajeskwartier masterplan has been accepted are unknown. A consortium of AM, AT Capital and Cairn won the tender and acquired the site from the Municipality of Amsterdam for 84 million euros (Dekker, 2017).

Spatially, The Bajeskwartier is divided in three sections: 'Woonkwartier', 'Designkwartier' and 'Kenniskwartier' (figure 1). The 'Woonkwartier' (trans. Living District) is the section that will support living. About 1350 homes will be built in seven living towers. Approximately 400 homes are allocated to social housing, the remaining homes will be available for private rental or as purchasable housing. The houses will be built in seven living towers. Healthy living is promoted through the availability of organic food markets and a health center. The Living District is divided in the Central District and the Amstel District. The 'Designkwartier' (trans. Design District) is situated in the heart of the neighborhood. It will function as a creative center where art, design, food, and sustainable initiatives come together. This creative heart also harbors the Green Tower, where resource flows of all three quarters will be connected. The 'Kenniskwartier' (trans. Learning District) is the knowledge center of the neighborhood. The area contains temporary housing for students, a high school, and a living lab. The knowledge created and shared in this area will be focused on healthy and happy living (AM BV, n.d.).

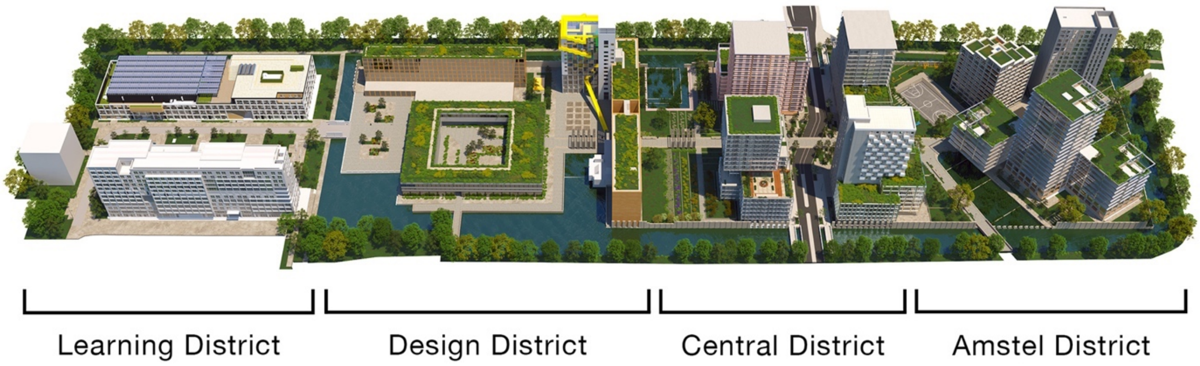


Figure 1: A render of the Bajeskwartier neighborhood, and its Learning District, Design District, and Living District (Central District + Amstel District). At the right top of the Design District, the Green Tower can be spotted by its external yellow staircase (AM BV., n.d.).

Sustainability and health in the Bajeskwartier

The two main goals of the Bajeskwartier masterplan, becoming climate neutral and supporting citizens in living a healthy life, are to be achieved through seven key design elements: Smart Electricity Grid, Thermal Grid, Circular Material use, Waste Cycles, Green-Blue networks, Healthy Urban Living and Sustainable Mobility. Both the design elements 'Waste Cycles' and 'Healthy Urban Living', have a strong focus on producing food locally from organic waste, and making it available to the public. The first step in becoming climate neutral has been taken in the demolition phase of the former prison grounds. All demolition waste from the former prison grounds has been sorted and stored locally. 98% of this material will be used in the development of the Bajeskwartier. Most material is used as underground filler for roads. Other iconic elements will be visibly repurposed, for instance some old prison doors will be used as rails for pedestrian bridges (Bajes Kwartier Ontwikkeling, 2020, June).

The transformation of a former prison tower to the Green Tower

The 16-story high former prison tower will become both the iconic centerpiece and functional heart of the neighborhood. An educational route that leads through the building will educate its visitor on the sustainable practices implemented in the Green Tower and the Bajeskwartier neighborhood. The tower will function as a hub where various resources are sustainably generated, recycled, or distributed: organic waste from the Bajeskwartier neighborhood will be transported to the tower and processed by a bio-digester, food will be produced in a vertical farm inside the tower, rainwater will be collected, and heat and electricity will be generated and stored or used. The generated or recycled resources will be locally used in the Green Tower, or in the Bajeskwartier neighborhood. Moreover, the building will include a semi-indoor vertical park, sports facilities, and room to display the sustainable practices to its visitors (Bajes Kwartier Ontwikkeling, 2020, June).

The Green Tower project (figure 2) has sky-high ambitions in improving the Bajeskwartier's technical (e.g., bio-digesting organic waste locally) and social (e.g., citizen's dedication to separating organic waste) sustainability. Three major stakeholders, BKO, FABRICations and AMS Institute, partake in the development of the Green Tower that operate from a design, research, and area development perspective. It appears that all ingredients for developing a successful neighborhood sustainability hub are there. However, designing such a multi-faceted sustainability hub is unknown territory for all stakeholders, and even worldwide there is little practical knowledge on this topic. A hub where food, energy, water, and people come together and resources are sustainably generated or recycled in a single location, creates a complicated system where many relations can be drawn.

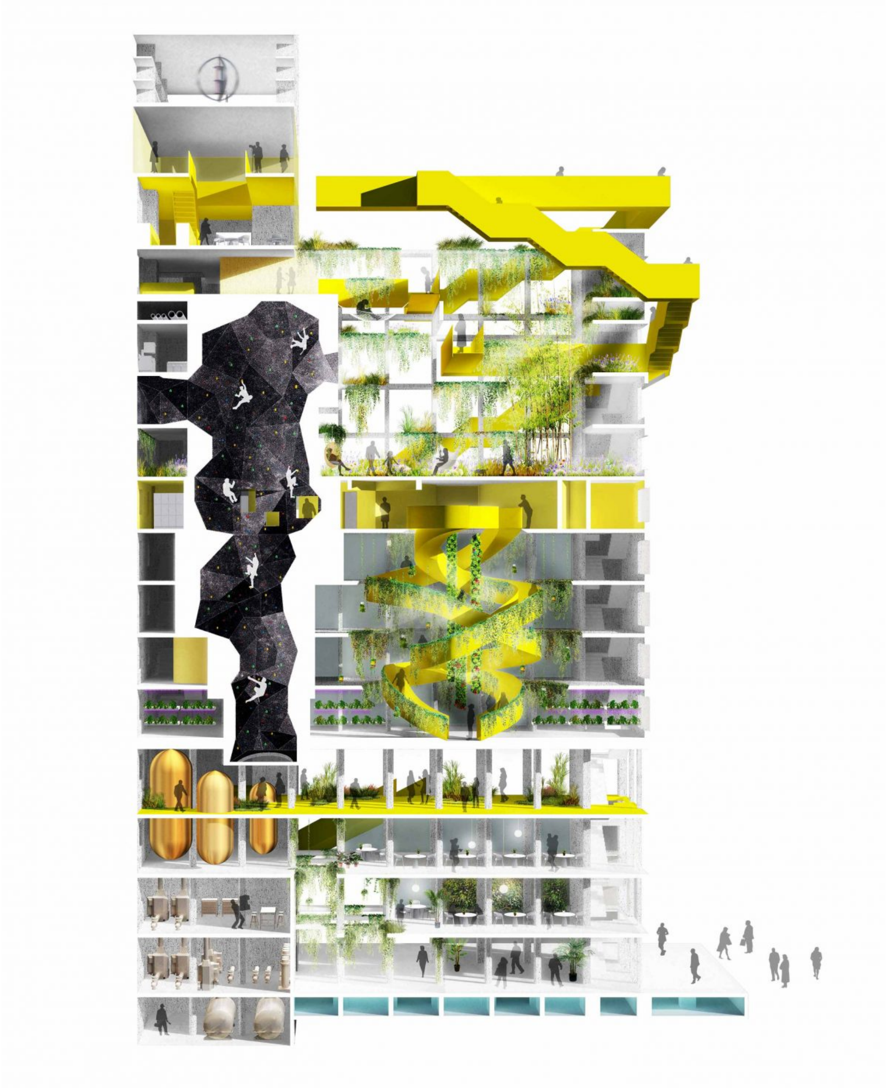


Figure 2: Internal render of the Green Tower showcasing some of its functions such as a climbing facility, vertical city park and bio-digester (FABRICations, 2018)

1.5 Structure of This Thesis

The remainder of this thesis will be structured by the following Chapters. Firstly, in Chapter 2 the theoretical foundation for this thesis is elaborated upon: *circular urban metabolism*, *circularity* and *FEW Nexus thinking*. These theories help understand the importance of: (i) creating circular resource loops, (ii) the circularity framework to operate within, and (iii) of looking at the interrelations between food, energy, and water systems. After that, in Chapter 3, the methodological basis used to answer the main research question and the four sub research questions is explained. Firstly, design thinking is introduced as overarching approach to answer the main research question. Second, it is explained how the stakeholder relation mapping was done and how SWOT analyses were executed to identify the strengths and weaknesses for all systems planned in the Green Tower. Third, the use of unstructured co-design sessions to create a visualization of the food, energy, and water ecosystem is highlighted. Then, it is explained which steps are taken to develop the quantitative model used to calculate the food, energy, and water balances. Last, the design of the focus group is elaborated upon. In Chapter 4 the results are presented. This Chapter describes both the results of the thesis and elaborates on the process coupled to getting the results. First, in Chapter 4.1, the stakeholder analysis, stakeholder relation mapping, and the SWOT analyses of the Green Tower's systems are presented. Then, in Chapter 4.2, the co-designed system diagram and theoretical model are given. After that, in Chapter 4.3, the quantitative model and its tabs, calculations, and dashboard are presented. Moreover, the results derived from the quantitative model regarding the food, energy, and water balances of the current design of the Green Tower are given. At last, in Chapter 4.4, the results of the hosted focus group are analyzed. In Chapter 5, the most important findings are concluded upon, and the main research question is answered. Afterwards in the reflection, in Chapter 6, the applied research methods are discussed, the results are reflected upon and recommendation for further research are given. In the final chapter, Chapter 7, recommendations are given to further develop the food, energy, and water sustainability hub tool.

1.6 Abbreviations

Before diving into the research, I will describe the abbreviations used in this thesis. From here on, these abbreviations will be used.

Abbreviations

FEW	Food, energy, and water
GT	Green Tower
BK	Bajeskwartier
ATES	Aquifer Thermal Energy Storage

2. Theoretical framework

2.1 From a Linear to Circular Metabolism

Just like a living organism, a city consumes resources to grow and flourish. However, traditionally this process of consuming also generates effluents, known to us as 'waste' (Wolman, 1965). This process is commonly referred to as the 'urban metabolism'. Understanding urban metabolisms is believed to be fundamental to developing sustainable urban areas (Kennedy et al., 2011). Research into urban metabolism is often focused on the quantification of inputs, outputs and storage of energy, water, nutrients, materials, and wastes (Kalmykova & Rosado, 2015).

The situation where no links are made between the input of resources and the output of waste within a city is referred to as a linear urban metabolism (Van Broekhoven & Vernay, 2018). At present, most cities have a linear metabolism making them completely dependent on their hinterlands for the supply of resources and the disposal of waste. This dependence makes cities vulnerable while also impairing the global rural 'hinterland' (Brunner, 2007). A situation where a city's outputs are cycled back into the system as inputs is regarded to as a circular urban metabolism (figure 3). By closing loops within the urban area, the pressure on hinterlands lightens and the impact on their environmental systems are reduced (Van Broekhoven & Vernay, 2018).

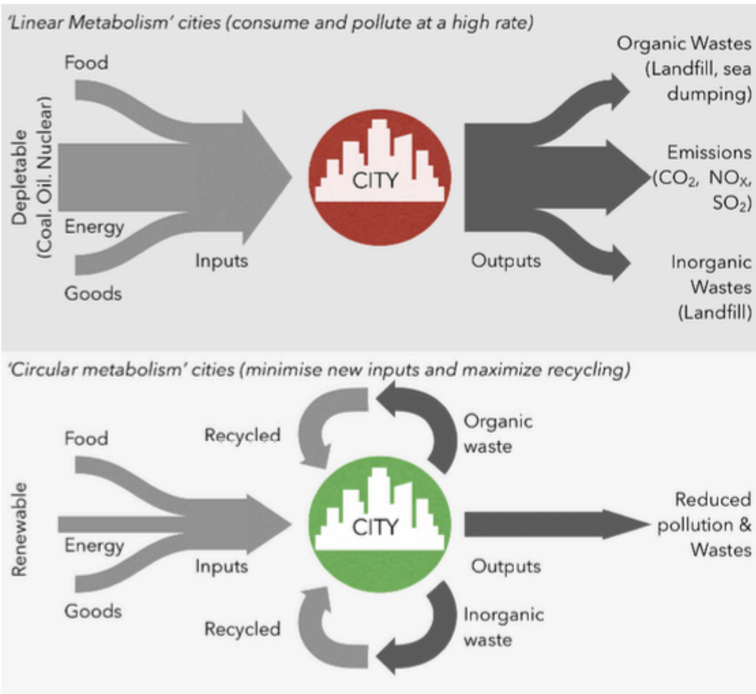


Figure 3: A linear metabolism versus a circular metabolism (Doughty & Hammond, 2004).

2.2 Amsterdam City Doughnut

The city of Amsterdam aims to be completely circular by 2050. The city wants to be a 'thriving and equitable city' that operates 'within the Earth's natural boundaries' (Circle Economy & City of Amsterdam, 2020). To do so, the city has adopted a circular economy strategy. The strategy mainly advocates limiting the use of (raw) materials across sectors. Ideally, all materials that currently are present in the system should be reused and recycled indefinitely. Meaning that the value of these materials should be retained throughout its lifecycles. Amsterdam aims to achieve this by for instance using the ladder of circularity (figure 4). Firstly, the use of materials should be refused, rethought, and reduced, leading to a decreased use of harmful materials and materials in general. Secondly, products should be reused, repaired, refurbished, and remanufactured to prolong their lifecycle. As last resort, a product should be repurposed, recycled, or recovered. Meaning its materials are used again elsewhere. As a last resort, a material can be incinerated to recover its energy. Through their circular strategy, Amsterdam aims to halve the use of raw materials by 2030 and achieve a full circular economy by 2050 (Circle Economy & City of Amsterdam, 2020).

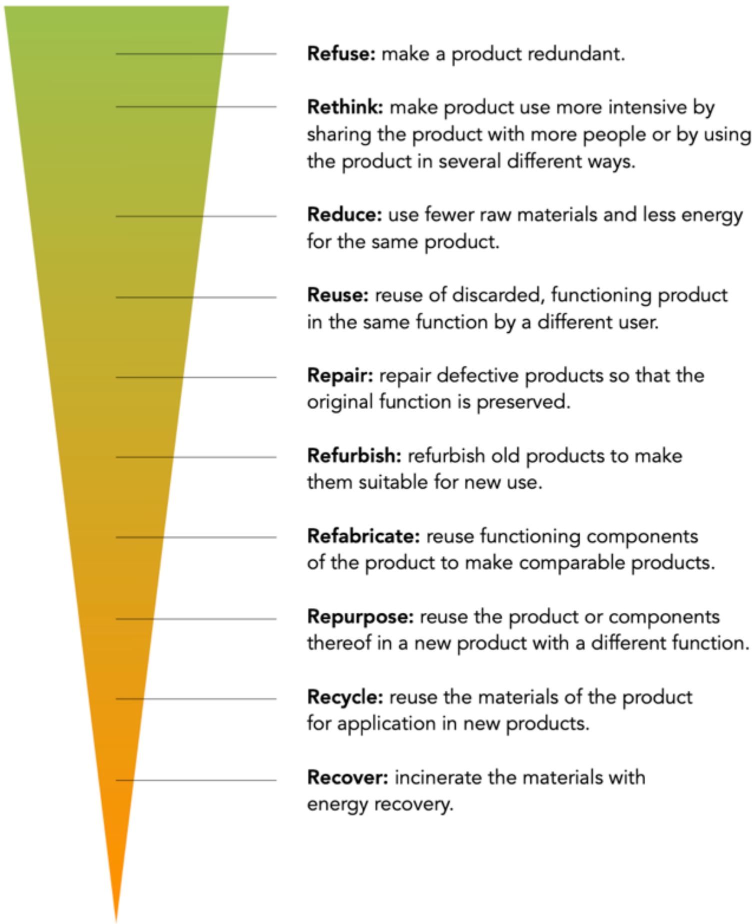


Figure 4: the ladder of circularity as adopted by the Municipality of Amsterdam in their circularity strategy. The ladder of circularity shows which processing options are preferable to others (Circle Economy & City of Amsterdam, 2020).

The circular strategy of Amsterdam incorporates the Amsterdam City Doughnut, developed by the Kate Raworth, who developed the Doughnut Economics framework. In the Amsterdam City Doughnut (figure 5), the Doughnut Economics framework has been turned into a tool for transformative action. The doughnut economics framework addresses an ecological ceiling and social foundation that should help humankind to develop sustainable economics (Raworth, 2020). The ecological ceiling is defined by the nine planetary boundaries that were defined by Rockström et al. (2019): ozone layer depletion, ocean acidification, nitrogen and phosphorus loading, chemical pollution, freshwater depletion, land conversion, air pollution, climate change and biodiversity loss. Social needs are indicated by access to energy, water, food, health, education, income & work, peace & justice, political voice, social equity, gender equality, housing, and networks. These indicators are measured by for example undernourishment, life expectancy, illiteracy and so on. In the dynamic balance between the ecological ceiling and social foundation humankind can thrive in an environmentally safe and socially just space (Raworth, 2017). In Amsterdam, the framework will guide city stakeholders in asking themselves the question: "How can Amsterdam be a home to thriving people, in a thriving place, while respecting the wellbeing of all people, and the health of the whole planet?" (Raworth, 2020). One of the goals of the strategy, is to reduce food waste with 50% by 2030 (Wray, 2020)

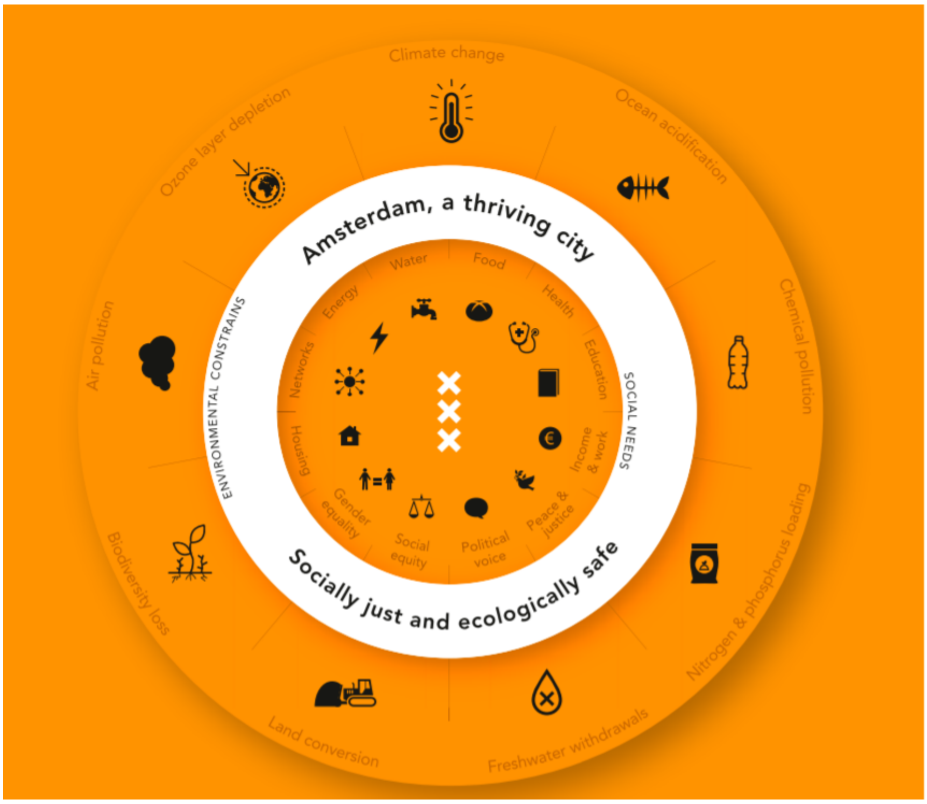


Figure 5: The Amsterdam City Doughnut, as developed by Kate Raworth for the Municipality of Amsterdam (Wray, 2020)

2.3 Food, Energy, and Water

FEW are essential for survival and securing an efficient supply of them is crucial for preserving a sustainable society. Securing adequate quantities and qualities of FEW can be challenging in developing countries (Hoff, 2011; Roggema & Yan, 2019). In general, in developing countries poor utility infrastructure and unequal access due to geographic and economic factors causes this deficiency. Concurrently, humanity is reaching its limits in global resource availability and faces the risk of crossing crucial environmental thresholds (Hoff, 2011). On the contrary, most citizens of developed countries see FEW as a given and allocate a relatively small amount of their interest and income to them. This security in FEW is supported by governmental economic and political systems, providing FEW as public goods rather than private commodities. Parties producing and distributing FEW are often heavily subsidized, and policies safeguard the quality and accessibility of FEW resources. Yet, in these countries governments and urban utility sectors are in a constant battle to keep providing these services in a way that is sustainable, stable and of high-quality (Romero-Lankao et al., 2017). The main reasons for this battle are the increasing scarcity of resources used for providing FEW, climate change induced extreme weather events such as droughts and flooding which can impact the supply of FEW, and the contamination of FEW sources.

2.4 Nexus thinking and FEW governance

2.4.1 Nexus thinking and FEW resources

In recent years, the interconnectedness of FEW has been increasingly extensively researched and has become increasingly evident (Avgoustaki & Xydis, 2020, -a; Roggema & Yan, 2019; Hoff, 2011). A Nexus approach (figure 6) integrates FEW management and governance across sectors and scales. Moreover, Nexus thinking is about improving efficiency in the use of FEW resources and land by understanding their interrelations (Hoff, 2011). FEW systems are usually dealt with as being separate sectors. Yet, literature and practice show that FEW systems can have both trade-offs and synergistic effects with one another (Vogt et al., 2012). Nexus thinking enables cross-sectoral thinking and thus provides an approach that can reduce trade-offs and build synergies in FEW systems (Hoff, 2011). Acknowledging the interconnectedness of FEW and the importance of Nexus thinking in approaching FEW challenges is referred to as the FEW Nexus (Roggema & Yan, 2019). The aim of the FEW Nexus is to "improve system efficiency, pursue sustainability and increase system performance through holistic understanding and management of resources" (Cai et al., 2018 p.6).

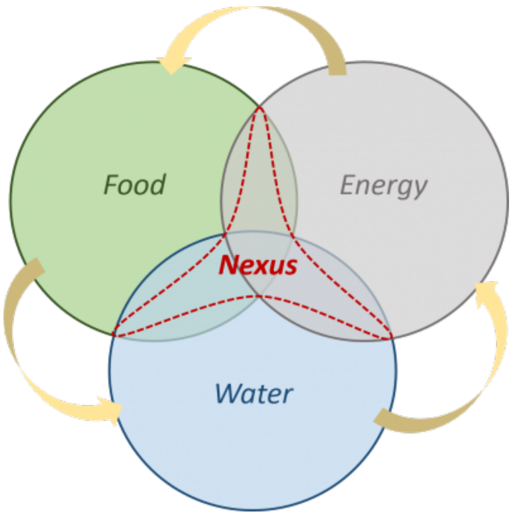


Figure 6: The Nexus approach to food, energy, and water is about understanding their mutual relations (SESYNC, 2018).

Over the past decades, tremendous effort has been put in eradicating hunger and meeting the food demand of a growing global population. Global agricultural production has more than doubled since 1960 (FAO., 2021). The increase in productivity has been achieved through agricultural intensification and agricultural land expansion, requiring an absolute increase of nutrient, water, and energy input (Foley et al., 2011; Hoff, 2011). Moreover, there is an enormous gap in energy use per capita between developing and developed countries. Increased energy consumption goes hand in hand with growing prosperity, showing that global energy consumption is far from its peak. Most energy is currently derived from non-renewable resources, mainly fossil-fuels. Other renewable resources for energy production, amount up to less than 20% of global energy production. While posing a sustainable and in theory inexhaustible source of energy, renewable energy production often causes negative externalities on the water and food sector through for instance hydropower and biofuels (Hoff, 2011). Which points to the need for Nexus thinking. A secure water supply is vital in sustaining a healthy and prosperous society. Water is a renewable resource and in theory there is plenty water available to support humanity. Yet, in practice only a very small percentage of this water supply is available for human use. At present, demand even outpaces supply leading to water scarcities around the globe. In the water sector a difference can be made between green and blue water, and consumptive and non-consumptive water use. Green water is water that comes directly from rainfall and supports the growth of natural plants and agricultural crops. Blue water is the water present in lakes, rivers, and aquifers. This water is often extracted for agricultural use, municipal use, industrial use, and other uses. Consumptive use of water is the situation where water is extracted, used, and not returned to its source by means of for instance evapotranspiration in agriculture. If water is returned to its sources without changed properties (chemically or thermally) it can be regarded to as non-consumptive use (Hoff, 2011). Many of the previously mentioned challenges in the supply of FEW are based on productionist thinking: producing more is the solution to solving deficiencies in FEW. However, from a Nexus perspective it is assumed that plenty FEW resources are available and the crux lays in using them efficiently to secure them four future generations.

2.4.2 Nexus thinking and FEW governance

Throughout their lifecycle (production, distribution, consumption & waste treatment) FEW are operated in separate sectors. As currently organized, the interlinkages between FEW sectors are not beneficial and typically even exhaust one another (Roggema & Yan, 2019). Firstly, about 80-90% of consumptive blue water is used by the agricultural sector, making it the largest water consumer by far. In reverse, food production can impact groundwater recharge and run-off while also affecting water quality of sources nearby, limiting fresh water sources. Secondly, in energy production water is used for the extraction of fossil fuels and growing crops for biofuel. Thirdly, water itself requires energy to be transported and treated. Fresh water reclaimed from municipal wastewater requires twice the energy of treating local surface water for consumption. Even more energy consuming is the desalination of seawater, which requires about tenfold the energy required for treating blue water. Moreover, pumping water, especially at great depths, is a highly energy consumptive practice. Lastly, the mechanization of food production and transportation causes the food sector to consume increasing amounts of energy. The full production process of food is estimated to consume about 30% of global energy demand (Hoff, 2011). Acknowledging and acting upon the interlinkages between FEW systems is essential to creating sustainable FEW systems.

But why are FEW sectors governed and managed independently, if their interwovenness is so evident? During the industrial revolution, the economic center of gravity shifted from rural to urban areas. As industrial activities flourished more wealth accumulated within these areas. To cope with the resource demand and waste generation in these densely populated urban areas, centralized systems for resource production, distribution and processing were developed (Roggema & Yan, 2019; Hang et al., 2016). For example, the remnant of the centralization of water production, distribution, and processing in Amsterdam, is the water authority 'Waternet'. Waternet is responsible for almost all water related topics: wastewater treatment, dike reinforcement, groundwater levels, purification of drinking water, maintaining the sewage, cleaning of water bodies and even servicing the bridges and sluices (Waternet, n.d.-b). Whilst being very efficient and robust, these systems are designed to provide in their own sector and often make large trade-offs regarding other sectors. The vast infrastructure installed for these centralized resource systems required enormous investments to be developed based on longevity. Due to the high sunk costs in these systems, altering their functioning is not economically feasible. Moreover, governance structures are very hard to change, since they are largely based on the sectoral and centralized nature of these systems (Roggema & Yan, 2019; Hang et al., 2016).

Creating local production systems pose a way out of these centralized systems and offer the ability to again connect various resource systems. Moreover, local production systems allow the ability to adapt technologies to local conditions to improve resource efficiency (Hang et al., 2016). Local production systems are advancing in urban areas. Alternative food networks, more localized food distribution networks (Whatmore et al., 2003) and urban agriculture focus on providing healthy and sustainable food. The negative externalities of large-scale farming operations, such as ecosystem degradation, eutrophication and groundwater depletion are often avoided in these localized alternatives. Decentralized energy systems making use of smart grids, such as cooperative net zero energy communities, are being established to provide stable and balanced local energy systems (Lopes et al., 2016). There are even examples of decentralized water systems, such as 'Waterschoon' in Sneek, the Netherlands. This decentralized system provides wastewater and organic waste treatment within a neighborhood. The system also generates renewable energy for the neighborhood and phosphate for local agriculture. Moreover, it focusses on minimizing fresh water use for the 550 residents coupled to the system (Graaf & Hell, 2014). However, it should be noted that a local system is not explicitly a system that improves sustainability from a Nexus perspective, as it is not a given that they consider all FEW domains. Operating local systems does usually give more flexibility to adapt and change components to benefit FEW.

2.5 FEW as Wicked Problem

Research in the FEW Nexus is mainly focused on how FEW resources can be securely supplied under a growing global demand. Only few studies investigate the design of solutions on the consumer and thus urban side of the context. In urban areas, local governments view issues in the sustainability of food, energy, or water resources as problems that should be solved within their own sector. This leads to the development of solutions that are limited to the food, energy, or water sector, such as smart-energy grids (Roggema & Yan, 2019). Research into the nature of food, energy, or water issues in metropolitan areas through a Nexus approach concluded that FEW issues in cities have a multifaceted nature. Apart from FEW issues being resource related, the research concluded that it is an issue of land use, resilience, and quality of life (Urban Nexus, 2013a; Urban Nexus, 2013b; Urban Nexus, 2013c). This makes FEW related issues a wicked problem (Roggema & Yan, 2019).

2.6 Synthesizing the theories

The concept of the circular urban metabolism presses the importance of looping resources within the city, to lighten the pressure on hinterlands. Cities should minimize their intake of raw resources and minimize their effluents. For me, it helps strengthen the concept of a neighborhood circularity hub, that support resource flows to be looped within the neighborhood. However, local, and circular flows, are not per definition sustainable. The circular economy provides a model that aims to help create loops in resources, from a social and economic point of view. The circular strategy of Amsterdam moves beyond just creating loops, as it also incorporates the ladder of circularity, in which circular practices are prioritized by the circular value they offer. Yet, the economic model seems to predominantly focus on products and prolonging their lifecycle. The doughnut economy provides a way to think about the circular economy as a model that could help us as society thrive, while maintaining a balance between social and ecological needs. The Amsterdam City Doughnut also focusses on FEW, among other resources. However, both the circular urban metabolism and Amsterdam City Doughnut lack understanding of the trade-offs among FEW systems.

Nexus thinking can function as glue that addresses the important interrelations between FEW resources for all types of systems. It helps me think about real sustainability, where not only the circularity of one flow of a system is considered, but also the effect of the system on other flows. For example, biofuels are often regarded to as a sustainable and renewable energy source. However, the production of biofuels requires vast amounts of water, land, and nutrients. Moreover, harvesting and transporting them requires energy. Therefore, the use of biofuels induces many trade-offs in FEW, making it a less preferable option. In this research, these theories are used to give guidance in looking at circularity and FEW related systems. By providing local production, distribution and processing of FEW resources, the GT can contribute to creating a circular urban metabolism for the Municipality of Amsterdam and BK neighborhood. The local processing of waste flows fits within the ideals of a doughnut economy. By including Nexus thinking, potentially a real sustainable urban system can be created, minimizing trade-offs among FEW.

3. Methodology

The findings of this thesis were derived from five research methods: (i) studying of literature, (ii) SWOT-analysis, (iii) unstructured co-design sessions, (iv) prototyping, and a (v) focus group. The overall structure of the research closely resembles the research method: design thinking. Design thinking involves six phases: (i) understand, (ii) observe, (iii) synthesize, (iv) ideate, (v) protype and (vi) test. This chapter describes, and justifies the methods applied and links the steps taken in this research, to the phases of design thinking. The research methods applied will be discussed per research question, as some research methods are tailored and combined to answer a single research question. The process of answering the research questions is also seen as a result, so this chapter will not describe every choice made and step taken, only the methodologic basis or idea behind it. The process will be largely presented in the results and reflection. Before describing the approach to each research question, the overarching approach to this this study and its relation to design thinking is explained. This overarching approach and research method are applied to answer the main research question.

3.1 MRQ: Design Thinking

MRQ: How can we make the relations between food, energy, and water systems of a sustainability hub easier to understand for designers?

3.1.1 Design thinking, how to use it

The problem we are dealing with in this study is a wicked problem. As described in the theoretical framework, wicked problems are usually problems that involve several stakeholders, with different interests and most likely various solutions. Wicked problems are difficult to solve, and holistic solutions are required to do so (Jobst & Meinel, 2014). The FEW resources flowing through GT also pose a wicked problem, as there is no one solution to the balances that can be created. There will not be one mathematical solution to problem, so there is no perfect balance. The solution depends on the specific sustainability goals of the project, which are volatile and largely undefined. Therefore, a flexible approach to the problem is required, and the result of the study also needs to be flexible. Design thinking is an approach that offers this flexible approach to a wicked problem (Jobst & Meinel, 2014).

3.1.2 The overarching approach

The design thinking process is composed of six steps: 1) understand, 2) observe, 3) synthesize, 4) ideate, 5) prototype, 6) test (Jobst & Meinel, 2014). The first step, understand, is handled in research question 1. The goal of this first research step is to understand what stakeholders are involved, how the stakeholders are related, what the current design of the GT is, and what strengths and weaknesses this design has from a FEW Nexus perspective. The second step, observe, was executed throughout the study. During stakeholder meetings, self-organized sessions and 1-on-1 meetings with stakeholders, many aspects of the GT project have been observed. The synthesis has been done by creating a system diagram of the GT, where all resource flows come together, and connections are made. The synthesis step also included the ideation for the end-product, in the co-design sessions both the system diagram and quantitative model were discussed. Next, a prototype of the quantitative part of the design tool has been made. The last step in this thesis, includes testing the design tool among the most important stakeholders in the GT design.

3.1.3 Software use

Three software programs have been of such importance throughout this thesis, that they require to be described: MIRO, Microsoft Excel, and ZOOM.

MIRO

MIRO is an online collaborative whiteboard platform. It enables teams to remotely, or cumulatively, collaborate and communicate using various formats and tools. Various board can be created in which invitees, with or without an account can contribute. MIRO has been of great use in the pandemic, serving as platform where teams can still collaborate in a creative setting (MIRO, 2021). It can be utilized through: https://miro.com.

Microsoft Excel

Microsoft Excel is a spreadsheet program from Microsoft, and part of the software package Microsoft Office. It can be downloaded on Windows and MacOS. Microsoft Excel is the market leader in spreadsheet software.

ZOOM

A video communications platform. Used to host meetings and collaborative sessions. It allows participants to share their screen, talk, chat, and record sessions.

3.2 RQ 1: Understand: SWOT-analysis & Literature Study

RQ1: What are the strengths and weaknesses of the current design of the Green Tower from a FEW-Nexus perspective, and who designed it?

3.2.1 Overview

This research question was tackled using two steps. First a qualitative analysis was conducted of the primary stakeholders involved in the design of the Green Tower. Their type of involvement and the power relations among stakeholders were highlighted. Second, the progress report of the BK neighborhood and Green Tower was analyzed from a FEW Nexus perspective and combined in a SWOT-analysis per FEW system of the Green Tower. The methods used and results generated with this step, formulate the '*understand'* step in design thinking, the first step in a design thinking process.

3.2.2 Research methods

Literature study

The purpose of a literature study is to critically analyze literature focused on a certain body of knowledge. A literature study commonly exists of the following four steps: 1) literature search, 2) detailed review of selected research documents, 3) writing up on the identified data, 4) putting your research in the perspective of identified data (Jørgensen, n.d.). This literature study makes use of secondary data. Data becomes secondary data, when the data is used for a different purpose than it was initially collected for (Hox & Boeije, 2005). In a secondary data source, primary data such as surveys, experiments or designs are already interpreted by the author and presented in an easily understandable manner.

SWOT analysis

A SWOT-analysis is the process of identifying and analyzing the strengths, weaknesses, opportunities, and threats, collectively known as "SWOTs". The process of a SWOT analysis exists of 1) identifying internal and external inhibitors and enhancers of performance, 2) analyze these factors on how they can contribute or obstruct the analyzed project, and 3) decide upon the required next steps based on the analyzed factors (Leigh, 2010). Below the meaning of the SWOTS is elaborated upon. Value is defined in its broadest sense, thus any type of value (social, environmental, economic, scientific, etc.).

Strength	Internal enhancer, valuable resource, or valuable attribute that increases value
Weakness	Internal inhibitor, resource, or attribute that decreases value
Opportunity	External enhancer, resource, or attribute that can be pursued to gain value
Threat	External inhibitor, resource, or attribute with the potential to reduce value

SWOTs are often depicted in a two-by-two matrix, such as figure 7.

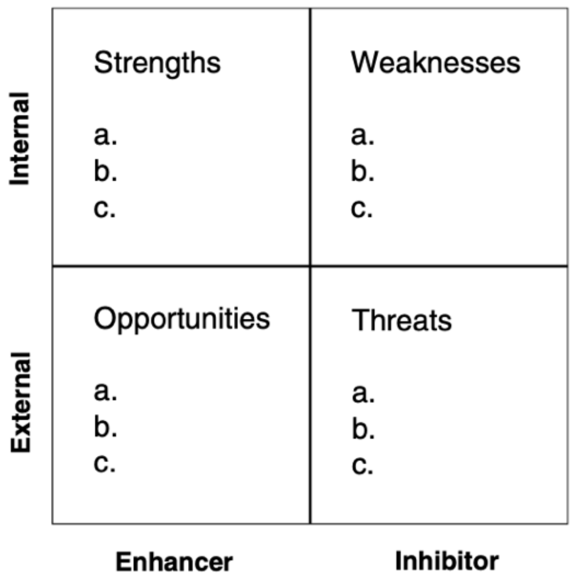


Figure 7: conventional 2-by-2 SWOT-table (Leigh, 2010)

3.2.3 Stakeholder analysis

A literature study was conducted to analyze stakeholder roles, ambitions, and relations. The literature study included the analysis of secondary data such as the progress report, stakeholder websites and news articles published about their involvement in the Green Tower project. The progress report (Bajes Kwartier Ontwikkeling, 2020, June), was provided by BKO, the main developer of the GT. The stakeholder websites and news articles have been searched upon through Google. The identity of the primary stakeholders was based on a combination of reading the progress report of the GT and BK, and informal conversations with members of the GT project team. It was decided to exclude future residents of the BK neighborhood and visitors of the GT as primary stakeholders, as they are not involved in the design of the GT. Naturally, they are a primary stakeholder and thus it could be argued that they should be part of the design process. However, the lack of understanding of who these residents will be results in excluding them in this part of the design process.

The two steps taken in the stakeholder analysis were executed as follows. First, the stakeholder descriptions were derived from accessing their websites, GT specific pages on their websites, and other online sources that included information of their involvement in the GT project. From the previously described sources, the organization structure of the GT project, individual stakeholder goals, and mutual project goals have been derived. Second, their relations have been mapped in a diagram, based on the power relation mapping (figure 8) of Bhattarai et al (2018). The mapping style has been slightly altered for this research. The relations used in this research were: indirect relation, purposive relation, and complementary relation. Moreover, the stakeholders have been categorized under developer, designer, researchers, and users. This mapping was then discussed.

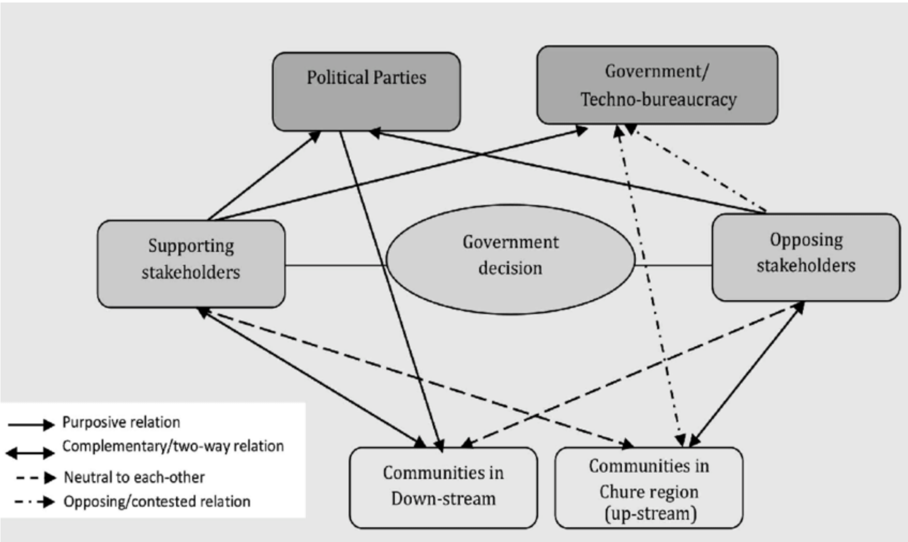


Figure 8: Stakeholders and Power-Relation Network in Chure Region. This mapping style (not the contents), served as basis for the power mapping of the stakeholders involved in designing the Green Tower (Bhattari et al., 2018).

3.2.4 Program analysis

The program of the GT was researched through a literature study and the results were mapped. The secondary data source used for the analysis of the program of the GT (i.e., the design of its components) was the progress report of the BK and GT (Bajes Kwartier Ontwikkeling, 2020, June). This progress report, written by BKO and FABRICations, is the latest version and describes the progress made in the design of the BK and GT. The identified systems had been subdivided in four ecosystems: Food and nutrients, energy, water, and experience and visitors. These four ecosystems were then further discussed, and their systems were explained based on additional secondary data sources, accessed through Google or Google Scholar. All systems in the program were then mapped in the online whiteboard tool, MIRO, to give an overview of all identified systems.

3.2.5 Strengths and weaknesses of the program

The program analysis of the GT served as basis for the identification of the SWOTs. For each in the program analysis identified (sub) system a separate SWOT analysis has been conducted. Afterwards, the SWOT analyses are discussed regarding their overarching ecosystem. Lastly, a summary is given where all analyses are brought together.

3.3 RQ 2: Observe & Synthesize: Prototyping & Unstructured Co-design Sessions

RQ2: How can the FEW eco-system and the interrelations of its components of the Green Tower be best displayed?

3.3.1 Overview

The first step in creating the FEW neighborhood sustainability hub design tool, is creating an overview of the overarching FEW-ecosystem of the GT and the interrelations between its components. This overview is the synthesis of all the FEW systems planned for the GT and the resource flows that these systems demand and/or supply. In multiple unstructured co-design sessions with two representatives of the GT project, an overview and visual representation of the FEW ecosystem of the Green Tower was created.

3.3.2 Research methods

Unstructured co-design sessions

Co-design is a form of creative cooperation between researchers, designers, developers and/or customers to collaboratively design a process or product (Steen et al., 2011). Sessions where many stakeholders are involved that adopt a co-design approach are shown to have strong impact on commitment and alignment among participants (Brandt, 2007). A collaborative work or project space is an important vehicle in creating the collaborative process (Buur & Bødker, 200). Moreover, co-design sessions have shown to hatch strong results in a very limited timeframe (Westerlund, 2007). Unstructured co-design sessions are co-design sessions for which no structure has been developed beforehand.

Literature study

Explained in 3.2.2

3.3.3 Resource flows

The resource flows of the systems of the GT program have been further researched upon, by means of a literature study. The described resource flows are food, nutrients, organic waste, heat, cold electricity, black wastewater, yellow wastewater, grey wastewater, rainwater, and drinking water. Secondary data sources have been used to write a synopsis on every resource flow. Mostly scientific papers have been accessed to gather this information. Each synopsis exists of a description on where the flow is used in the GT, followed by a description of the flow based on the literature. The description is quite general and serves as basis to specify the flows to the GT context later in the chapter.

3.3.4 Connecting FEW systems

A combination of a literature study and 1-on-1 co-design sessions, lead to the connection of the FEW-systems through the identified resource flows. The two 1-on-1 co-design sessions were held on the same day, with two representatives (figure 9) of the GT design team, through ZOOM. In the first session the connection between FEW-systems were made, together with a representative of AMS Institute. The second session was held with a representative of FABRICations and built further on the results of the first session. The sessions' goal was to "co-design three diagram representing the FEW systems of the GT and their connections". The sessions were hosted on ZOOM, and the co-design took place in MIRO. The results of the sessions were not documented in the form of a transcript or report, but the three MIRO boards, one for each FEW, were the end-result and report of the sessions.

Name	**Organization**	**Function**	**Function in GT project**
Aranka Dijkstra	AMS Institute	Program Developer Living Labs	Green Tower / Bajeskwartier Living Lab researcher
Stijn Riemen	FABRICations	Architecture intern	Intern (working on GT metabolism)

Figure 9: Attendees of 1-on-1 unstructured co-design sessions.

3.3.5 Visualizing FEW systems

After the FEW systems had been connected in three MIRO boards, the three boards were combined to one MIRO board. A first draft was made for how the FEW systems could be visualized in one diagram. Two co-design sessions were hosted through ZOOM with the same two participants as the previous Co-design session. The sessions' goals were to "co-design a diagram representing the FEW systems in the GT". The result of the sessions was the MIRO board, with a system diagram of the FEW systems of the GT and their interrelations, divided in users and transformers (further elaborated upon in the results section). A system diagram is a model that is used to understand a complex system by making a visual representation of the components and their dynamics of that system. In system thinking, creating a system diagram is the first step in understanding the complex relations among components and help to understand and manage the complex phenomena (Senge, 2006). The system diagram was simplified into a diagram representing the theoretical basis behind it. This diagram explains the relations between the main groups of systems and can be observed in the results.

3.4 RQ 3: Ideate & Prototype: Prototyping

RQ3: How can food, energy, and water flows be captured in a quantitative model for a sustainability hub?

3.4.1 Overview

The main product of this study is a quantitative model that calculates FEW resource balances for the GT. First, a clear goal was set for the model. Second, a workflow was determined for the quantitative model. Afterwards, all tabs and underlying calculations of the model were explained. The quantitative model, together with the previously created theoretical model, suffice as a prototype. As there is not one solution for creating a sustainable FEW ecosystem for the GT and the BK neighborhood, the prototype enables the confrontation between the designers and possible solutions.

3.4.2 Research methods

Prototyping

Prototyping is a term often used in software development. A prototype literally means 'the first of a type'. The prototype is a preliminary version of a product that has been made to exhibit all essential features of the final product and is to be used for testing. The testing can result in recommendations for further development or production (Floyd, 1984). Moreover, confronting users with a prototype creates the possibility to test the proposed solution and analyze the response of the users (Jobst & Meinel, 2014).

3.4.3 Defining model goal

Based on the information derived from the strengths and weaknesses of the GT and the visual representation of the FEW ecosystems of the GT, the goal for the quantitative model was defined. Before defining the goal, necessary information for defining the quantitative model goal is given. This information elaborates on the impossible task of 'creating resource balances' and the influence of 'space, users, and project goals' on the functioning of the model.

3.4.4 Defining model workflow

With the model workflow, the sequential order of steps taken in the quantitative model is meant. This includes the order in which the individual tabs of the model are built up, and how they relate. The workflow of the model was inspired by the "ZED Energy Tool TUD 2021 version 0.2.xlsx'. This zero-energy design (ZED) tool is used in the zero-energy design course at the architecture faculty of TU Delft and was provided by my supervisor Siebe Broersma. The tool shows the energy performance of a building in one dashboard. The dashboard shows information derived from multiple tabs that calculate for instance the electricity generation by PV-panels, heat and cold demand, stored energy of used materials, etc. The model workflow defined for the quantitative model made in this research, is composed of a dashboard, backed by three tabs in which the FEW flows are calculated, and multiple tabs in which the separate FEW systems are calculated (figure 10).

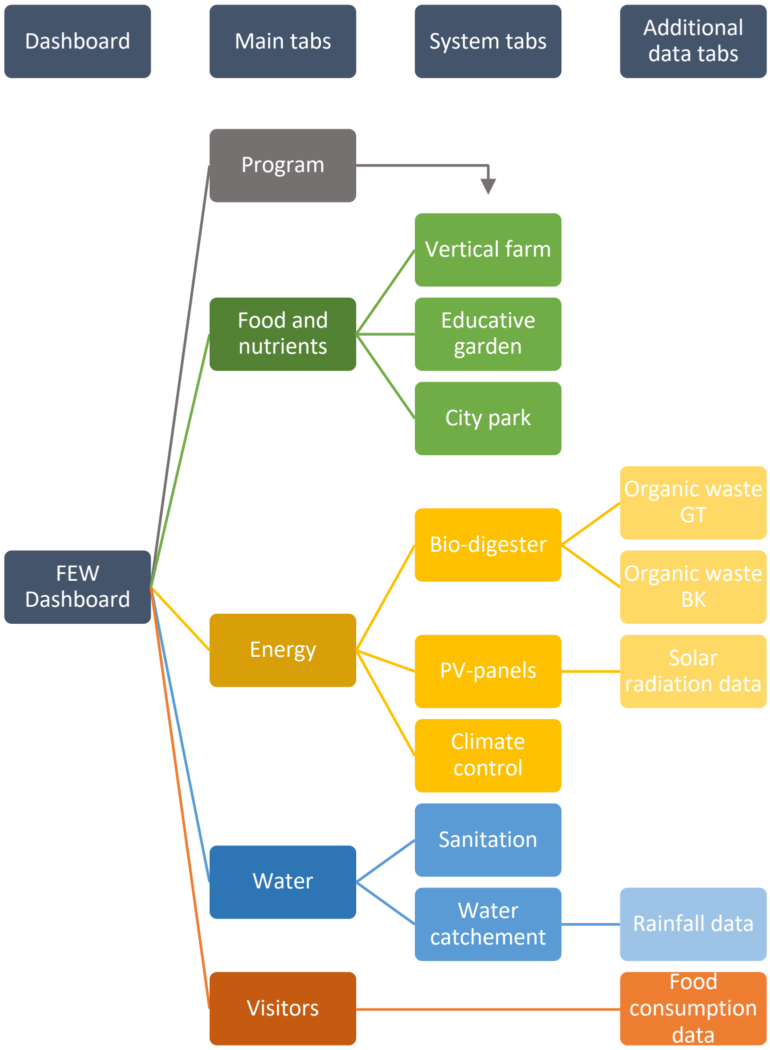


Figure 10: The defined workflow of the FEW sustainability hub quantitative model, used for making the model. It exists of a dashboard, connected to the main tabs, connected to system tabs, connected to additional data tabs. The program tab is also connected to all system tabs. All tabs can be found in the Excel file.

3.4.5 Developing system quantifications

The quantifications used in the quantitative model are mostly derived from secondary data sources. The sources are mentioned in the quantitative model and/or in the results section of this study. The quantifications themselves are mentioned in the results section. Some quantifications have been based on common sense. For instance, calculating the catchment capacity for precipitation of a roof, precipitation per m2 * roof m2, no sourcing is deemed to be required. Moreover, the results of the model, based on the floor plan inserted in the program tab is given per tab.

3.4.6 Creating model dashboard

A part of the prototype is the dashboard. The dashboard has been created based on my opinion on which elements are essential in the dashboard and how they can best be displayed. Whether this visualization method makes sense, will be reviewed in the testing phase. The dashboard can be observed in the results section. If time would have allowed it, an iteration of the model would have been made and the feedback on the dashboard would have been processed. However, due to time constraints, only one iteration has been done. Therefore, apart from reporting on the feedback, no actual changes were made to the dashboard after this session.

3.4.7 Feed Green Tower program

The latest version of the Green Tower program was provided on February 16, 2021. The new program differed from the program used in the previous step of this research. Therefore, the systems in the quantitative model differ from the systems of the synthesis on the FEW systems in the GT.

The final step of making the quantitative model, was testing if it would work. Therefore, the latest known program of the GT was inserted into the program tab of the quantitative model. The dashboard now showed the results of the model for the latest program.

3.5 RQ 4: Test: Focus Group

RQ4: How do the outcomes of the created tool influence the decision making of stakeholders in the Green Tower project?

3.5.1 Overview

The final step in this study was to test and evaluate the created tool. In this step, the tool is applied to the GT and its results are shared in a focus group. The focus group then discusses these results. The results are evaluated to see how the tool can influence the decision-making process of the design team, and how it can be improved to be of more value.

3.5.2 Research methods

Focus group

A focus group is a research technique that (i) collects data by hosting a (ii) group interaction on a (iii) topic defined by the researcher (Morgan, 1996). In a focus group, is important that the session is devoted to including all three previously mentioned components. Firstly, a focus group should be distinguished from group meetings that do not primarily target research. Secondly, the focus group must allow interaction among participants. Thirdly, the researcher must play an active role in guiding and steering the discussion (Morgan, 1996). Focus groups can be organized for any top of qualitative data collection and does not limit itself to a certain research field.

3.5.3 Focus group design

The design of the focus group was organized with the goal to put the prototype, the FEW sustainability tool, into practice. The focus group was held on May 9, 2021, at 14.30 and took 90 minutes. Representatives of AMS Institute, FABRICations and BKO were invited. Moreover, representatives of various faculties of TU Delft and Wageningen UR were invited to provide scientific feedback on the model and validate the correctness of statements made in the session. Fourteen representatives had been invited, and a 50/50 percent balance between practitioners from the Green Tower project and scholars was aimed for. The expected number of attendees was estimated to be six to eight, with a maximum of eight. The maximum number of attendees was chosen to create a setting where there would be enough room for all attendees to contribute and discuss with one another. The invitees were selected in consultation with Aranka Dijkstra of AMS Institute and Micha Wijngaarde of Wijngaarde &

Partners. Invitees of the Green Tower project were selected based on their level of responsibility within the project. A high level of responsibility within the project was preferred. The scholars have been selected based on their field of expertise, inviting a scholar for vertical farming, nutrient loops, urban energy systems and sanitation systems. The e-mail addresses of the invitees were gathered through conversations with AMS Institute staff. The invitations were sent 1,5 weeks ahead of the session, which resulted in limited availability of the invitees. The actual session was attended by five of the invitees, who are shown in figure 11.

Name	**Organization**	**Function**	**Function in GT project**
Aranka Dijkstra	AMS Institute	Program Developer Living Labs	Green Tower / Bajeskwartier Living Lab researcher
Willie van den Broek	AMS Institute	Program Developer metropolitan Food Systems	-
Leisa Topolnyk	FABRICations	Senior Architect	Lead architect of Green Tower
Micha Wijngaarde	Wijngaarde & Partners (BKO)	Founder	Project manager Green Tower
Marco van de Ploeg	ABT (BKO)	Design manager	Construction / design manager Green Tower

Figure 11: List of attendees for focus group ‘Follow-up: Co-design Session Green Tower Living Lab’.

The session was hosted on May 19. The hosted session was not the session that was planned in first instance. The original plan was to organize a series of three sessions, with each their own focus. However, after setting up the session and inviting the participants, it was decided to cancel them. This was due to two reasons: 1) The interest in the session was very low, as it was poorly timed and it becomes harder and harder to motivate people to participate in online sessions, 2) AMS Institute preferred to partner up in the organization and offered to help gaining traction with the representatives of the Green Tower project and scholars. These challenges will be further discussed in chapter 6, the reflection.

The new program was created in consultation with AMS Institute. The session was built up of three elements: 1) an introduction to the session, 2) discussions on design perspectives, 3) discussion on operationalization of the tool. The introduction introduced the goals of the sessions on the link to this master thesis. Afterwards the visualization of the FEW systems of the Green Tower and the quantitative model were presented.

The tool created in this study was used to calculate the outcomes of five design perspectives created for this session. The design perspectives are different perspectives based on various goals of the Green Tower Living Lab. These goals were derived from two documents: the results of a co-design session hosted by the Green Tower Living Lab (Appendix 5) and a later provided document on the updated goals of the Green Tower Living Lab. These goals were assessed from a FEW Nexus perspective and reviewed on whether the tool could provide relative data for these goals. As an example, a goal focused on material cycles was exempted because the tool does not focus on material cycles. The created perspectives can be seen in the results in chapter 4.4.2.2.

3.5.4 Choosing data visualization method

The quantitative model created in this research, includes a data visualization method that was not deemed optimal enough to be easily interpret in a focus group. Therefore, a new visualization method was developed. There is no theoretical or methodological basis for the choice in visualization method, however, the goal of the session was to test it. The data visualization can be seen as part of the prototyping executed for the creation of the quantitative model. The data visualization method chosen, was based on an informal conversation with a staff member of AMS Institute.

3.5.5 Data analysis

The session was recorded, the recording was turned into a transcript, and the transcript into a session report. The session report was sent to the attendees for them to check whether it contained sensitive information. The participants were asked to consent with the contents of the report. After receiving the consent of the participants on the session report, the report was used to extract information on how the perspectives had been received, how the data visualization had been received and how the tool as a total had been received. In the results section a qualitative analysis of the report is given.

3.6 Research Design Matrix

An overview of the four research questions, their sub-objectives, methodological approach and required data is presented in a research design matrix (figure 12). A research design matrix is a method for planning research projects. The matrix can contain several components: goals, objectives, definitions, hypotheses, variables, methods of analysis, expected outcomes, research questions, etc. To keep the matrix easy to interpret, it was decided to only include the four research questions, their sub-objectives, methodological approach, and required data. The research matrix is included as a summary of the methods section.

MRQ: How can we make the relations between food, energy, and water systems of a sustainability hub easier to understand for designers?

Research question (Objective)	Sub-objectives	Methodological Approach	Data
1. What are the strengths and weaknesses of the current design of the Green Tower from a FEW Nexus perspective, and who designed it?	1.1 Analyze individual and mutual goals of the stakeholders of the GT design team	1.1.1 Literature study: analyzing secondary data sources 1.1.2 Power relation mapping: mapping all stakeholders actively involved in designing the GT	1.1.1 GT progress report, stakeholder websites, online news articles 1.1.2 Example power relation mapping and data from 1.1.1
	1.2 Analyze the current program of the GT	1.2 Literature study: analyzing the systems planned for the GT	1.2 Main source: Rapport gedurfde duurzaamheid Bajes Kwartier (2020).
	1.3 Point out the strengths and weaknesses of the current program of the GT	1.3 SWOT analysis: analysis of the previously identified systems	1.3 Outcomes of 1.2
2. How can the FEW eco-system and the interrelations of its components of the Green Tower be best displayed?	2.1 Research the resource flows of the FEW systems in the GT's program and consider their spatial boundaries	2.1 Literature study: analyze the FEW systems and identify their resource flows	2.1.1 Scientific literature and other online data sources
	2.2 Create a system diagram and theoretical model of the FEW systems and their flows	2.2.1 Unstructured co-design session: 1 on 1 sessions with stakeholders to co-design the (potential) relations between FEW systems. 2.2.2 Unstructured co-design session: 1 on 1 sessions with stakeholders to co-design an overview of the GT's FEW ecosystem.	2.2.1 Data from 2.1 2.2.2 Data from 2.1
3. How can food, energy, and water flows be captured in a quantitative model for a sustainability hub?	3. Create quantitative model capable of showing FEW resource balances	3. Prototyping: creating the model in Excel and running it	3. Secondary data defining the key performance indicators of the FEW systems
4. How do the outcomes of the created tool influence the decision making of stakeholders in the Green Tower project?	4. Test tool	4. Focus group: existing of at least 1 representative of each invested party, discussing visualization of data and sustainability hub tool.	4. Data created in focus group

Figure 12: research design matrix for this thesis

4. Results

4.1 Analyzing the Sustainability Hub

This chapter will answer the question: "What are the strengths and weaknesses of the current design of the Green Tower from a FEW-Nexus perspective, and who designed it?". Two steps are taken to create an understanding of the current program of the Green Tower. The first step entails an overview of the main stakeholders involved in designing the Green Tower, including their individual and mutual goals. Afterwards, a diagram is presented in which the power relations between the main stakeholders is given. In the second step, the program of the GT (Bajes Kwartier Ontwikkeling, 2020, June) is investigated and visualized from a FEW perspective. By means of a SWOT analysis, the strengths, weaknesses, opportunities, and threats of the GT are analyzed. These executed steps have helped creating an understanding of the GT project, for the following research steps to be based on.

4.1.1 Stakeholders involved in programming the Green Tower

To gain a better understanding of how the current program of the Green Tower has been shaped, it is of importance to understand who designed it. Apart from having the mutual goal to create a sustainability hub in the BK neighborhood, all main stakeholders also have their own agenda. These agendas potentially influence the design and thus program of the Green Tower. To find out how the main stakeholders are aligned and what their goals are, the following questions are answered in this sub-chapter: *"What stakeholders are involved in the design of the Green Tower"* & *"What individual and/or mutual goals do the main stakeholders have and how are they aligned?".*

4.1.1.1 Organizational structure in programming the Green Tower

The design of the Green Tower has a relatively unique organizational structure. In the process, developers, designers, and researchers design the building and the program together. There is not one problem owner or commissioner, making the design process dynamic. There is a need for the design team to be able to cope with constantly changing key questions and design orientations (Bajes Kwartier, 2020, October 30). The design team consists of Bajes Kwartier Ontwikkeling ('BKO': A consortium of AM, AT Capital, and Cairn), FABRICations, AMS Institute and Wageningen UR . The design team of the Green Tower should not be confused with that of the BK. In the development of the BK neighborhood many more stakeholders are involved.

The design team presents the Green Tower project as a challenge without a problem owner or real commissioner (Bajes Kwartier, 2020, October 30). However, the land is owned, and the project is commissioned by BKO. This makes them the primary stakeholder. They oversee project management, funding, and realization. The architectural firm, FABRICations, has supported BKO in developing the plans for the Green Tower from an architectural point of view. They have also been involved in winning the tender and creating the masterplan for the entire BK neighborhood. Wageningen UR was part of the tender, as one of the knowledge partners. Through Wageningen UR, AMS Institute was involved in a later stage.

Bajes Kwartier Ontwikkeling CV | BKO

This consortium of AM, AT Capital and Cairn are the initiators for the masterplan that won the tender to redevelop the old Bijlmer Bajes. Their plan was best according to the jury of the tender, due to having "the most added value for the citizens of Amsterdam and its visitors" (AM BV, 2019, 8 augustus).

AM is a property developer and part of the Koninklijke BAM Groep. The Koninklijke BAM Groep is a construction group operating throughout Europe. AM sees sustainability as an integral part of their projects and works according to their five key themes: bold sustainability, inclusive city, healthy urban living & working, city & area maker, and happy living. With these themes in mind, they aim to create inspiring and sustainable living environments (AM, 2021, April 20). Cairn is a real estate investment management platform, from the Netherlands. They invest in future-proof buildings to ensure long-term value for their investors, users, and surrounding community (CAIRN Real Estate., 2021, March 25). AT Capital Group is an Asian private investment firm, based in Singapore. Their asset portfolio is composed of investments in residential and commercial real estate, hospitality, natural resources, engineering, and construction. They have incorporated principles of responsible investing, supporting both sustainable and equitable projects (AT Capital Group, 2020). They will most likely profit most from the development of residential plots.

All three consortium members, with AM and Cairn leading, seem to have interest in creating sustainable and equitable real estate. However, making profits from redeveloping the area will be the goal of the consortium. To ensure a healthy and happy living environment while maximizing profits, it was chosen to develop high rise living blocks with considerable public space in between them. Cairn and AT Capital have a passive role and low interest, but a high say in what happens. They appear to be the two main investors in the project. AM is actively involved in developing the BK and the Green Tower. Being the developer of the three, they show high interest in what happens within the project. They are also involved in Green Tower meetings. They oversee project management and realization.

FABRICations

In charge of the architecture and design of the GT is FABRICations. The relatively young firm (2007) operates in architectural design, urban planning, and regional strategies. The current design of the Green Tower has been developed by FABRICations. Moreover, they oversee developing the concept for the metabolism for the Green Tower (FABRICations, 2018).

FABRICations is commissioned by BKO, and thus also reports to BKO. They have high interest in the outcomes of the project, as it will become one of their flagship designs. They have medium power, they make the design for BKO, but are also highly involved.

Amsterdam Institute for Advanced Metropolitan Solutions | AMS Institute

AMS Institute is a research institute that focusses on sustainable metropolitan solutions in the field of energy, circularity, digitization, climate resilience, mobility, and food. It was founded in 2014 by Delft University of Technology (TU Delft), Wageningen University & Research (WUR), and Massachusetts Institute of Technology (MIT). AMS Institute’s main partner is the Municipality of Amsterdam, and the city of Amsterdam is its primary testing ground (AMS Institute, n.d.-b).

AMS institute is involved as knowledge partner and in charge of setting up the Green Tower Living Lab. The ‘Living Lab way of Working’ as developed by AMS Institute aims to provide “a co-innovative setting, in which multiple stakeholders jointly test, develop and create metropolitan solutions” (AMS Institute, n.d.-a; Steen & Van Bueren, 2017). This living lab focusses on giving space to experimentation and scientific research in urban innovations. The focus will be on realizing a circular urban food system, applying circular and sustainable resource recovery, realizing healthy and circular living (AMS Institute, 2020).

The Green Tower Living Lab and AMS Institute have relatively little power in the design of the Green Tower. They do have high interest, since setting up a successful living lab in the Green Tower can offer them a great space to do research and showcase the results.

Wageningen University of Research | WUR

WUR is a university specialized in the field of healthy food and living environment. The university is involved as knowledge partner and has been involved in setting up multiple preparatory projects in the BK area, such as 'Design the Ultimate Urban Greenhouse'. In this project student teams were challenged to come up with a design for the Green Tower.

In the BK and Green Tower they are actively involved through their flagship project 'Circularity by Design'. This project is a joint effort by WUR and AMS Institute and is also linked to the Green Tower Living Lab. The Circularity by Design project is researching design principles for creating sustainable agri-food systems in the Metropolitan region of Amsterdam. The research has a strong focus on up-cycling biological waste streams to reuse them in food systems (Wageningen University & Research, 2020).

4.1.1.2 Mutual and individual goals of the main stakeholders

Apart from stating what the Green Tower will become, mutual and individual goals are not specifically listed in the project's design updates or stakeholder's websites. Stakeholder interviews would have been a good method to fill this gap in knowledge. However, due to time constraints this method was not applied. The below mentioned goals therefore are a synthesis of the author's findings from design updates, stakeholder websites and participant observations of the two co-design sessions, hosted by the BK Living Lab team and me.

The goal of the Green Tower, as stated by BKO and FABRICations, is to create a place where "sustainable systems come together and are displayed to citizens of the neighborhood and city" (Bajes Kwartier Ontwikkeling, 2020, June). In the two co-design sessions held within the timeframe of this thesis, hosted by AMS Institute with BKO, FABRICations and AMS Institute, all stakeholders' focus seemed to be on the public character of the building. Educative routes, indoor gardens, vertical farm food experiences and fine dining are the main topics being discussed. The building functions as landmark for the neighborhood, attracting visitors from within and beyond the neighborhood's borders. The sustainable character of the building is not leading in the design. However, it is an important aspect in making design decisions for the design team. The sustainability of the building is important, but the public character is more important. Having a landmark like the GT also enhances the neighborhood's character, which in its turn can lead to all kinds of social and economic benefits for the BK neighborhood.

BKO's goal is to develop a sustainable landmark in the BK. FABRICations' goal is to make an architectural design and systems design for the building. AMS Institute's goal is to set up a successful Urban Living Lab and WUR aims to accelerate their CbD project through participating in the Tower's development.

4.1.1.3 Power relations between the main stakeholders

The design team (BKO, FABRICations, Wageningen UR & AMS Institute) has a relatively horizontal power structure. Meaning that all main stakeholders, operate at the same level of power and complement each other by their expertise. The power relations between the main stakeholders and users of the GT are given in figure 13. However, in practice BKO overrules the other stakeholders, followed by FABRICations. Meaning that the research parties have relatively least power. This power division can be explained by the level of responsibility and financial stake in the GT project. BKO having the highest level of responsibility and financial stake, the two research parties having the lowest.

In figure 13 the power relations of the main stakeholders to the future users are given as well. The future citizens of the BK are future users of the GT as it is their neighborhood's city park. BKO and FABRICations have an indirect power relation with the future citizens of BK, as their design greatly influences the types of future citizens. BKO and Fabrications are also indirectly related to the future visitors of the GT. The programming and appearance of the GT will attract a certain group of visitors. A purposive relation will be established from BKO and AMS Institute with the future users of the GT, as they have direct influence on who will settle in the building. All users (companies) that settle in the Green Tower are purposively chosen by BKO and AMS Institute to fit their goals of the Green Tower building and the Green Tower Living Lab.

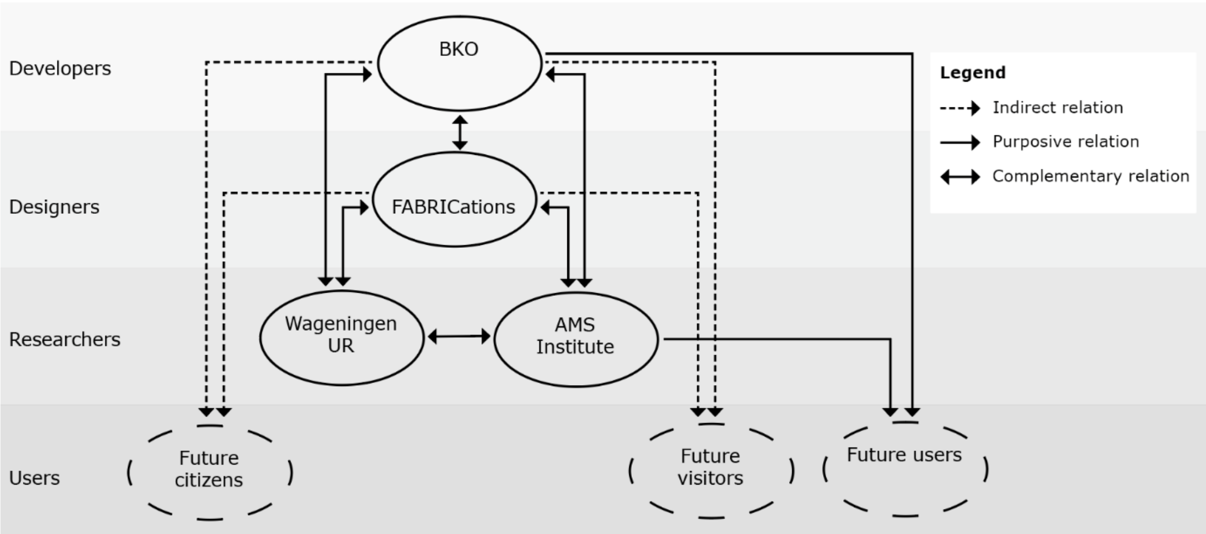


Figure 13: Power relations between main stakeholders of the Green Tower, and users. The design team has a horizontal power structure, complementing each other in expertise. As there are no users yet, all users are indicated as 'future' users. The design team has an indirect or purposive relation with these future citizens, visitors, or users, as their decisions have indirect or direct impact on who or what these users will be. Moreover, the city and utility providers are not included in the chart, as they do not play an active role in the design of the Green Tower.

4.1.2 Analysis of the preliminary program of the Green Tower

As mentioned before, the GT harbors multiple systems that are specifically focused on generating, recycling, or distributing resources related to FEW. In this paragraph, the functions planned in the GT are analyzed from a FEW-Nexus perspective to answer the question "what FEW systems are currently planned in the program of the GT?". This means, that all systems will be assessed on whether they demand or supply FEW and if there are already resource relations, direct connections between systems, drawn between FEW. Moreover, it will be analyzed if systems' their main purpose can be categorized under either of the FEW domains. The progress report (Bajes Kwartier Ontwikkeling, 2020, June) gives a first insight into what they call 'the circular (eco-)systems of the Green Tower'. They have divided their circular systems in the categories: 1) innovative energy systems, 2) waste cycles and food production, 3) rainwater collection and storage, 4) healthy living and sports. In these eco-systems, some resource connections have already been made.

The eco-systems as defined in the progress report, are slightly changed in this study. For instance, the 'waste cycles and food production' ecosystem was downsized to only organic waste, as technical waste is not within the scope of this study. Food production was expanded by also including food consumption. The ecosystem will from now on be regarded to as 'food and nutrient systems'. Food and nutrient systems are systems that focus on producing, distributing, and recycling nutrients or nutrient rich substances (such as food). The vertical farm is a good example of one of these systems, because its main function is producing nutrient rich substances, namely vegetables.

The category 'innovative energy systems' was unchanged and named 'energy systems'. An energy system is formulated as a system that processes energy, this can be thermal or electrical energy. The Lumniduct is an energy system which main function is producing both electricity and thermal energy.

The category 'rainwater collection and storage' has been expanded to also including wastewater and drinking water and was named 'water systems'. A water system is a system focused on processing various kinds of water, from rainwater to wastewater. The water storage planned in the basement, is a system which primary function is the collection and distribution of water. The construction of the roof does not have the carrying capacity for a green roof, or other roof related water storage related systems.

'Healthy living and sports' is unchanged and referred to as 'experience and visitor systems'. The experience/visitor systems are systems focused on receiving visitors and offering an experience, such as education, sports activities, or fine dining. As the GT has no residential purpose, the visitor stands central in these systems, while also demanding FEW flows and producing FEW flows. An example is the planned restaurant, a place where the visitor stands central, while requiring FEW flows and creating FEW waste flows.

For all functions planned in the GT, I have asked the question: "do they demand or supply FEW?" and "is the system specifically focused on generating FEW". These questions helped to categorize the systems under the four previously described categories.

In the following paragraphs, the identified systems are discussed per category and additional information is given on the functioning of these systems. This information is used in the next chapter, where each system its strengths and weaknesses are analyzed. The progress report of the BK contained little detail on the systems of the GT. Therefore, secondary data sources such as websites and scientific articles have been used to describe these systems. It should be taken in account, that this secondary data will not translate one-on-one with the systems as the design team of the GT has intended them. Moreover, exact sizes and resource demand and supply capacities of all systems are not yet known in this stage of the design. These capacities will be calculated in Chapter 4.3.

4.1.2.1 The food & Nutrient ecosystem

The food & nutrient ecosystem, as planned in the program, has four main components: an organic waste collection point, an indoor vertical farm, a swinging herb garden, and a vertical city park (figure 14). Three other important systems of this eco-system are the bio-digester (discussed in 4.1.2.2), the restaurant (discussed in 4.1.2.4) and the bar (discussed in 4.1.2.4). Some connections between the food & nutrient systems seem to be missing, such as the demand of nutrients by the vertical farm, or the production of organic waste by the vertical city park. No connections are made between these systems and the energy ecosystem. Moreover, some odd connections are made between the water demand and production of these food & nutrient systems.

Indoor vertical farm

An indoor vertical farm is a novel type of farming where food is grown indoors in controlled conditions. Solar radiation is replaced by artificial lighting, just providing the range of light required for the growth of crops. Most often, crops grow in soilless cultivations systems such as hydroponics (roots in substrate with a water nutrient solutions) aeroponics (mist solution) or aquaponics (fish cultivation combined with hydroponics) (Avgoustaki & Xydis, 2020, -b). Vertical farms allow crops to be produced in multiple layers per floor in completely airtight and highly insulated conditions. The controlled condition of vertical farming minimizes food waste during production, as all plants grown in equally optimal conditions and weather, or pests do not compromise yield (Despommier, 2013). Moreover, vertical farms offer a way to produce fresh and healthy food in a local urban context. Theoretically, they can be placed anywhere in an urban context, posing a great solution for food scarcity and security (Avgoustaki & Xydis, 2020, -a). A vertical farm requires electricity, high quality water, high quality nutrients, CO_2, and seeds, and produces heat and fresh crops. The energy requirements of vertical farms are relatively high compared to other types of farming. Usually plant waste, like stems, and water are recycled within the vertical farm.

The integration of the vertical farm in the design of the circular systems of the green tower is limited (figure 14; figure 16; figure 17; figure 18). It is not indicated where the nutrients required for the crop growth come from. Water is derived from the rainwater storage tanks; however, it could be questioned if this water has the quality and consistency required for the vertical farm. Its energy demand is not specifically indicated, most likely it comes from the ESCO. The food produced is used for the bar and restaurant in the GT. Moreover, the vertical farm will be open to visitors, as a place where they can see how producing food locally, could look like.

Organic waste collection point

All organic waste produced in the GT and BK are collected in the GT (Bajes Kwartier Ontwikkeling, 2020, June). Reasoning that BK exists of 1350 households and many other functions, this organic waste collection point should be of considerable size. Moreover, the bio-digester should be able to process most of this waste.

This organic waste is used to feed the bio-digester, which in it turn provides the ESCO of heat and electricity and the GT and BK from a nutrient rich sludge (figure 14).

Vertical city park

The design of the Green Tower contains an open structure, meaning that the building's façade at certain places is removed. This leads to open air spaces within the building. One of these spaces a vertical city park. The vertical city park will be positioned over multiple floors of the building and function as public park for residents of BK and visitors of the GT to reside. The vertical city park, just like a conventional city park, contain many types of plants and trees. The planting of the park also provides space for birds and bees (Bajes Kwartier Ontwikkeling, 2020, June). Plants require water and nutrients and produce organic (plant) waste.

In figure 14 it is indicated that the vertical city park requires fresh water, stores rainwater, and produces rainwater. The production of rainwater is an odd flow, most likely it is meant that in case of extreme precipitation there is too much rainwater for the vertical city park. It is indicated that the rainwater is then discharged outside of the building. The nutrient rich sludge of the bio-digester is used to feed the vertical city park. It is not indicated that the vertical city park also produces organic waste, nor how it is processed (figure 14).

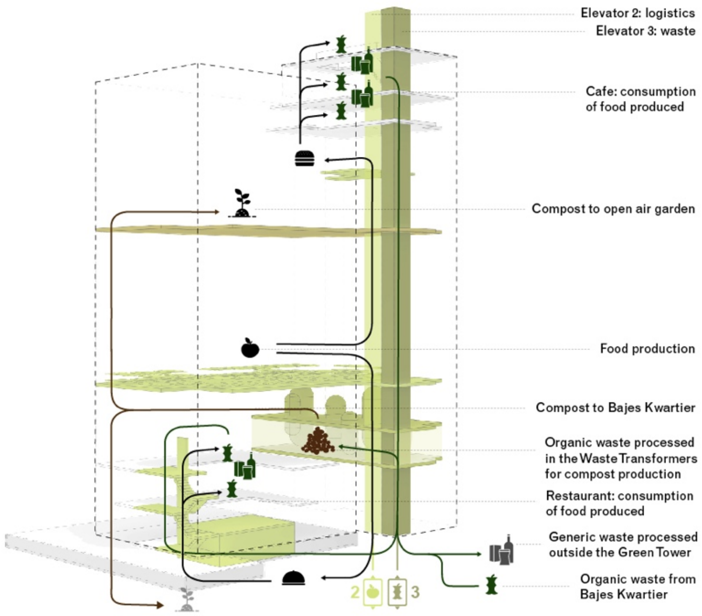


Figure 14: 'Waste cycles and food production' systems in the GT. This figure is a representation of the (organic) waste and food systems and their relations, as described by the GT design team (Bajes Kwartier Ontwikkeling, 2020, June).

4.1.2.2 The energy ecosystem

On a local level sustainable energy will be generated through innovative practices: a bio-digester, energy service company (ESCO), Lumniduct & Powernest. These systems will be elaborated upon in this paragraph. For all systems their relation to FEW resources is indicated. The connections between the energy systems of the GT seem to be complete. However, it is unknown if the electricity or thermal energy generation and demand are in balance.

Bio-digester (by WasteTransformers)

The WasteTransformers is a company that provides a ready to use bio-digester system. A bio-digester processes organic waste, and turns it into biogas, heat, and a nutrient rich sludge. A bio-digester uses anaerobic digestion to produce the biogas form organic waste. The biogas is burned in a CHP engine (CHP = combined heat and power) to generate both electricity and heat (Zhang et al., 2021). The organic waste does not disappear; the organic waste is transformed into a nutrient rich sludge. In the process, it loses some water content. The water condensates and can be reused in for instance watering plants. The heat and electricity can be used in any heat or electricity demanding system. The nutrient rich sludge can be applied as fertilizer (Kjerstadius et al., 2015)

According to the circular system of the GT (Bajes Kwartier Ontwikkeling, 2020, June), the bio-digester is fed with organic waste from the restaurant and bar in the GT, and by organic waste from the BK. The nutrient rich sludge is used for the indoor gardens and gardens elsewhere. It is not indicated where this effluent will go exactly. The energy and heat are redirected to the ESCO, which redistributes it to the GT and BK (figure 16). The bio-digester will be 'opened up', meaning that all components of the system are visible to visitors of the Green Tower.

Energy service company

The (re)distribution of heat and electricity will be conducted by an energy service company (ESCO), which will also be located within the building. An ESCO is a company that provides various services and measures that should lead to the reduction of energy use. The ESCO is responsible for reaching energy reduction target, and only makes profit when it does so. Moreover, an ESCO relieves the owner of the building, in this case the GT, from dealing with burdens of energy management of all its energy systems. The installation of an ESCO is mainly focused on climate control and energy provision of a building (Rijksdienst voor Ondernemend Nederland, n.d.).

The ESCO includes energy storage and an ATES (Aquifer thermal energy storage). It is part of both the energy and heat provision of the GT and BK. The ATES (figure 15) stores thermal energy in ground water and requires additional electricity as 'working power' to upgrade the thermal energy to useable heat with a heat pump (Andersson, 2007). The systems of the ESCO receive electricity from the PowerNest and Lumniduct, and a combination of electricity and heat form the bio-digester and electricity and heat network of the BK. The ESCO then redistributes this electricity and heat to the GT or BK (figure 16).

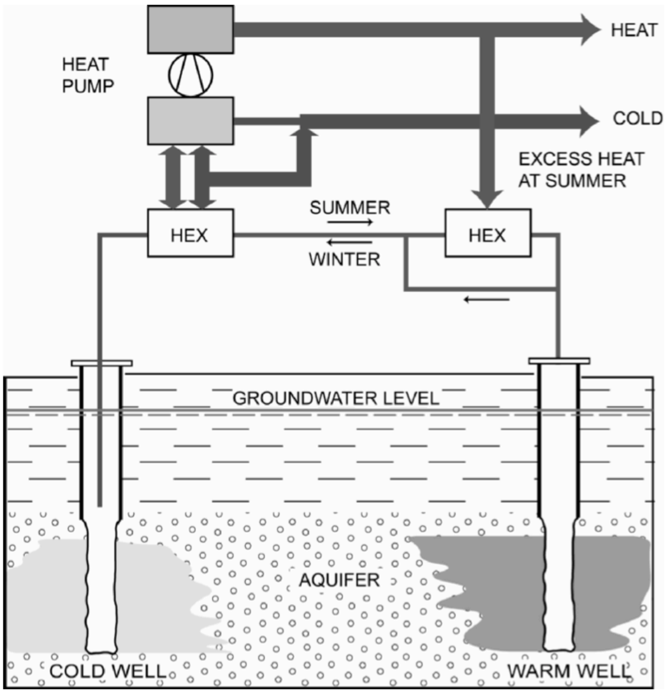


Figure 15: Basic ATES configuration (Andersson, 2007)

Lumniduct

This system provides electricity generation and climate control for the building. The Lumniduct is a full glass façade with integrated solar panels. The solar panels can move and can therefore provide shading in the summer. In the winter, the glass façade can be closed off and used to retain heat, by creatin a greenhouse effect (Wellsun, 2019). The Lumniduct provides climate control for the building itself, while also generating electricity which will be redirected to the ESCO (figure 16).

PowerNest

The PowerNest is a system that generates electricity with solar panels and small wind turbines. It is placed on top of the building. The Powernest provides electricity to the ESCO (figure 16).

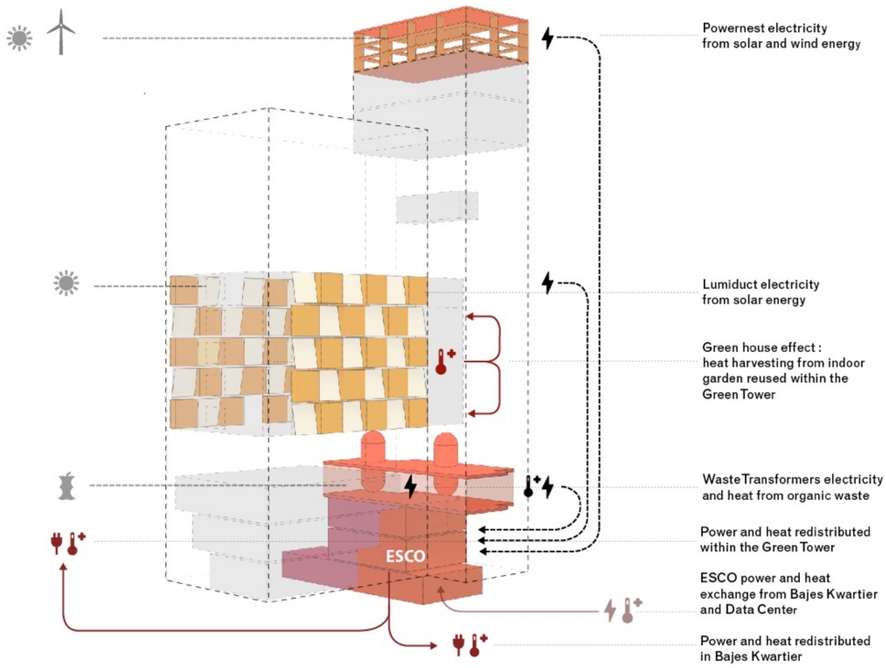


Figure 16: 'Innovative energy generation' systems in the GT. This figure is a representation of the energy systems and their relations, as described by the GT design team (Bajes Kwartier Ontwikkeling, 2020, June).

4.1.2.3 The water ecosystem

Precipitation on the roof of the GT will be collected and a water storage in the basement of the building will allow it to be stored. This rainwater will be purified for use in the indoor vertical farm of the building. The description of the water related systems of the GT differs throughout the progress report. The water purification is mentioned in figure 17, but nowhere else in the report. Therefore, only the water catchment on the roof and storage in the basement will be further elaborated upon. The purification will be discussed within the storage paragraph. Moreover, the water system does not include fresh water or wastewater streams. The demand of drinking water is not indicated in any of the circular eco-systems, and the production of wastewater is not included either. Logically, there are also no local treatment systems planned for wastewater flows. Overall, the connection made for the water systems in the GT are very limited.

Water catchment

The roof will function as water catchment area. The water will flow through the vertical city park, into the purification or storage facility. Moreover, rainwater can be discharged on the canal next to the GT (figure 17).

Water storage

Water will be stored in the basement of the GT. Pumping water through the building and purifying it requires electricity. Nutrifying the water, for watering plants, also requires nutrients of sufficient quality to be dissolved in water. In figure 17 it is indicated that rainwater will be purified and nutrified to be used in the vertical farm. Moreover, the rainwater can be used directly for the vertical city park.

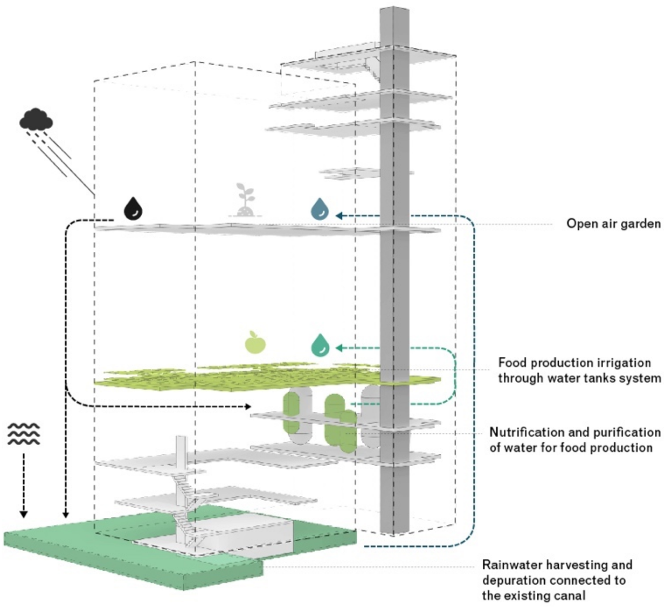


Figure 17: 'Water catchment and storage' systems in the GT. This figure is a representation of the water systems and their relations, as described by the GT design team (Bajes Kwartier Ontwikkeling, 2020, June).

4.1.2.4 The experience & visitor eco-system

Visitors of the Green Tower are educated on healthy and sustainable living. The education on sustainability is executed by showcasing the sustainable systems, such as the vertical farm, bio-digester, and vertical city park. An educative route will connect these systems. What the exact contents of this educative route will be, has not been planned out yet. However, systems that are specifically focused on receiving visitors have been planned. These systems include a restaurant, bar and climbing hall. There will also be rentable office spaces, in which innovative companies can meet and work. Apart from food being provided by the vertical farm, no connections to FEW flows and thus the other systems in the GT have been made yet for these systems (figure 18).

Restaurant

All that is known about the restaurant in the GT from the progress report, is that it will serve food with some ingredients of the vertical farm (Bajes Kwartier Ontwikkeling, 2020, June). Many educative activities could be undertaken in the restaurant, such as cooking workshops and education on how to prevent food waste. A restaurant generally would require fresh water, electricity, heating, food, and beverages, and it produces organic waste and wastewater (sanitary and kitchen). The food produced in the vertical farm is probably of a limited variety (only some vegetables and leafy greens), so food also needs to be imported.

Panoramic bar

In the top floor of the GT a panoramic bar will be placed. A bar generally would require fresh water, electricity, heating, food, and beverages, and it produces organic waste and wastewater (sanitary and kitchen). The bar could also be used for educational activities.

Climbing hall

A climbing hall is a facility where the sport of indoor climbing sports is done. In figure 18, 'logistics for climbing wall' is indicated as flow. What this entails is unclear. From a FEW perspective, the climbing hall will most likely require electricity, heating, cooling, and water, and produces mostly sanitary wastewater. The climbing wall offers a place for sports. It could be questioned if this specific climbing wall educates its visitors on more on healthy living, than a normal climbing wall would.

Rentable office spaces

The rentable office space does not specifically seem to give visitors of the Green Tower a leisure experience or educational experience. An office space requires electricity, heat, water and produces mostly sanitary wastewater.

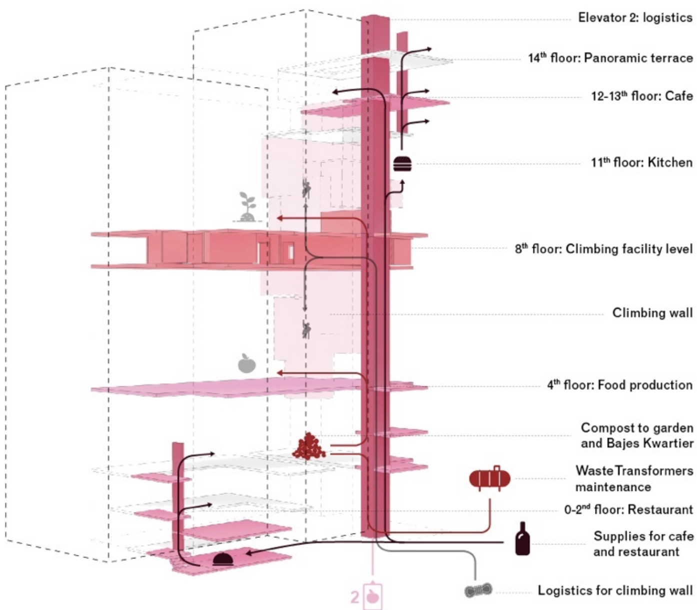


Figure 18: 'Healthy living and exercise' systems in the GT. This figure is a representation of the visitor systems and their relations, as described by the GT design team (Bajes Kwartier Ontwikkeling, 2020, June).

4.1.3 Strengths and weaknesses in the preliminary design of the Green Tower

The current program of the GT harbors systems to locally handle FEW resources. This paragraph will evaluate the preliminary design of the Green Tower to answer the question: "What strengths and weaknesses can be identified in the current program of the GT from a FEW Nexus perspective". All systems identified in chapter 4.1.2 have been combined in figure 19. To evaluate the strengths and weaknesses for the GT from a FEW Nexus perspective, a SWOT analysis has been conducted of the GT's systems.

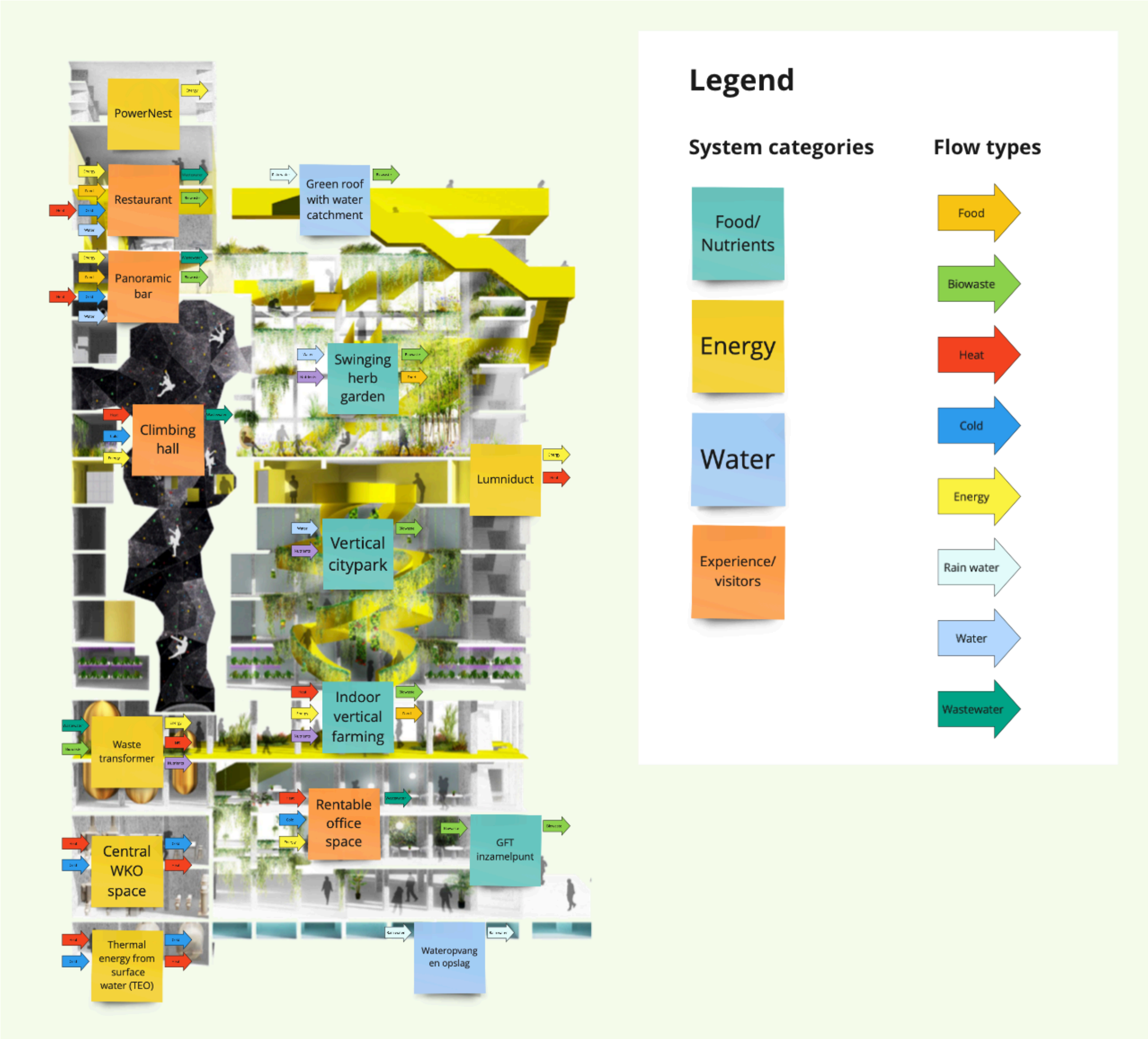


Figure 19: Preliminary design of the Green Tower, categorized under food/nutrient, energy, water, and experience/visitor categories. A first estimation of the FEW resource flows entering and leaving these systems is added.

4.1.3.1 Strengths and weaknesses of current GT design

This paragraph will highlight the strengths and weaknesses of the current design of the Green Tower. Nexus thinking is about improving the efficiency of resource and land use, by acknowledging the interrelations between FEW and their impact on land use, and acting upon them (Hoff, 2011). Layering FEW systems in a single 16 story high building is making good use of limited space. However, in the preliminary design there is no explicit mention nor incentive to aim for resource balances within the building. The building showcases sustainable practices and does not necessarily seem to be a sustainable (in balance) building itself. The educational program, however, has also not been elaborated upon in the progress report (Bajes Kwartier Ontwikkeling, 2020, June). In this chapter, for each system described in chapter 4.1.2 a SWOT analysis has been conducted, from a FEW Nexus perspective (figure 20). Lastly, the results of the SWOT analyses are discussed.

Category	System	SWOT analysis	
Food & Nutrients	**Vertical city park (indoor)**	***Strengths*** - Place for leisure - Natural cooling of building - Increased biodiversity - Rainwater retention	***Weaknesses*** - Missed opportunity for food production - Mostly requires FEW resources (only produces organic waste)
		Opportunities - Using space for production (for instance fruit trees) - Using plant waste for bio-digester	***Threats*** - Lack of sunlight indoors. If too little, it would require additional lighting - In times of heat and drought, large additional freshwater demand - Unsure benefit for biodiversity as it is indoor
	Indoor Vertical farming	***Strengths*** - Food security: producing food locally, without risks in climate variability - Healthy food: produces vegetables & leafy greens production and thus local food security - Productivity: high productivity on limited space - No soil required for farming - Consumes rainwater	***Weaknesses*** - High energy demand - Limited produce variety (for instance, no proteins) - Food access: only available in bar & restaurant - Food inequality: only the wealthy will be able to visit bar & restaurant
		Opportunities - Using nutrients from bio-digester sludge - Using more space for vertical farm to increase production - Let visitors taste produce at VF (for free)	***Threats*** - Not enough rainwater available, need for fresh water - Rainwater not of high enough or consistent quality for use in VF - Production is dependent on electricity -Public character hard to achieve with controlled and closed environment of VF

	Organic waste collection point	***Strengths*** - Nutrient cycles: enables local reuse of organic waste - Prevents organic waste from being transported over long distances - Prevents organic waste from being landfilled or incinerated	***Weaknesses*** - Does not tackle the problem of organic waste production: source reduction (1^{st} in Food Recovery Hierarchy) - Does not promote higher value reuse: feeding the hungry, or feeding animals (2^{nd} & 3^{rd} in Food Recovery Hierarchy)
		Opportunities - First use organic waste as animal feed (3^{rd} in Food Recovery Hierarchy) - Have animals to feed of organic waste in GT or BK - Provide opportunity to prevent food waste, such as community fridge (2^{nd} in Food Recovery Hierarchy)	***Threats*** - Food that could have been fed to the hungry might be thrown away more easily (2^{nd} in Food Recovery Hierarchy)
Energy	**Bio-digester**	***Strengths*** - Local treatment of food waste (4^{th} on Food Recovery Hierarchy) - Produces energy (electrical & thermal) for GT and BK - Produces nutrient rich sludge, fertilizer for city parks and potentially other systems	***Weaknesses*** - Requires waste, not an incentive to stop wasting food - Is dependent on organic waste
		Opportunities - Use black wastewater (feces) for bio-digester - Reuse condensated water	***Threats*** - If organic waste production is reduced, energy and nutrient consumption of bio-digester is as well - Presence of bio-digester might decrease the incentive to limit food waste, increasing organic waste production (opposite of Food Recovery Hierarchy)

Energy service company	***Strengths*** - Decreased energy consumption: ESCO benefits if energy consumption is low - Can redistribute excess heat or cold from GT - Energy storage (electrical & thermal)	***Weaknesses*** - Electrical energy storage requires lithium batteries, which is a scarce resource
	Opportunities - Provide some free energy to neighborhood as some of it comes from their food waste	***Threats*** - Lumniduct and bio-digester produce heat, this might be unbeneficial for the heat cold balance in the ground coupled heat exchanger
Lumniduct	***Strengths*** - Produces renewable energy - Improves indoor climate	***Weaknesses*** - Use of rare minerals in PV-panels - Uneven energy supply throughout the year due to changes in solar radiation
	Opportunities -	***Threats*** -
PowerNest	***Strengths*** - Produces renewable energy - More stable energy supply year-round due to wind energy component	***Weaknesses*** - Energy supply is dependent on climate
	Opportunities -	***Threats*** -

Water	**Water catchment on roof**	***Strengths*** - Catches rainwater for direct use in vertical city park. - Enables rainwater storage	***Weaknesses*** - Prevents water from entering its natural cycle
		Opportunities - Store water on roof or higher floors	***Threats*** -
	Water storage in basement	***Strengths*** - Stores rainwater for later use - Provides water for indoor vertical farm and vertical city park - Reduced demand for fresh (blue) water	***Weaknesses*** - Water transportation requires electricity - Water processing (purification) requires electricity and separate system - Water storage prevents rainwater from replenishing ground water, negatively impacting ground water levels
		Opportunities - Store water higher in the building, to create natural water pressure on lower floors. Less electricity required	***Threats*** - Droughts impacting water supply - Climate change impacting rain patterns
Visitors & experience	**Restaurant & bar**	***Strengths*** - Lets visitors experience food grown in vertical farm - Vertical farm can provide a part of its food demand	***Weaknesses*** - Only serves people who can afford to go out for dinner - Most of its food and beverages still needs to be imported - Consumes vertical farm food that could have also been sold to the neighborhood
		Opportunities - Let the restaurant and vertical farm co-design the menu and food production.	***Threats*** - Importing food (the part that the vertical farm cannot produce) from non-local sources

Climbing hall	***Strengths*** - Provides a place to exercise	***Weaknesses*** - Has no active educational purpose - Requires a lot of space that could have been used for educational purposes - Probably has entrance fees, making it not 'publicly' accessible - Only demands FEW and produces wastewater, which is not treated locally
	Opportunities - Incorporate educational program - Filter magnesium (climbing chalk) from air - Generate energy by using Auto Belay Devices with traction motor	***Threats*** -
Rentable office spaces	***Strengths*** - Offers space for innovative and sustainable companies to develop	***Weaknesses*** - Only demands FEW and produces wastewater, which is not treated locally
	Opportunities - Make it an open workplace, for everyone	***Threats*** - Only wealthy people will use the space

Figure 20: SWOT analyses of the systems of the GT.

SWOT of food & nutrient systems

The vertical city park offers a place for visitors of the GT and residents of BK to find leisure. In summer, the vegetation present in the park will offer them a cool place to reside. The layering of this system makes the vertical city park a very space efficient public function. However, BK will have vast amounts of public space in their masterplan. The space used in the GT, could have also been used for vertical farming to increase the local food production. Moreover, the vertical city park is a sink for resources, as it requires water, food and potentially energy in case of low lighting. It only produces some organic waste which can be composted or used for the bio-digester. In times of heat and drought, which are likely to increase soon due to climate change, the vertical city park might even become a larger water user than it already will be.

The indoor vertical farm can provide food security in the neighborhood. It can produce crops year-round that can be consumed locally. Moreover, the food produced in the vertical farm has limited accessibility as it is only sold in the restaurant and bar of the GT. The fact that the food is only sold in the bar and restaurant, also leads to food inequality, as not everyone is wealthy enough to eat at a restaurant or bar. A possibility would be to have people taste the crops straight from the vertical farm or offer residents and neighbors the possibility to buy them at lower cost. The layered production system of the vertical farm makes it a very space efficient system as well, requiring little floor area for high production. An opportunity would be to increase the space used for the vertical farm, produce more food and be able to offer food in other places than just the restaurant and bar. In the cultivation process of the vertical farm no soil is needed, only nutrients. An opportunity is to use nutrients from the bio-digester as input for the vertical farm, as that relation is currently not drawn in the plans. Rainwater will be used to water the crops, which is a good alternative to fresh water. However, this also makes the sustainability of the system dependent on rainfall. In times of drought the water demand of the vertical farm might be higher than the supply. This would lead to using fresh water. Moreover, the food is also healthy, as a vertical farm can only produce vegetables and leafy greens. This is also a downside, as the vertical farm produces a limited variety of crops and thus is not able to provide an entire nutritious meal. Another major downside of vertical farming is its energy demand. The lighting in the vertical farm requires vast amounts of electricity, and all process are robotized, also requiring electricity. This also forms a threat, as the food production is completely dependent on a stable energy supply. Lastly, the vertical farm is supposed to have a public character. However, a vertical farm is a controlled system that is highly insulated and airtight. Making this a public system, would be very challenging.

The organic waste collection point enables the neighborhood to create a local nutrient loop, reusing all organic waste from the neighborhood, within the neighborhood. This also prevents the organic waste from being transported to central treatment facilities, avoiding greenhouse gas emissions. Moreover, after transportation the organic waste is most likely landfilled or incinerated. Landfilling organic waste leads to methane production, and incineration to a variety of greenhouse gasses. However, collecting organic waste to be composted or bio-digested is not the highest value in the Food Recovery Hierarchy figure 21. The presence of an organic waste collection point like this, might even give residents the feeling that wasting food is not that bad, as it used well anyway! Therefore, the system might be in contrast with the most preferred option in the Food Recovery Hierarchy: source reduction. However, the system also creates the opportunity to do better on the Food Recovery Hierarchy, for instance by providing a place to feed the hungry, by adding a community fridge. Or use the collected organic waste to feed animals. Preferably, the animals are kept on the BK grounds.

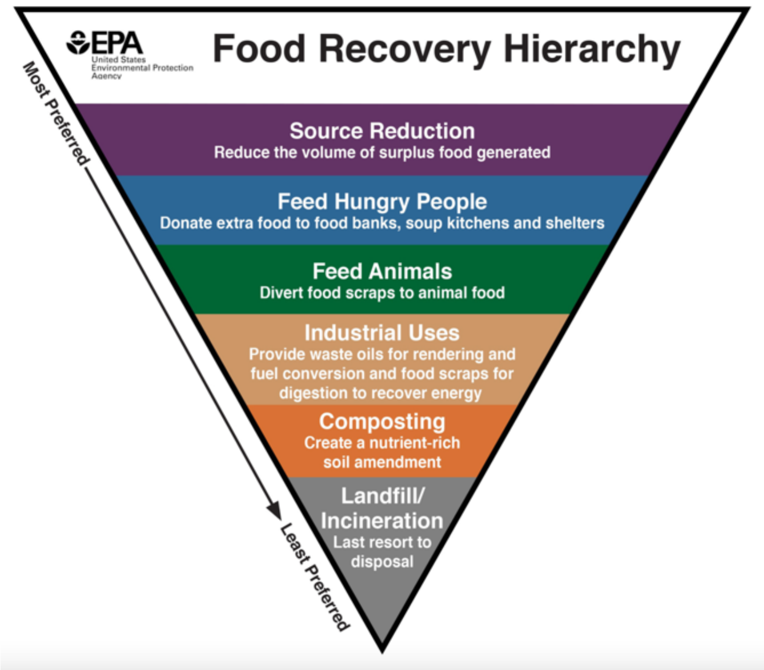


Figure 21: The Food Recovery Hierarchy. The hierarchy prioritizes actions that can be taken by organizations to prevent and divert food waste (United States Environmental Protection Agency, 2021, January 2).

SWOT of energy systems

The bio-digester enables organic waste, both food waste and plant waste, to be processed locally into the valuable resource flows electricity, heat, and liquid fertilizer. The downside of a bio-digester is the need of organic waste for it to operate. Bio-digestion is the fourth option in the Food Recovery Hierarchy, so it should be aimed for to take the higher ranked actions before using the food waste for the bio-digester. However, if the actions are successful, no organic waste is left for the bio-digester. Using feces for the bio-digester is an opportunity to tackle this problem. Keeping the bio-digester running, will become important for the area, as it provides nutrients, electricity, and heat for many other systems.

The energy service company provides all electricity and heat distribution of the GT and from the GT to the BK. The structure of the ESCO rewards energy use reduction, improving the energy balance of the building. Moreover, redistribution and storage of energy (both thermal and electrical) are advantages of the system. It should be realized that some of the heat and electricity the ESCO distributes to the neighborhood, theoretically partly belongs to its residents, as their food waste is used to generate it. Offering compensation for this, is an opportunity for the system. A weakness of the system is the use of scarce resources, such as lithium, for some of its systems. Moreover, the heat produced by the Lumniduct and bio-digester and the lack of a cold counterpart within the building to balance it, creates a threat for the aquifer thermal energy storage and heat pump that are part of the ESCO.

The Lumniduct offers renewable energy and provides a tool to improve the indoor climate of the GT. A downside are the scarce minerals used in its PV-panels. Moreover, the system provides an uneven electricity supply as it peaks in summer and drops in winter due to the change in solar radiation.

The PowerNest also provides renewable energy and offers an energy supply that is a bit more stable than the supply of the Lumniduct. This is due to the combination of PV-panels and wind turbines. However, the energy supply is still dependent on weather conditions.

SWOT of water systems

The rainwater catchment on the roof of the GT allows the water to be reused directly in the vertical city park. Excess water can be stored or discharged elsewhere. A weakness of this approach is that the water cannot replenish ground water levels, as the plants will evapotranspire the water. Instead of storing the water in the basement, storing the water on the roof or a higher floor, would be beneficial as it creates natural water pressure and thus reduces the electricity demand for pumping the water back up.

Water storage in the basement allows water to be stored for times of drought and/or heat when additional watering is required in the vertical city park. It also allows the water to be purified and nutrified for the indoor vertical farm. The same as said in the previous paragraph holds true here, storing water higher in the building would lead to decreased electricity demand for transporting the water. Moreover, purification and nutrification also demand electricity.

SWOT of visitor & experience systems

The restaurant and bar of the GT offer a place where visitors of the GT can experience the food of the vertical farm in a culinary way. However, the vertical farm does not provide food for a complete nutritious meal, so the import of food is still required. The import of food can lead to a poor insight into where the food is coming from, has it been produced locally? Moreover, the restaurant and bar only offer food to people who are wealthy enough to dine there. Furthermore, there is a possibility that the vertical farm controls what the restaurant and bar serve, it would be better if the restaurant, bar, and vertical farm would co-design their menus and the type of crops produced.

Apart from a place to exercise, there is no real benefit to be spotted for the *climbing hall*. The climbing hall will require a lot of space, which could have also been used to produce FEW. It has no clear educative purpose, yet. And it most likely will charge an entrance fee, making its public availability limited. Again, only the ones that can afford to enter will be able to experience the system.

The rentable office spaces possibly offer a place for innovative and sustainable companies to work. An opportunity would be to also offer free workspaces, to make it more inclusive. From a FEW perspective the rentable office spaces just consume FEW.

4.1.4 Summary of the stakeholder and program analysis

In theory, the GT is designed by BKO, FABRICations and AMS Institute with a horizontal organizational structure. All parties complement each other in with their expertise. However, in practice most power will lie with BKO, as they oversee the management of the project, are in closest contact with the investors and are the owner of the land. The interplay between the three stakeholders fits the idea behind the GT, namely that it has no fixed program. The design team has the potential to be flexible and resourceful. The adaptive capacity of the design team also creates a right basis to tackle challenges regarding FEW governance. However, as none of the stakeholders has expertise on any of the FEW themes, knowledge on how to solve these challenges is missing.

The overall goal of the three stakeholders is to turn the GT into a space where sustainable systems come together and are displayed to the residents of BK and visitors of the GT. Apart from being a public and educational hotspot, it can also be speculated upon that the creation of this iconic building will help increase land and housing prices around it. For BKO the most important goal surrounding the GT is for it to contribute to the character of BK as a whole and tell the healthy and sustainable story they have created around the neighborhood. FABRICations is also invested in this character of BK, being part of the BK masterplan. Moreover, the design and appearance of the building can function as business card for them. AMS institute is involved in setting up a living lab in the building and making it part of their scientific program.

In summary, the food and nutrient systems of the GT enable the neighborhood to locally process organic waste, produce and consume healthy food and maintain a public green space through an organic waste collection point, an indoor vertical farm, and a vertical city park. However, the organic waste collection does not target actions highest on the Food Recovery Hierarchy. Food waste should be first aimed to be 1) reduced, 2) fed to the hungry, 3) fed to animals, before being used for bio-digestion or composting. Moreover, the food security created by the vertical farm, is created not for everyone. Therefore, it can be argued if you can call it food security at all. The system also seems to support food inequality and poor food accessibility, as its produce is not available to anyone or everywhere. Furthermore, the vertical city park could also be used as productive area, making it less of user and more a producer. Lastly, all systems rely on nutrients, water, and energy. The availability of nutrients should be of no concern due to the bio-digester. The precipitation on the roof will most likely not be enough to feed all these systems, and times of drought and heat form an even bigger risk of having water scarcity. The vertical farm also requires vast amounts of energy, making the system and the food security it brings, dependent on a stable energy supply.

The energy systems of the GT are better aligned than the food and water systems. The connections made are very straight forward. The bio-digester influences the food and nutrient systems by creating a constant demand for organic waste. Using feces as an alternative to organic waste, is an opportunity for the system to improve its sustainability. The bio-digester is a very important player in the neighborhood, as multiple systems will rely on the electricity, heat, and nutrients it supplies. The ESCO provides an incentive to reduce energy consumption and create a good energy balance. The strengths of the energy ecosystem are the dependence on renewable electrical and thermal energy sources. However, the weather dependence of the Lumniduct and PowerNest make the energy system a bit less robust. Moreover, PV-panels and energy storage systems require the use of scarce resources, which is the main weakness of these systems.

The first and foremost problem with the water systems is that currently it only focusses on rainwater. Drinking water and wastewater are excluded from the equation, while these will most like flow through the GT in way larger quantities than rainwater. Including these flows and possible systems to process them are essential in getting an overview of the water eco-system of the GT. As for rainwater, it is used for the indoor vertical farm and the vertical city park. The water is collected on the roof of the GT and stored in its basement. Collecting and storing rainwater prevents it from entering its natural cycle, the ground water. Moreover, depending on rainwater makes the system vulnerable to times of drought and heat. Lastly, transporting, purifying and nutrifying rainwater will consume electricity.

The visitor and experience systems mostly just seem to consume FEW resources. Their educational and experience function seems very limited in this analysis. This might be because they are still developing the program and its educational activities. However, it can be concluded for now that they are very limited. Moreover, the visitor and experience function all cost money to experience them, making the systems not equitable. However, if you take the public character of the bio-digester and vertical farm into account, and the vertical city park, there is also space to experience the building without having to pay. Sadly, their public character is not very clear yet. One of the two main goals of the BK was to ‘support its citizens living a healthy life’ (Bajes Kwartier Ontwikkeling, 2020, June). The lack of equitability in certain systems and the unclear purpose of the educational activities momentarily seem to create limited benefits to reaching this goal through the GT.

4.2 Creating a Universal Sustainability Hub System Diagram

The second step in this research is focused on finding a way to visualize the relations between the FEW systems in the GT. This system diagram is important to understand how the entire eco-system of the GT will operate. The system diagram will function as basis for the quantitative model, which will be developed in chapter 4.3. The system diagram of the GT's ecosystem will also form the first part of the design tool, created in this thesis. This chapter will answer the question: "How can the relations between FEW systems in the Green Tower be best displayed?". To answer this question, three steps have been taken. First the various resource flows of the GT are identified and described. Second, relations between systems by means of their resource flows are drawn. Third, the visual representation, which resembles a system diagram the most, is created in a co-design process with relevant stakeholders. The results are synthesized in one system diagram. Last, a visual overview with the FEW Nexus as theoretical basis is created.

4.2.1 The resource flows of the FEW systems in the Green Tower

A better understanding of the resource flows of FEW systems in the Green Tower is required to be able to create a theoretical and visual representation of the GT's FEW systems and their interrelations. FEW are built up from various resources. The water system for instance, does not only demand or supply fresh water. Various types of resources flow through the system, such as rainwater, yellow wastewater, and black wastewater. Moreover, these flows have a different spatiality. They are collected, generated, distributed, or processed at various spatial scales. For instance, in conventional practice black wastewater is collected by a city or region wide sewage system and processed outside the city, in the city's region. The spatial scales used in this research are: 1) building (GT), 2) neighborhood (BK), 3) city (Amsterdam), 4) region (Metropolitan Region Amsterdam (MRA)), and 5) external (beyond the MRA). In principle, almost all resources can be treated on various spatial scales, depending on the type of system you implement. To identify these resource flows and locate where they flow, the following questions were asked: *"What types of resources flow through the FEW systems of the GT?"* & "How are the FEW flows spatially distributed?".

4.2.1.1 Resource flow types

Below, the various resource flow types per FEW systems that are included in this research will be elaborated upon. The information given mainly informs on generic features of the resource flow. The flow types are based on data collected from secondary sources.

Food

Food for human consumption is produced and sold in the GT, through various channels such as a restaurant, bar or even straight away from the indoor vertical farm.

Humans consume food to maintain biological processes essential for survival (Jacobs & Tapsell, 2007). The pattern of food consumed by an individual is called a diet. Apart from a normal mixed diet, various popular diets are plant-based, vegetarian, moderate (low energy intake) and even meal-replacement diets (for instance nutritional drinks) (Turner-McGrievy et al., 2021). Which diet you follow, also influences your nutrient intake. A diet contains various food groups that collectively provide the nutritional needs of the body. A western diet (consumed in western countries) includes the following food groups: cereals and cereal products, vegetables and fruits, roots and tubers, milk and other dairy products, meats, fish, eggs, other sources of protein, fats, and oils. The human body requires both macronutrients (carbohydrates, protein, and saturated and unsaturated fats) and micronutrients (vitamins and minerals) (Geissler & Powers, 2017). The main sources of food production are the agricultural practices of crop production, livestock production, and fisheries production (Porter et al., 2014). Most foods are then processed in food processing facilities before consumption. In the Netherlands, we eat foods that are produced all around the world.

Nutrients

In the GT, multiple green systems such as the indoor vertical farm and the vertical city park require nutrients for their plants to grow.

Nutrients are essential to a plant's growth. In nature, nutrient availability regulates itself through natural composting and soil processes. However, intensification of agricultural practices has led to an increased need for mineral nutrients. The main required nutrients for agriculture are phosphorus and nitrogen, and their availability depends on phosphate mining and nitrogen fixation. Phosphate is a finite resource and nitrogen fixation costs vast amounts of energy. Therefore, nutrient recycling is gaining traction. Nutrients such as phosphorous and nitrogen can be recycled from food waste, green waste, and various types of wastewaters (Kjerstadius et al., 2015).

Organic waste

In the BK, organic waste consists of *food waste* and *green waste*. The Green Tower will collect food waste from households and shops, and plant waste from gardens, green roofs, and city parks.

Food waste is a bio-degradable effluent from various sources such as the food processing industry, households, and hospitality sector. It contains, among others, vegetables, fruits, meat, dairy products, cereals, and baked goods. The FAO estimates that about 28% of the world's agricultural lands used for food production, produce food that is wasted. In conventional practices, food waste ends up in municipal incinerators or landfills (Paritosh et al., 2017).

Green waste is the by-product of produced from the maintenance of public green areas, city parks, forestry, and other green spaces. It contains dead trees, tree stomps, pruning of trees and shrubs, leaves, grass, and dirt. Due to its low energy content and high water content, green waste is usually sent to composting plants or landfills (Pedrazzi et al., 2019).

Heat

Heat is thermal energy used in the GT (and BK) to heat indoor spaces.

The energy transfer from an object or substance with a high energy content to air, is called heating. There are various heating options for spaces: electric heating, water heating, steam heating or heat pumps. For all types of heating, an energy source is required, such as the combustion of fossil fuels or electricity. Solar radiation is also capable of heating a space, and even humans or running machines transfer heat to air. Heat can be stored underground, in groundwater and the substrates around it (Andersson, 2007).

Cold Cold is thermal energy used in the GT (and BK) to cool indoor spaces.

The energy transfer from air to and object or substance causes cooling. There are various cooling options for spaces, for instance: radiators, HVAC, coolant, or heat exchangers. For all types of cooling, an energy source is required, most often electricity. Cold can also be stored in groundwater and the substrates around it (Andersson, 2007).

Electricity Electrical energy is used throughout the GT (and BK), mainly to power systems, appliances and provide lighting.

Electricity can be generated by renewable and finite resources. Renewable resources, such as wind, wave and solar energy are becoming increasingly important in the city’s electricity provision. Finite resources such as coal, oil and gas are becoming increasingly scarce, and their combustion has negative impact on the climate. Energy can be generated locally, for instance by PV-panels, or centrally, for instance by a gas-fired power station.

Black wastewater Sanitary facilities in the GT (and BK) will produce black wastewater.

Black wastewater consists of (flushing) water and feces. This type of wastewater has a high phosphorous and nitrogen content, which could be recycled (Kjerstadius et al., 2015). In conventional practice, black wastewater is combined with other domestic wastewater flows (grey and yellow wastewater) and is transported over large distances to central treatment plants in the city region. The aerobic treatment processes it will undergo, uses a vast amount of energy, and creates a sludge that is too heavily contaminated (with for instance heavy metals) to be reused in agriculture recycled (Kjerstadius et al., 2015). Decentralized practices, such as treatment by a neighborhood bio-digester, allow reuse of the effluents.

Yellow wastewater Sanitary facilities in the GT (and BK) will produce yellow wastewater.

Yellow wastewater consists of (flushing) water and feces. From this type of wastewater struvite can be extracted, which consists of phosphorous and nitrogen (Ishii & Boyer, 2015). In conventional practice, yellow wastewater is combined with domestic wastewater and undergoes the same path as black wastewater, described above. However, source separation of yellow wastewater allows local treatment and the recovery of phosphorous and nitrogen from struvite (Ishii & Boyer, 2015).

Grey wastewater Grey wastewater is produced in the GT (and BK) in kitchens and other water using facilities.

Grey wastewater originates mostly from showering, washing hands, dish washing and washing clothing. It contains relatively high amounts of chemicals, pathogens and micropollutants (Capodaglio et al., 2017). In conventional practice, grey wastewater is combined with domestic wastewater and undergoes the same path as black wastewater, described above. Grey wastewater can also undergo local biological membrane treatment (Capodaglio et al., 2017).

Rainwater Rainwater that falls on the GT, can be harvested, and used in for instance the indoor vertical farm and vertical city park.

Rainfall events are becoming more intense in the Netherlands, causing street flooding and other runoff related problems. Proper measures must be taken to prevent disturbance by rainwater, one option is harvesting it. Domestic rainwater harvesting is the process of collecting water from roofs, streets, and courtyard runoffs (Helmreich & Horn, 2009). This water can be used for instance in agriculture or watering plants in times of drought.

Drinking water Fresh, drinking water is mainly used for humans visiting the GT. However, most fresh water will not be directly consumed, but used for washing dishes, flushing toilets and possibly for watering plants.

Filtered water of high quality used for drinking, usually from blue water sources. In Amsterdam, Waternet provides drinking water and is also the only institution allowed to do so. The water is extracted from surface water and groundwater, is treated through multiple natural and artificial steps (Waternet, n.d.-a).

4.2.1.2 Spatiality of resource flow types

Resource flows operate at various scale levels. From a sustainability perspective treating resource flows locally, preferably on building level, is often a best practice. However, benefits of scale also apply to treating resource flows. For instance, treating wastewater on a large scale, outside of city borders, allows it to be a very energy efficient process with a high space efficiency. Filtered water is discharged back into nature and the effluents incinerated. The adoption of a sewage systems and centralized wastewater treatments in developing countries still save many lives by eradicating diseases caused by cross contamination between locally discharged wastewater and drinking water sources (Kohli, 2014). However, by combining black, yellow, and grey wastewater the ability to retrieve nutrients and generate electricity are lost. Local, source separated, wastewater treatment does allow nutrient recovery and electricity generation recycled (Kjerstadius et al., 2015). The produced nutrients can be applied in for instance urban farming practices, and the electricity can feed the urban area surrounding the treatment facility. The scale levels of the resource types identified for the GT, are given below.

Food	Food will be produced on a building level in the Green Tower. However, this only accounts for leafy greens, vegetables, and herbs. The restaurant and bar will still have to import other foods, that are probably produced on a regional, national, or even international scale level.
Nutrients	The bio-digester will most likely produce enough nutrients for the Green Tower. This means that the nutrients operate on a building scale. There is a possibility that nutrients even must be exported to different locations, such as city parks or agricultural lands in or around Amsterdam. It could be argued that the nutrients do not come from the tower itself, as the food waste they come from, are not all produced locally, and possibly from around the world. Meaning that these nutrients come from soils or mines, from international sources.
Organic waste	The organic waste is collected from within the BK neighborhood, thus comes from a neighborhood scale level. The organic waste is treated within the building.
Heat	Heat is generated, distributed, and stored within the GT and BK neighborhood, and thus operates on a building and neighborhood spatial scale level.
Cold	Cold is captured, distributed, and stored within the building and neighborhood, and thus operate on a building and neighborhood spatial scale level.
Electricity	Electricity will be generated on a building level, however, if the building is not energy neutral or positive, it will require additional energy from neighborhood, city, or even regional sources.
Yellow wastewater	As there are no plans for a local 'new sanitation' system, the yellow wastewater will be discharged in the central sewage system and treated by the municipality's wastewater treatment plants. The yellow wastewater will be produced on a building scale and treated on a regional scale.
Grey wastewater	As there are no plans for a local 'new sanitation' system, the grey wastewater will be discharged in the central sewage system and treated by the municipality's wastewater plants. Grey wastewater will be produced on a building scale and treated on a regional scale.

Black wastewater As there are no plans for a local 'new sanitation' system, the grey wastewater will be discharged in the central sewage system and treated by the municipality's wastewater plants. Black wastewater will be produced on a building scale and treated on a regional scale.

Rainwater Rainwater will be collected and used within the building and/or neighborhood.

Drinking water Drinking water will be sourced from Waternet, and thus come from a regional scale.

4.2.2 Theoretical and visual representation of the FEW systems in the Green Tower

4.2.2.1 Mapping the FEW systems of the GT and Bajeskwartier

As a next step, the most important FEW systems were mapped (figure 22). The mapping includes all important systems within the GT, all relevant systems in the BK, relevant utility systems in the BK and connecting infrastructure that is built in the neighborhood. Moreover, the resource flows that enter the GT as resource, and leave the GT as effluent are depicted.

The mapping was based on the progress report of BKO, which is also used as input for most other GT related design questions in this research (Bajes Kwartier Ontwikkeling, June 2020). Throughout the document systems are mentioned which were mapped. The inflows and outflows of these systems are based on desk research and some conversations with stakeholders from the GT project. The goal of this mapping was to get the best possible understanding of the FEW systems of the GT and BK, with the information currently available. A larger version of the mapping can be found in Appendix 1.

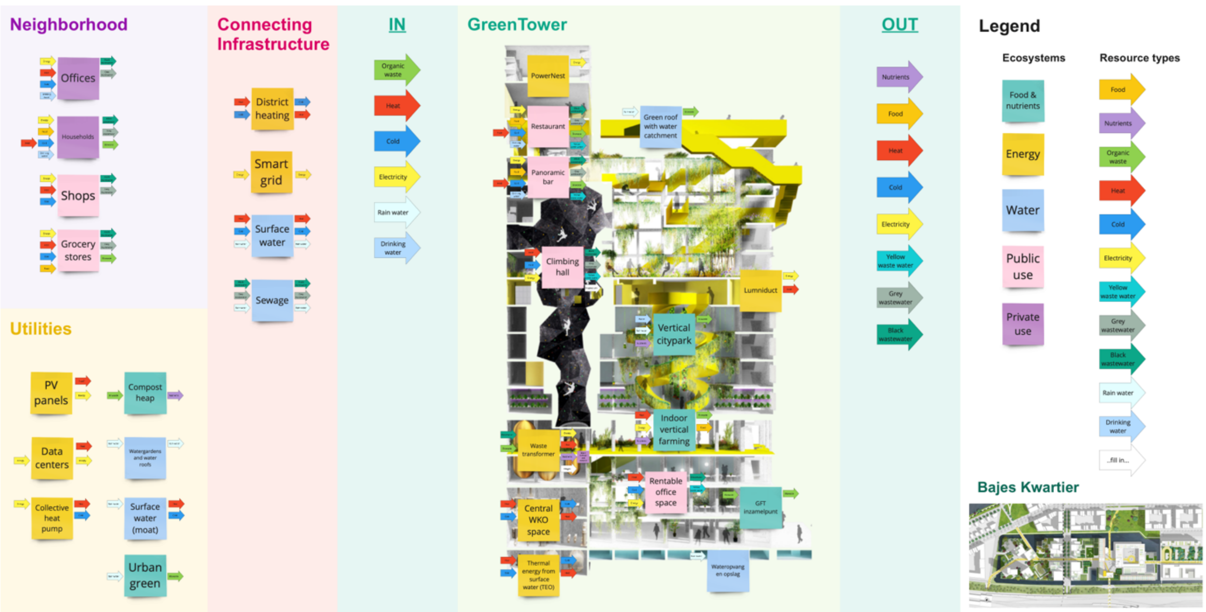


Figure 22: Mapping of the FEW systems in the GT and BK. The mapping includes food & nutrients, energy, water, public use, and private use ecosystems. The flows described are food, nutrients, organic waste, heat, cold, electricity, yellow wastewater, black wastewater, grey wastewater, drinking water and rainwater. A larger version of the mapping can be found in Appendix 1 (own illustration).

4.2.2.2 Connecting resource flows within the Green Tower

The systems of the GT, and their in- and outflows have been mapped. In this step, relations are made between the in- and outflows of the various systems. This is done for each of the FEW systems separately. The mapping of the relations was mostly done using common sense and accessing secondary data sources. Moreover, two separate one-on-one co-design sessions were hosted with a member of the BK Living Lab, and an intern at FABRICations. In these two sessions, the initial connections made were discussed and additional connections added. All theoretically possible relations are mapped, this also includes relations that are not made in the design of the GT yet. Moreover, the relations have been discussed with representatives from the GT design team, to validate their correctness.

Relations between the food systems of the Green Tower

Three major flows are identified in the food system of the GT: organic waste, food, and nutrients. The relations between the food systems can be observed in figure 23. Organic waste is an effluent generated by several systems in and around the GT. The organic waste of households and urban green is collected in the GT. The bar, restaurant, vertical farm, and vertical city park produce organic waste, which is collected in the organic waste collection point. Some organic waste from the urban green from the BK can be collected in the compost heap and turned into nutrients used in the vertical city park. The organic waste collected in the organic waste collection point, can be used in the bio-digester. The bio-digester, compost heap and sanitary facilities have the potential to produce nutrients. The vertical city park and indoor vertical farm require nutrients for their plants to growth. The indoor vertical farm is the only food producing system in the building. The produced food can be used in the bar and restaurant in the GT.

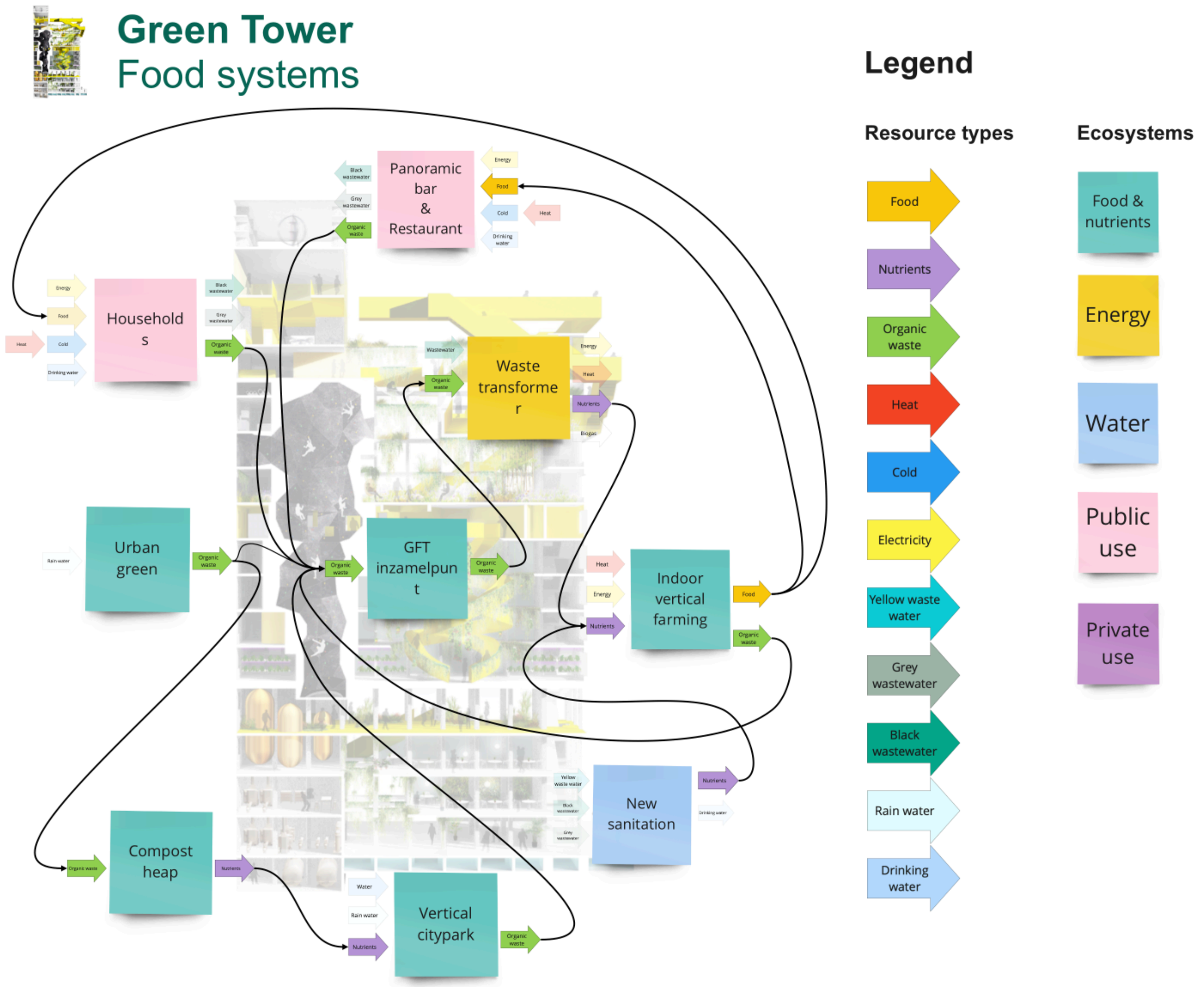


Figure 23: Food systems of the GT and their interrelations

Relations between the energy systems of the Green Tower

The energy system is composed of three resource flow types: electricity, heat and cold. The relations between all the energy systems can be observed in figure 24. Electricity generating systems are the PowerNest, PV-panels in BK, the Lumniduct and the waste transformer. The electricity generated by these systems is transported through a smart energy grid and dispersed to various systems in the neighborhood and in the Green Tower. For the energy balance of the GT however, it would be better to include only the energy demanding systems and the electricity generating systems within the boundaries of the GT itself. This way it becomes evident whether the GT itself is energy neutral, or not. Therefore, in later steps, the electricity demand of households, and the electricity generation of PV-panels in the BK neighborhood will be excluded. Other electricity demanding systems are the restaurant, bar, office spaces, indoor vertical farm, and heat pump.

Heat generating systems are the Lumniduct, waste transformer and indoor vertical farm. Moreover, the ATES captures heat in the summer. Heat is used by functions in winter, to provide a comfortable climate for their visitors. Heat consumers are the restaurant, bar, office space and through the district heating network, households of the BK.

Cold is not specifically generated through any system in the GT. Cold is captured in winter to counter the heat provided to a system. In summer, the cold is once again used to cool systems. Systems that require cooling are the same as systems that require heating.

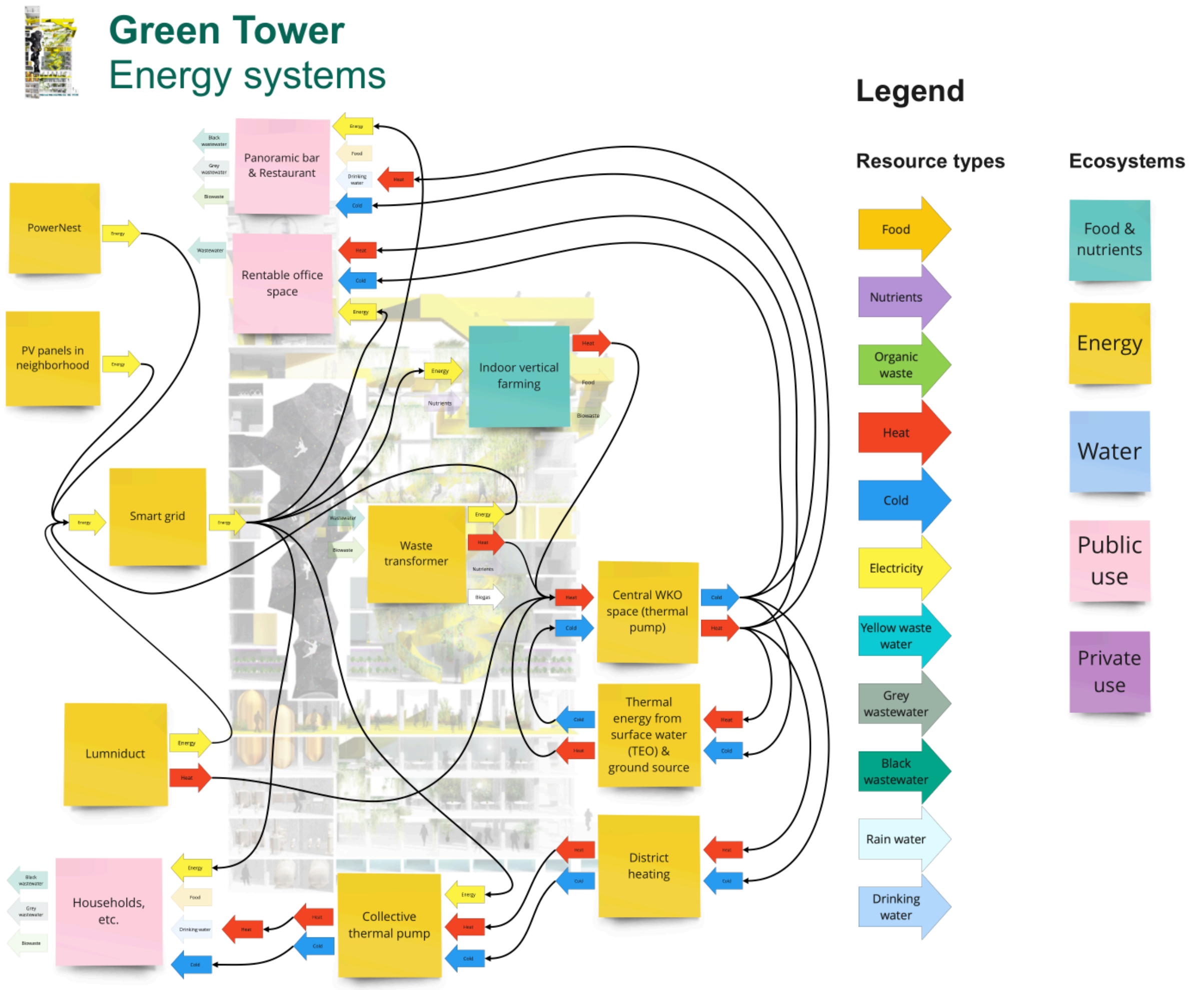


Figure 24: Energy systems of the GT and their interrelations

Relations between the water systems of the Green Tower

The water system of the GT is composed of five resource flow types: fresh water, rainwater, black wastewater, yellow wastewater, and grey wastewater. Relations between all water systems can be observed in figure 25. Drinking water is provided by the water authority, Waternet. This water is used in the bar, restaurant, households, Indoor vertical farming, and vertical city park. Drinking water is not produced anywhere in the GT or BK, as only the water authority Waternet is allowed to produce drinking water. Precipitation can be caught on the roof of the GT and stored or retained in a green roof or water storage. Rainwater can then be reused to water plants. This would reduce the use of fresh water for watering plants, to only being needed when there is limited precipitation.

Black, yellow, and grey wastewater is produced by the systems that service visitors: the restaurant, bar, and office space. These wastewater streams could be locally processed by local treatment installations. These local water treatment installations are grouped under the term 'new sanitation'. If these systems would be applied, clean water and nutrients could be locally generated.

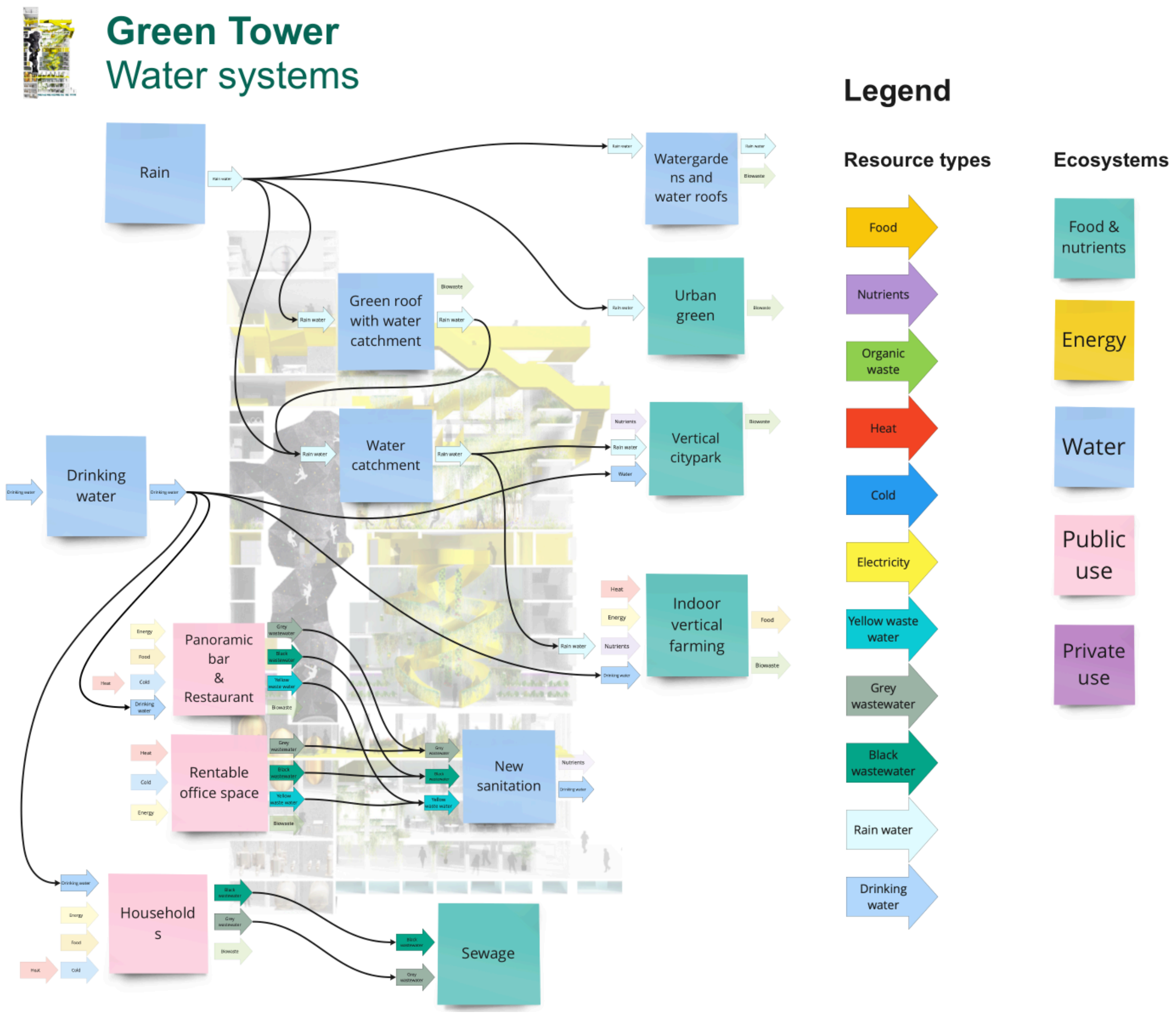


Figure 25: Water systems of the GT and their interrelations

4.2.3 The visual representation of the FEW systems in the Green Tower

4.2.3.1 Theoretical basis for the system diagram

The system diagram of the Green Tower is based on the FEW Nexus. In the previous paragraphs the various systems planned for the GT and their resource flows are discussed. In 2.2.1, connections are made between the systems of the GT through their resource flows, within their own domain: food, energy, or water. In this chapter the systems in the GT and their resource flows across the FEW domains, will be combined. Besides serving as the basis for the quantitative model in the next chapter, this confluence of FEW domains enables the user to see the interrelations between FEW and their systems. Being aware of the interrelations between FEW and realizing how making changes to one domain effects the others, is the essence of the FEW Nexus (Hoff, 2011). The goal of the system diagram made, and is shown in the next paragraph, is to capture exactly that essence for the FEW systems in the GT in one figure.

4.2.3.2 All systems of the GT visualized in one figure

Creating the system diagram of all FEW systems in the Green Tower, and their relations to the BK and Metropolitan Region Amsterdam, has been a joint effort between stakeholders of BKO and this research. The process included two one on one sessions with a member of the BK Living Lab and two one on one sessions with an employee of Fabrications. In these one-on-one sessions, the system diagram was thoroughly discussed and data on various systems was gathered. The most important outcome of the sessions was the format of the system diagram itself and the relations between all systems. The sessions had been hosted through ZOOM, and MIRO was used as online collaborative space. The MIRO board can be observed in Appendix 2. Moreover, while doing the sessions, both stakeholders improved their knowledge on how the GT was operating. This has translated to changes in the design of the Green Tower.

The system diagram and theoretical model were created through two one-on-one co-design sessions. The data from 4.2.1 and 4.2.2 were presented in two separate sessions to a member of BK Living Lab, and an intern at FABRICations responsible for creating a metabolism for the GT. The two presentations were followed by a one-on-one co-design session where the best way to visualize these FEW systems as one system in MIRO, was discussed. From the first session it was concluded that a system, showing circular flows, such as the circular economy model of the Ellen McArthur Foundation (figure 26), was something to be aimed for. Moreover, it was decided that adding the experience center, as transformation center, suited the ambitions of the building well. As the building is not merely focused on being sustainable, but also teaching sustainable practices. In the second session, the first draft of the system diagram was discussed. Mostly the correctness of the new interrelations between FEW systems were discussed. The system diagram was updated according to the latest designs. Also, a first step to quantifying some streams was made. This data was used as input for the quantitative model.

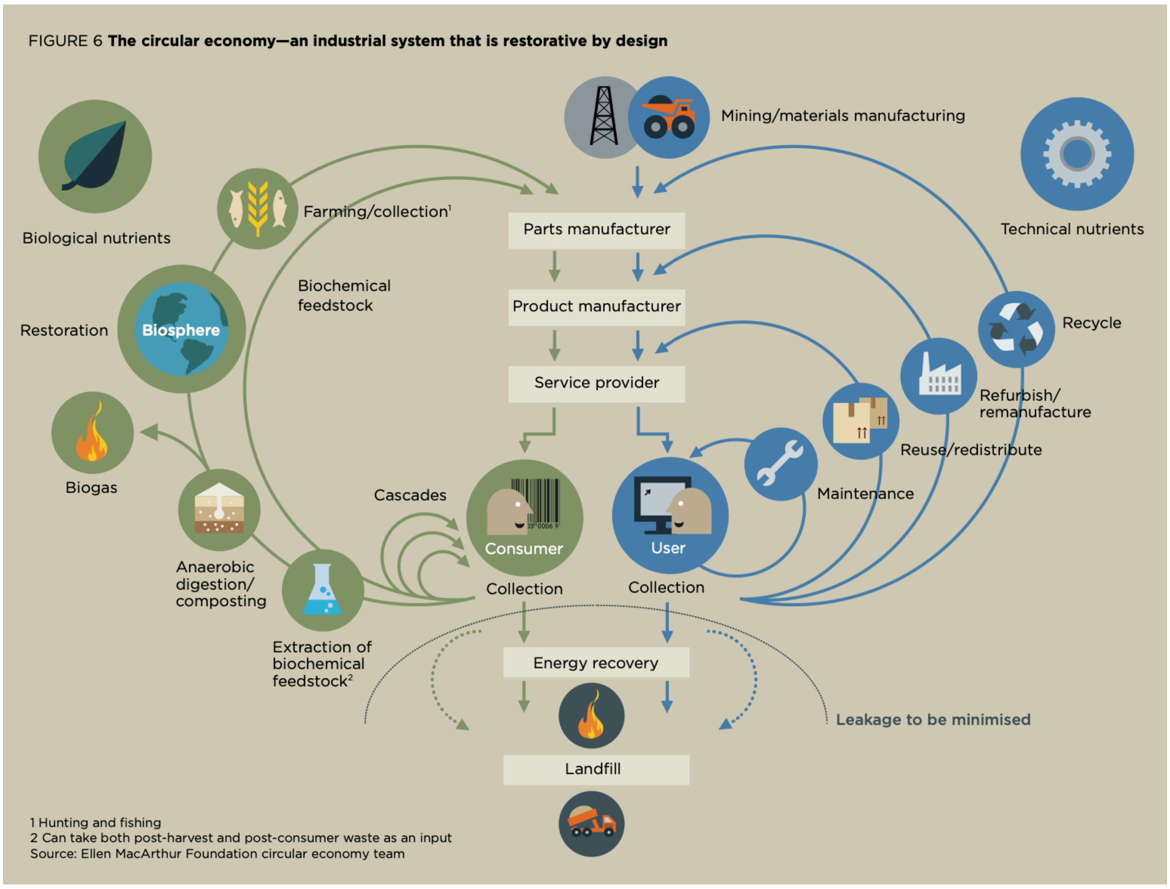


Figure 26: The circular economy as depicted by McArthur (2013). The diagram depicts how technological and biological nutrient-based products and materials cycle through the economic system (McArthur, 2013).

A starting point for the system diagram is the well-known circular economy diagram of the Ellen McArthur foundation (MacArthur, 2013). In this diagram (figure 26), the circular flows of technical and biological materials are displayed. The diagram shows how at the end-of-life status of a product, it should be brought back into the system, creating almost infinite loops. The goal of the system diagram created in this thesis, is to keep FEW resources circulating in the system, at the most local level as possible. Residual FEW flows from the GT and BK are transformed into valuable resource flows within the GT. However, transforming all FEW flows locally is not possible. In that case the flows need to be treated by the MRA. For instance, wastewater treatment, is currently not planned in the BK neighborhood and will be treated in the central wastewater plants of the MRA. The theoretical model shows that resource flows should be processed as local as possible.

The system diagram of the GT's FEW systems can be observed in figure 27 and Appendix 3. The system diagram is the result of multiple design iterations which were executed together with two of the three involved parties in designing the GT. The system diagram shows the relations between the planned systems for the GT, relevant systems in the BK and relevant systems of the MRA region. The relations are based on FEW resource flows. Moreover, the systems are divided over two types: users and transformers. Users mainly consume resource flows and generate residual flows. Transformers transform residual resource flows into resource flows ready to be consumed by the users.

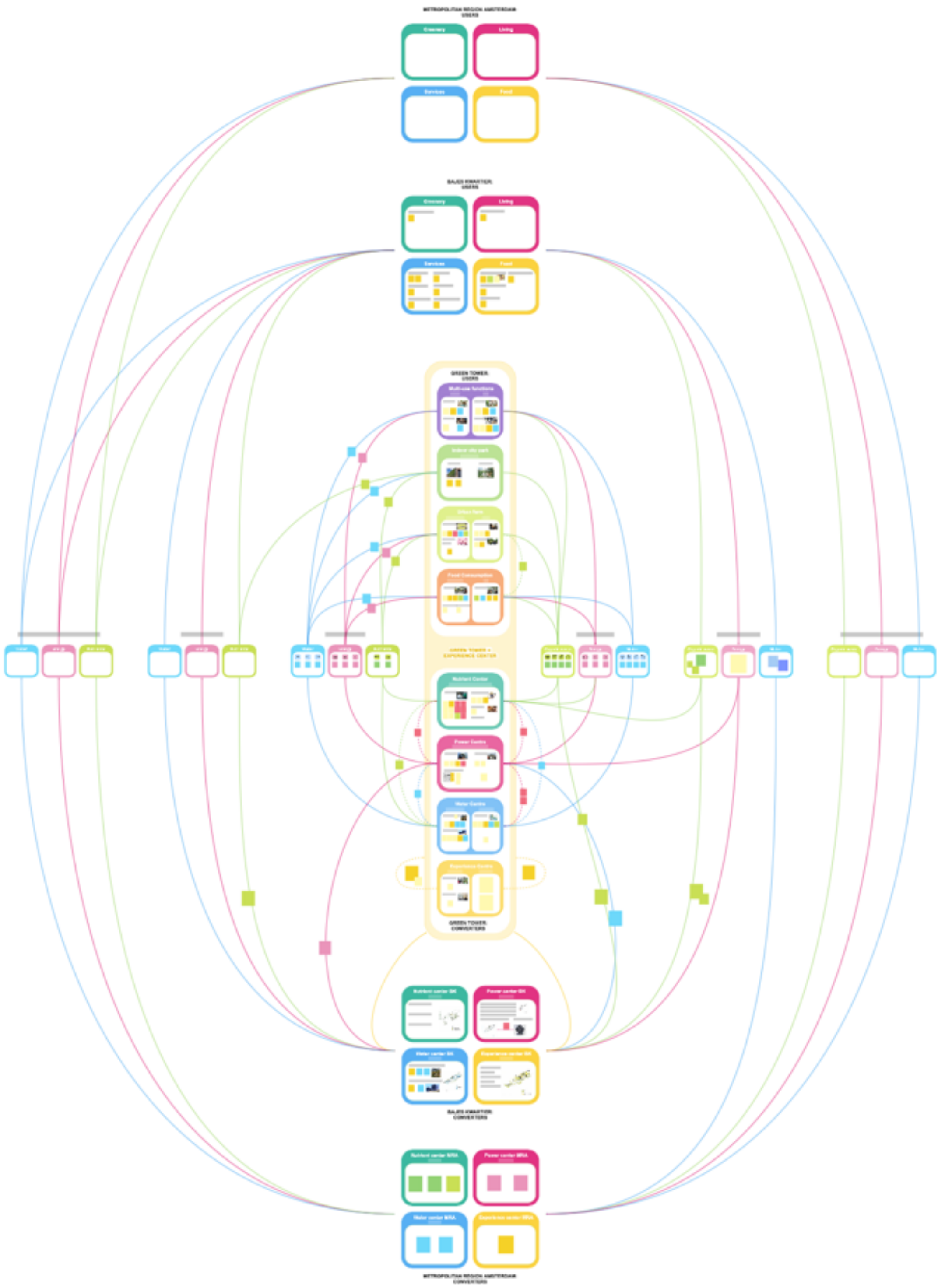


Figure 27: The system diagram of the Green Tower's FEW systems and relations, based on co-design sessions with stakeholder of the design team. In this example, and extra transformation center is added: the experience center. This transformation center provides knowledge. It is not part of the FEW Nexus and will also not be elaborately discussed.

The system diagram has been turned into a theoretical model (figure 28). This theoretical model shows how the relations in FEW between the users and transformers, the relations between the transformation centers, and the relations between the building, neighborhood and city scale level can be made. The transformation centers produce FEW resources, which are used by the users, the users create residual resources, which will be transformed into resources again in the transformation centers. The model also shows how resource flows can flow between scale levels.

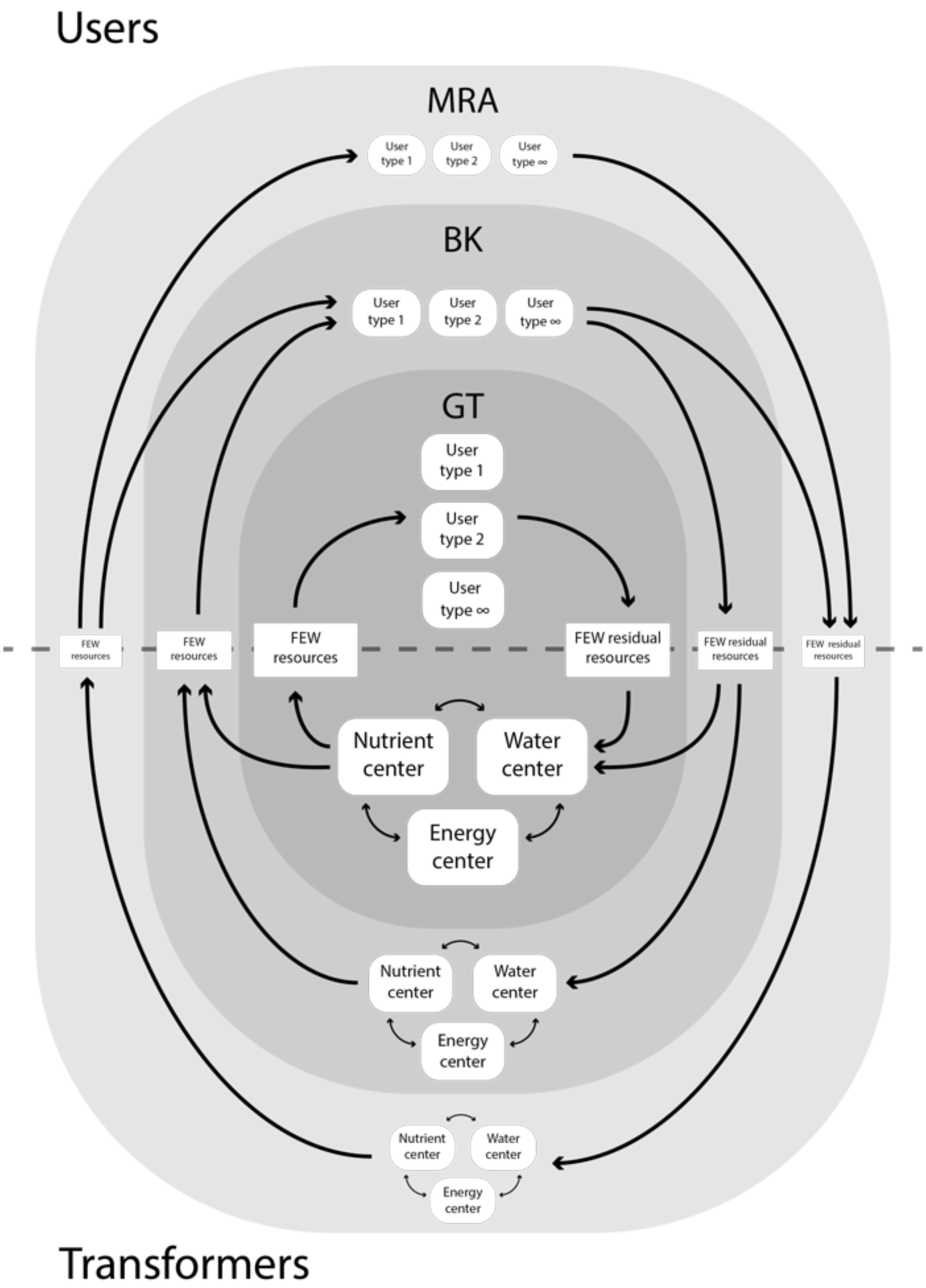


Figure 28: Theoretical model of FEW relations in a neighborhood sustainability hub, showing how user and transformer interrelated over the scale levels of the GT, BK and MRA. The transformers are a set of water, nutrient, and energy systems capable of producing valuable resource flows from residual resource flows (own illustration).

To clarify the system diagram, a few elements will be highlighted: the transformation centers, the users, and the flows. In Appendix 3, a closer look can be taken to further inspect the other elements.

The transformation centers can be seen in figure 29. The term 'center' is more a theoretical term than a technical term. The term is used to indicate a set of systems, that has a strong focus on one of the FEW themes. For instance, the nutrient center, includes the bio-digester and compost heap. Apart from containing the systems of the center, the relations between the centers are also given. The nutrient center also produces heat and electricity. The water center requires energy for water transportation and purification. The water center can also provide the nutrient center from sludge to be turned into nutrients. The bio-digester in the nutrient center also produces water, which can be purified in the water center. And so forth.

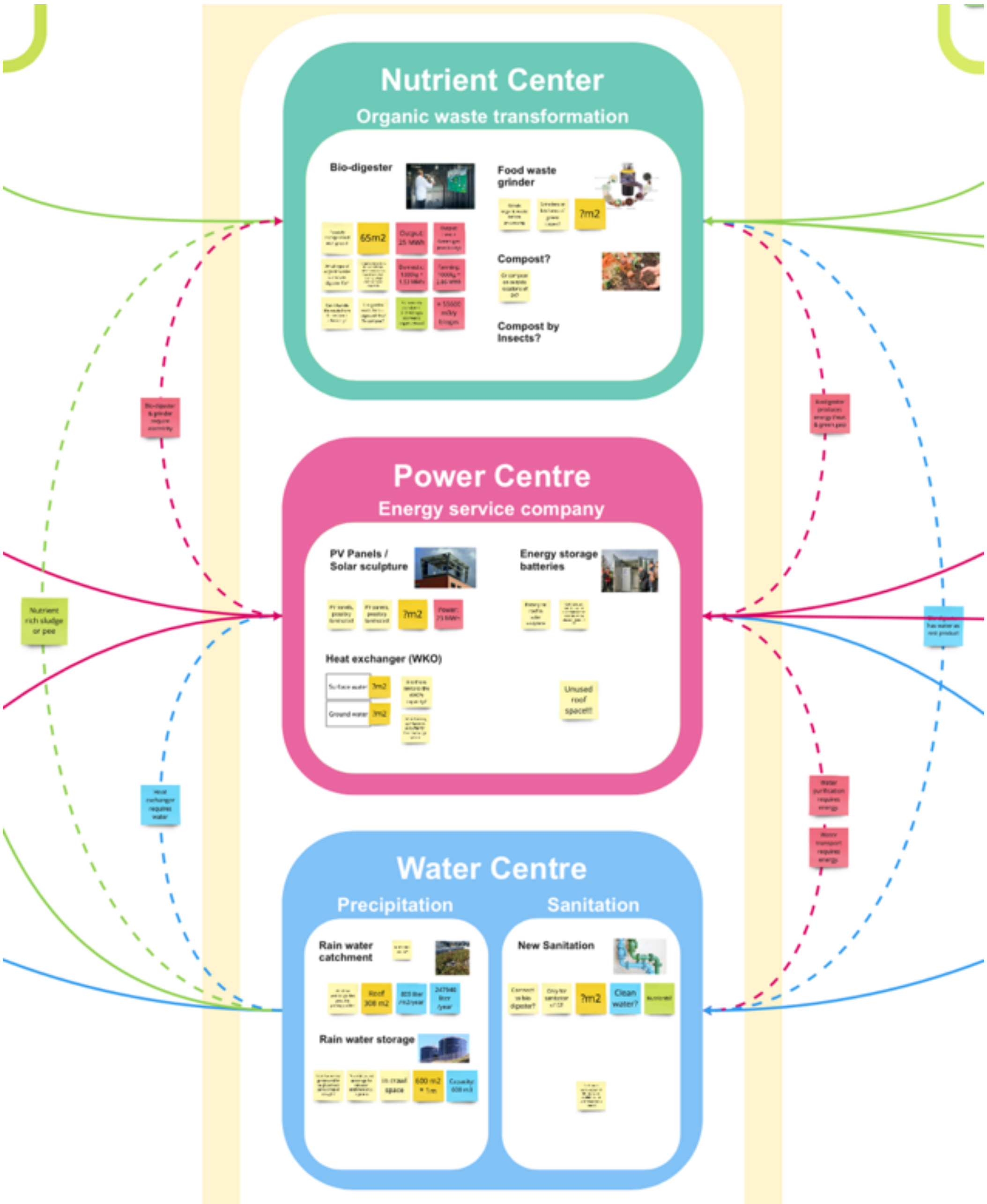


Figure 29: Screenshot from the GT system diagram. The screenshot shows the water, power and nutrient center and their interrelations.

The user types 'multi-use functions' and 'indoor city park' are shown in figure 30. This example of user functions shows to functions with different resource inflows. The multi-use functions require drinking water, electricity, and thermal energy. Whereas the Indoor city park requires compost, drinking- or rainwater and nutrients.

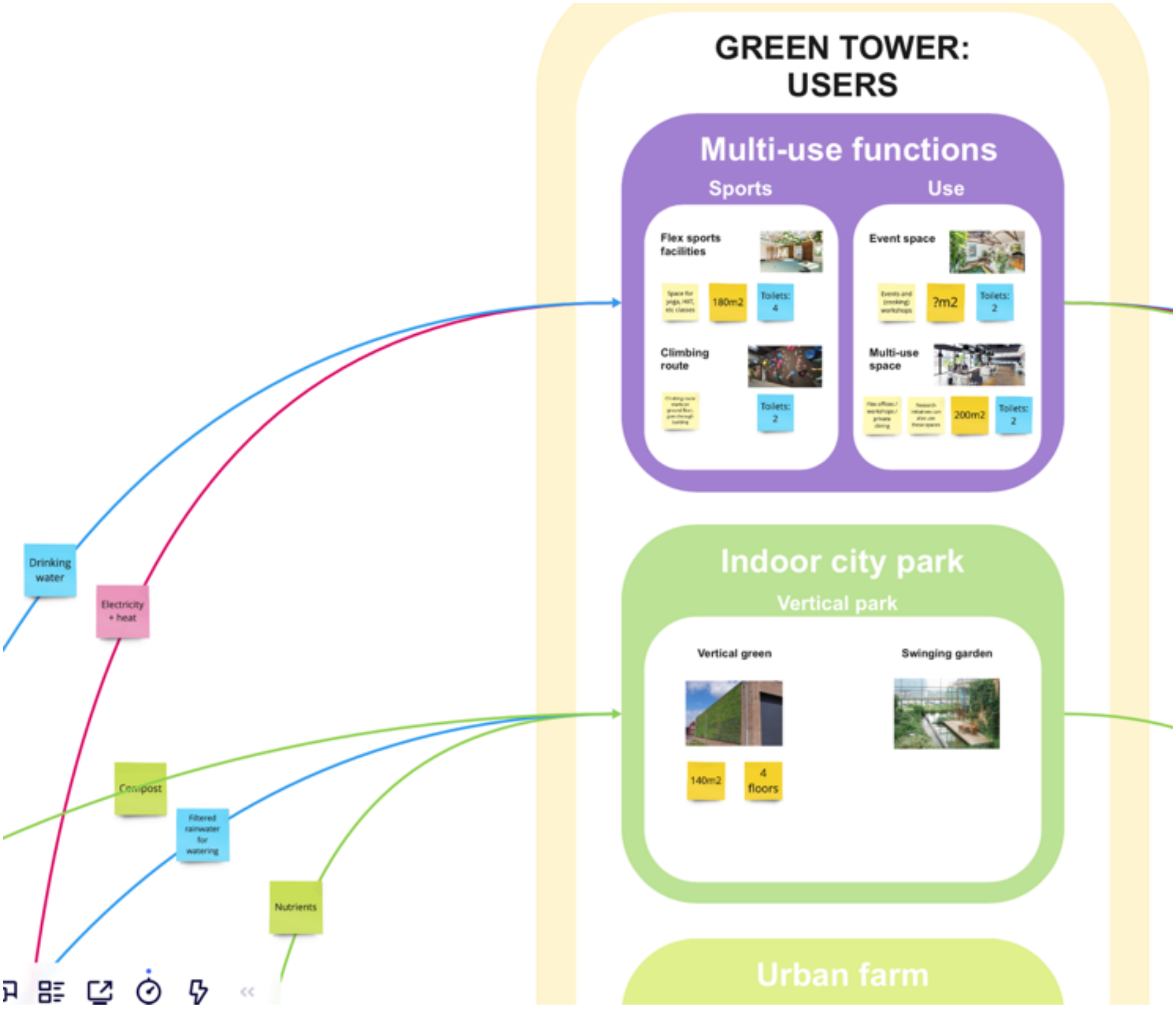


Figure 30: Screenshot from the GT system diagram. The screenshot shows the user types: multi use functions and indoor city park. Moreover, the inflows of these user types can be seen on the left

The residual flows of the Green Tower, as displayed in the system diagram, are shown in figure 31. In the system diagram, organic waste has been divided in garden waste, domestic organic waste, kitchen organic waste (from bar and restaurant) and urban farming waste. All these waste types can be processed in the bio-digester. The energy flows are divided in electricity, heat, and cold, and the water flows in rainwater, black wastewater, grey wastewater, and yellow wastewater. A first attempt to quantify the flows had already been made in the system diagram. This was done as initialization for the quantitative model and had the purpose to indicate which flows were quantifiable.

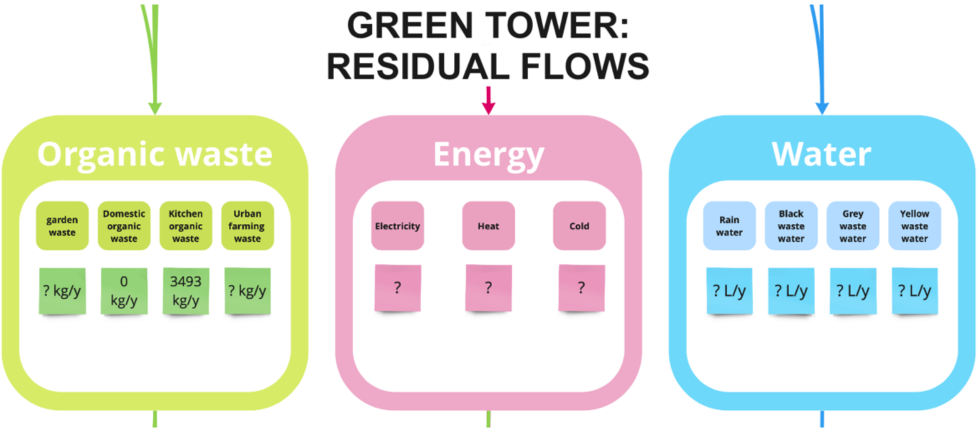


Figure 31: Screenshot from the GT system diagram. The screenshot shows the residual flows of the Green Tower, being organic waste, energy, and water.

4.2.3 Summary of system diagram of Green Tower FEW systems

FEW systems are essential in urban areas. Thinking about their interrelations is new and a difficult process. Thinking from a FEW Nexus perspective has helped to get an overview of the FEW demand and supply of FEW systems. The system diagram is an effective tool to help show the interrelations between FEW systems. The most important resources that flow between the FEW systems of the Green Tower are:

Food & Nutrients

- Organic waste
- Nutrients
- Food (vegetables & leafy greens)

Energy

- Heat
- Cold
- Electricity

Water

- Yellow wastewater
- Black wastewater
- Grey wastewater
- Rainwater
- Drinking water

In the preliminary program of the GT, the FEW relations drawn between the food systems, closely resemble the potential nutrients relations as drawn in 4.2.1. Potential new relations could be drawn between the nutrients derived from yellow and black wastewater to nutrient demanding systems like the indoor vertical farm or the vertical city park. The energy ecosystem of the GT has been well described in the preliminary design. Quantifying the relations drawn in 4.2.1 will have to show whether the energy ecosystem is well balanced. The water ecosystem had been very poorly described in the preliminary design. This chapter has shown the valuable relations that can be drawn from black and yellow wastewater flows, if treated by local wastewater treatment systems.

The theoretical model, based on the system diagram of the FEW systems and relations in the GT, can potentially be used as a model to use as basis for mapping the flows of other future sustainability hubs as well.

4.3 Quantifying the flows of a sustainability hub

The aim of this study is to understand the relations between FEW on a building and neighborhood level and create a tool that shows and quantifies these relations. This chapter will answer the question: *"How can food, energy, and water flows be captured in a quantitative model for a sustainability hub?"*. In the previous chapter a system diagram has been created, showing the FEW systems of the GT and how they operate over various spatial scales. The systems and relations identified in chapter 2, will be used as basis to create a quantitative model that shows the balances in FEW resources for the GT. This model should be flexible, easy to use and easy to interpret by the user. Before making the quantitative model, the goal of the tool and the quantitative model is elaborated upon. Next, it is decided how the quantitative model will be built up, based on the earlier identified goal. Afterwards, for all elements of the model the main data sources, calculations and outcomes will be explained.

4.3.1 The quantitative model and its goal

The goal of this research, the tool, and quantitative model created in this chapter is to be able to quantity and scale all FEW systems and related systems to balance their resource flows. Before creating a balance, it should be clear what you are balancing and how the balance is created. Moreover, whether an actual balance in FEW resources can be reached depends on the available space, the number of users and the goals of the project the tool is used for.

4.3.1.1 Creating resource balances

What is a resource balance? For this model, balance is achieved if the supply of a resource meets its demand within the ecosystem's limits. As we are working in three domains, FEW, a balance can be reached for all resource flows within each of the domains. In theory, if all resources are in balance, your FEW ecosystem is in balance. Reaching a balance is not as easy as increasing your production in one system, to meet the demand in the other. This is because, from a FEW perspective, increasing the production of one system effects its demand for resources from other systems. As an example, if there is a food shortage, increasing the space planned for a vertical farming system can supply the gap in food demand. However, increasing vertical farm production, increases the demand for energy, water, and nutrients from other systems. Luckily, there are also systems that do not require resources from other systems such as PV-panels. If this was not the case, changing one system would set a chain reaction indefinitely requiring the growth of other systems.

Creating a resource balance at the scale of the GT is very well possible, however creating an actual balance in FEW will be impossible for the GT. This will be explained in the following sub-chapter.

4.3.1.2 Space, users, and project goals

Before going deeper into the effects space, users and project goals have on choosing which resource balances are aimed for, it should be realized that creating an ecosystem that is in perfect balance, is more of an ideal than a realistic goal. It requires a closed system with closed boundaries, which is impossible in our open society. A neighborhood for instance, is part of a city with people, goods and resources traveling to other neighborhoods, or even other cities, nations, or continents.

With full circularity and closed loops as an ideal, choices can be made based on space, users, and goals. Limitations in space lead to having to make choices between systems. For this choice to be made, questions can be asked like: which system serves the purpose of the project best? On which of the

FEW eco-systems lies most pressure within the urban context the project is situated in? Which systems give the project the highest benefits for the least space? A focus on water retention and reuse, might be very valuable if the building or targeted area has a very large lot size and the building you are working with has only a few floors. In this case you will have a large water catchment potential. However, if you are working with a rather small plot size and a high-rise building, like the GT, your water catchment potential is very small. Therefore, focus on water retention and catchment is not the most logical or important option. Producing food in this high-rise building can be far more beneficial. Using multiple floors for food production, can make this relatively small plot a highly productive food system.

If tool is used for a project with a user-oriented program, it can be chosen to tailor the selection of systems to the user's needs. In the GT, the users are the restaurant, bar, climbing hall, sports facilities, educative spaces, offices, and event spaces. What do the users offer to their visitors? What stories do the users want to tell? Imagine your users are oriented on feeding people sustainable food, such as a restaurant or a fresh market. In that case it, it is logical to put your focus into systems that produce vegetables and recycle nutrients. Another focus of your users could be to offer their visitors an experience in a sustainable way, such as a cinema, museum, or arcade. For them, being energy neutral or positive might be more valuable. What your users and their visitors want is very important because in the end you are designing a sustainable and efficient system for them.

The sustainability hub also serves the neighborhood, creating a different type of users. The neighborhood might be very interested in making sure their organic waste is locally produced. Or they want their neighborhood to be energy positive. In the end, a sustainability hub is always user oriented; whether it focusses on the users inside of the building the hub is based in, or on the neighborhood the hub operates in

The goals of the project, and thus the design team using the tool, is very important in choosing the resource balances aimed for. Their goals are, hopefully, well aligned with the user's needs and the space available. However, the goals of the project can serve a bigger purpose than to serve the needs of the users within the sustainability hub's direct reach. Maybe they want to align goals set by local or national governments. Or perform better on a FEW topic than another neighborhood. This can also lead to choices in FEW systems and aimed resource balances to be made.

4.3.1.2 The goal of the quantitative model

The goal of the quantitative model is to understand the effect of the scaling systems on resource balances within the building. The balances aimed for, depend on the building's available space, (future) users and the project's goals. In the case of the GT, the users and their visitors in the tower are a very important driver for the choices made in FEW systems. This is also visible in its program, where a very large part is public space. It is also indicated that its FEW systems also have a public function. Meaning that a part of space planned for FEW functions, such as the vertical farm and bio-digester, is used to receive visitors to observe how the FEW systems operate.

4.3.2 Workflow of the model

A workflow is a sequential series of performing tasks and making decisions. In this research, the workflow of the quantitative model is the logical sequence of tabs used in the model. The sequence and content of the tabs is based on the goal of the model; creating a quantitative model that shows the balances in FEW resources for the GT and is flexible, easy to use and easy to interpret by the user. The user referred to in this sub-chapter, differs from the user explained in the previous chapter. The previous chapter described the user of the building and its systems, while this sub-chapter refers to the user of the model. In the following paragraphs, the sequence of model tabs and content will be explained, followed by a more thorough explanation of the contents of each tab.

The goal of the model is to show and scale resource balances in a sustainability hub, in this case the GT. To show the resource balances, it must first be determined what the demand and supply of certain resources is. To do so, two types of data are needed. First, the resource demand and supplies of all systems planned in the tower for a certain spatial unit must be clear. For instance, electricity demand in kilowatt-hour (kWh) per square meter (m2). Second, the sizes in a measurement unit, for instance square meter, per planned system must be known. If these sizes of all planned systems and the resource demand and supply of all systems are known, the total demand and supply of a certain resource can be calculated, and thus its balance.

The most important element of the model for its user, are the resource balances. These resource balances should be showed in a dashboard that is easy to interpret and includes all essential information about these balances. From this moment on, this tab will be referred to as "the dashboard", it is the first and most important tab in the model. This tab should inform the user on which decisions regarding FEW systems, must be made. Next, the second most important part of the model is its flexibility. Therefore, the program of the project, in this case the GT, should be easy to insert in the model and should be easy to alter incase the program of the GT changes. The second tab of the model will be the program of the model and from hereon be referred to as "the program tab". For the balances in the dashboard to be made, the supply and demand of all resource flows must be calculated. This will be done in three tabs, each focusing on the resource flows connected to one of the FEW domains. The tabs will be referred to as "the food tab", "the energy tab" and "the water tab". Next, important for FEW demand and supply are the visitors, visiting the user functions in the building. These will be calculated in a separate tab, based on the space dedicated to receiving visitors. This tab will be referred to as "the visitor tab". In the following tabs, the resource demand and supply for each system that is planned in the GT will be calculated. This series of tabs will be referred to from hereon as "the system tabs".

4.3.3 The quantitative model explained.

This chapter explains how the model is built. It will start by explaining why Excel is used to create the model. Afterwards, all tabs that have been made in the Excel model will be elaborated upon. The purpose of the tab, and underlying main calculations are highlighted followed by the main results from the tab. The tabs are explained in the order of creation of the tabs. This means that first, the program tab will be explained, followed by the system tabs, visitor tab, FEW tabs and finally the dashboard.

Excel was chosen as software to create the model in for multiple reasons. First, the wide availability of the program was a reason to use it. It can be assumed that any potential future user of the model has access to Microsoft Excel. The widespread use of Microsoft Excel also leads to a widespread basic understanding of the program. Anyone with a school degree, will most likely have used Excel at some point in their life. Besides making the model well accessible, Microsoft Excel was also used because of the relatively basic understanding of modeling of the author of this thesis. This combined with the relatively easy calculations to be executed and its good accessibility, Excel seemed like a well suiting modeling software.

A downside of Microsoft Excel is that it is not specifically 'idiot-proof', as cells can be easily deleted or unintentionally changed.

4.3.3.1 The program

In the program tab, the size of a system in the sustainability hub can inserted and changed. The systems are already given in the tab. The program tab includes most systems identified in the system diagram of chapter 4.2. However, during the research phase of this thesis a more recent and detailed floorplan of the GT was shared. Some systems identified in chapter 4.2, for instance the Lumniduct, had been omitted from the GT's program. The changes in the program will be elaborated upon further on in this sub chapter. The floor sizes inserted to the model have derived from this same floorplan. This data is classified. If the model would be further developed, it would be valuable to add more types of systems and / or various options within a system. The program tab can be seen in figure 32 and Appendix 4.

GFA: Gross Floor Area (m2)								
Spaces (floors)	Floor area	Staircase	Unuseable space	Roof Space	Indoor space	Outdoor space	Available indoor	Available outdoor
14	127	18	0	109	0	109	0	-109
13	316	22	104	190	0	190	0	0
12	430	15	7	0	408	0	0	0
11	428	14	85	0	329	0	0	0
10	428	14	148	0	266	0	0	0
9	429	12	128	0	289	0	0	0
8	445	12	157	0	276	0	0	0
7	437	12	87	0	338	0	0	0
6	428	12	79	0	337	0	0	0
5	428	14	71	0	343	0	0	0
4	440	14	47	0	379	0	0	0
3	439	17	0	0	422	0	0	0
2	476	18	54	0	404	0	0	0
1	584	18	105	0	461	0	0	0
0	556	18	0	0	538	0	0	0
-1	769	0	0	0	769	0	643	0
...fill in...								
Total	7160	230	1072		5559	299	643	-109

Experience	Office space	Indoor climbing	Sports facilities	Expo space	Bar	Restaurant	Education space	...fill in...
Access	Public	Public	Public	Public	Public	Public	Public	...fill in...
Place	Indoor	Indoor	Indoor	Indoor	Indoor	Indoor	Indoor	...fill in...
Climate control	Yes	No	No	No	Yes	Yes	No	...fill in...
Energy use type	Office	Sports	Sports	Office	Gathering	Gathering	Office	...fill in...
14	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
12	0	0	0	0	0	301	67	0
11	61	54	0	91	0	0	79	0
10	61	0	0	0	0	0	76	0
9	61	0	0	0	0	0	72	0
8	61	0	0	0	0	0	78	0
7	61	0	0	0	0	0	101	0
6	0	0	0	0	0	0	72	0
5	0	0	0	0	0	0	76	0
4	0	0	181	0	0	0	94	0
3	0	0	0	0	0	0	83	0
2	0	53	0	0	0	0	139	0
1	0	53	0	126	29	0	171	0
0	0	36	0	0	117	0	167	0
-1	0	0	0	0	0	0	66	0
...fill in...	0	0	0	0	0	0	0	0
Total	305	196	181	217	146	301	1341	0

Nutrients	Vertical farm	Educative garden	Vertical city park	Green roof	...fill in...
Access	Private	Public	Public	Private	...fill in...
Place	Indoor	Indoor	Indoor	Roof	...fill in...
Climate control	Yes	No	No	No	...fill in...
Energy use type	Own	Office	No	No	...fill in...
14	0	0	0	0	0
13	0	0	0	0	0
12	0	0	40	0	0
11	0	0	44	0	0
10	0	81	48	0	0
9	0	78	78	0	0
8	0	40	97	0	0
7	0	0	176	0	0
6	0	179	86	0	0
5	0	181	86	0	0
4	0	0	104	0	0
3	315	0	24	0	0
2	209	0	3	0	0
1	0	0	0	0	0
0	0	0	0	0	0
-1	0	0	0	0	0
...fill in...	0	0	0	0	0
Total	524	559	786	0	0

Energy	Bio-digester	WKO space	PV Panels	...fill in...
Access	Private	Private	Private	...fill in...
Place	Indoor	Indoor	Roof	...fill in...
Climate control	No	No	-	...fill in...
Energy use type	Own	Own	-	...fill in...
14	0	0	109	0
13	0	0	0	0
12	0	0	0	0
11	0	0	0	0
10	0	0	0	0
9	0	0	0	0
8	0	0	0	0
7	0	0	0	0
6	0	0	0	0
5	0	0	0	0
4	0	0	0	0
3	0	0	0	0
2	0	0	0	0
1	57	25	0	0
0	22	196	0	0
-1	60	0	0	0
...fill in...	0	0	0	0
Total	139	221	109	0

Water	Rainwater storage	Rainwater catchment	...Fill in...	...Fill in...
Access	Private	Private	...fill in...	...fill in...
Place	Indoor	Roof	...fill in...	...fill in...
Climate control	No	-	...fill in...	...fill in...
Energy use type	-	-	...fill in...	...fill in...
14	0	109	0	0
13	0	190	0	0
12	0	0	0	0
11	0	0	0	0
10	0	0	0	0
9	0	0	0	0
8	0	0	0	0
7	0	0	0	0
6	0	0	0	0
5	0	0	0	0
4	0	0	0	0
3	0	0	0	0
2	0	0	0	0
1	0	0	0	0
0	0	0	0	0
-1	0	0	0	0
...fill in...	0	0	0	0
Total	0	299	0	0

Figure 32: Screenshot of a part of the program tab of the quantitative model from Excel. A more detailed version of the program can be found in Appendix 4.

The gross floor area, figure 33, includes the following elements. The rows in the tab indicate the floors of the building. Floors can be added or deleted as a whole. In this case, there are 14 upper floors, a ground floor, and a basement. The columns on the left side of the tab indicate the floor area per floor, staircase space, unusable space, roof space, indoor space (=floor area – staircase – unusable space, roof space), outdoor space, available indoor space (=indoor space – [sum of all indoor spaces of system tabs on that floor]), available outdoor space (=outdoor space – [sum of all indoor spaces])

GFA: Gross Floor Area (m2)								
Spaces (floors)	Floor area	Staircase	Unuseable space	Roof Space	Indoor space	Outdoor space	Available indoor	Available outdoor
14	127	18	0	109	0	109	0	-109
13	316	22	104	190	0	190	0	0
12	430	15	7	0	408	0	0	0
11	428	14	85	0	329	0	0	0
10	428	14	148	0	266	0	0	0
9	429	12	128	0	289	0	0	0
8	445	12	157	0	276	0	0	0
7	437	12	87	0	338	0	0	0
6	428	12	79	0	337	0	0	0
5	428	14	71	0	343	0	0	0
4	440	14	47	0	379	0	0	0
3	439	17	0	0	422	0	0	0
2	476	18	54	0	404	0	0	0
1	584	18	105	0	461	0	0	0
0	556	18	0	0	538	0	0	0
-1	769	0	0	0	769	0	643	0
...fill in...								
Total	7160	230	1072		5559	299	643	-109

Figure 33: Screenshot of the GFA in the program tab of the quantitative model from Excel.

The columns of on the right side are divided under experience, food, energy, and a water section. The experience section includes all user specific functions, like the restaurant. The food section all food specific systems, like the vertical farm. The energy section all energy specific systems, like the ATES. The water section all water specific systems, like the rainwater catchment.

Apart from the square meter of a system, per floor, it is also indicated whether the system:

- is publicly or privately accessible
- is positioned indoor, outdoor or on the roof
- requires climate control (cooling and heating)
- has its energy usage included in its own subtab, or not

	Experience				
	Office space	Indoor climbing	Sports facilities	Expo space	Bar
Access	Public	Public	Public	Public	Public
Place	Indoor	Indoor	Indoor	Indoor	Indoor
Climate control	Yes	No	No	No	Yes
Energy use type	Office	Sports	Sports	Office	Gathering
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	61	54	0	91	0
	61	0	0	0	0
	61	0	0	0	0
	61	0	0	0	0
	61	0	0	0	0

Figure 34: Screenshot of the experience section of the program tab from Excel. The screenshot shows a few systems (office space, indoor climbing, etc.) and their information on access, place, climate control, and energy use type.

Changes to the GT program

The mapping performed in Chapter 4.1 and Chapter 4.2 had been based on the progress report of the GT that was shared with me at the start of this research (Bajes Kwartier Ontwikkeling, 2020, June). The progress report included the planned systems for the GT; however, it lacked a floor plan. During the research, a floorplan was shared with me which I used to initialize the program tab. Below, the systems of the initial mapping and the systems included in the latest floorplan are displayed. Major changes are the replacement of the PowerNest and Lumniduct for a solar sculpture. The solar sculpture is a cube placed around the highest floor of the GT consisting of PV-panels, therefore PV panels are added. Moreover, three types of visitor & experience systems were added: sports facilities, expo space, and education space.

	Progress report (old)	**Floor plan (new)**
Food & Nutrients	Vertical city park (indoor) Indoor Vertical farming Organic waste collection point	Vertical city park (indoor) Indoor Vertical farming ➔ *included in bio-digester space* + Educative garden

Energy	Bio-digester Energy service company Lumniduct PowerNest	Bio-digester ATES Space ~~Lumniduct~~ ~~PowerNest~~ + PV Panels
Water	Water catchment on roof Water storage in basement	Water catchment on roof Water storage in basement
Visitors & experience	Restaurant Bar Climbing hall Rentable office spaces	Restaurant Bar Climbing hall Office space + Sports facilities + Expo space + Education Space

Results from the program tab

The latest version of the floor plan of the building has been inserted in the model. There is no space available on any of the floors or ground floor, except for the basement. In the basement 643 m2 is available, a considerable amount. In terms of used roof space, the roof of the 14^{th} floor is used twice, as it can be used for both rainwater collection and PV-panels. Also interesting is the total floor area, 7160 m2, compared to the floor area that requires climate control. Only 1276 m2 requires climate control. This is due to the open structure of the GT. The largest part of the building is not insulated, nor has windows. The tower is largely transformed into an actual outside city park, and many functions are planned inside the building as outside function.

4.3.3.2 Vertical farm tab

The vertical farm tab includes all information related to the vertical farm. A vertical farm is an urban farming system where crops are produced in an indoor controlled environment. Sunlight is replaced by artificial lighting and its indoor climate is completely controlled. In most cases, the crops are cultivated without soil in hydroponic, aquaponic or aeroponic conditions (Avgoustaki & Xydis, 2020, -b). In broad terms, a vertical farm requires electricity, water, nutrients, and seeds and produces vegetables. The types of produce are limited and mostly consist of leafy greens.

It was chosen to use one of the most produced crops in vertical farms as benchmark for the data, namely lettuce. The layer capacity, maximum yield and water demand are derived from a paper on vertical farms of Avgoustaki & Xydis (2020, -b). The yield is given in kilograms wet weight. The energy requirements per kg dry weight produced and the dry weight percentage of lettuce are derived from a paper on the energy consumption of vertical farm from Graamans et al. (2018). Dry weight is the weight of a crop if all moisture is extracted. In lettuce, the dry weight is 7% of its ‘wet’ weight. Data on the nutrient uptake of lettuce is based on a presentation on the nutrition and lighting requirements of lettuce by Nemali (n.d).

Some assumptions were made in the creation of this tab. Firstly because the vertical farm operates as a controlled environment it was assumed that the only thing leaving the system is the produce, in this case lettuce. Meaning that the only nutrient and water inputs the system require, equalize the water and nutrient content of the lettuce leaving the system. On the contrary, the energy demand is not regarded as a closed system. The energy required is calculated in kWh needed per kg dry weight of lettuce. The model does not account for possible energy reuse.

Specifically for the nutrient demand some additional assumptions have been made to match the nutrient demand of the vertical farm to the nutrient supply of the bio-digester, which is introduced in the next sub-chapter. First, a vertical farm requires relatively pure nutrients, meaning that they should be clean and not bound to one another. The effluent of the bio-digester, a nutrient rich sludge, consists of about 90% water and many nutrients are bound to one another. To use them in the vertical farm, extra treatment is needed. However, this is not taken up in the model, to not over complicate the model. Furthermore, the nutrient demand is purely based on the nutrient requirement of lettuce. These nutrient ratios are different for each plant species. The input for the bio-digester is composed of a wide variety of food scraps and plant waste. This results in the bio-digester sludge most likely not containing the same ratio of nutrients as the vertical farm requires. Also, this discrepancy, is not considered in the model, to not overcomplicate the model.

Moreover, the model shows how much of each nutrient is required as well. The data form Nemali (n.d.) was used for this. Lettuce requires the following nutrients: N, P, K, Ca, Mg, S, Fe, Zn, Mn, B, Cu.

The yearly totals of resource supply and demand are calculated as follows:

Supply:

$$Total\ yield\ (kg/year) = Yield\ (kg/m2/year) * Productive\ area\ (m2)$$

Demand:

$$Total\ water\ demand\ (L/year) = Water\ demand\ (L/kg) *\ Yield\ (kg/m2/year) * Productive\ area\ (m2)$$

$$Total\ energy\ demand\ (kWh/year) = Energy\ demand\ (kWh/kg) *\ Dryweight\ yield\ (kg/m2/year) * Productive\ area\ (m2)$$

$$Total\ nutrient\ demand\ (kg/year) = Nutrient\ uptake\ (kg/kg) *\ Yield\ (kg/m2/year) * Productive\ area\ (m2)$$

The total surface area planned for the vertical farm in the GT is 524 m2, for now, the productive response was set at 50%. This means that 50% of the planned surface, is used for producing crops through vertical farming. This relatively low percentage assumes that the vertical farm also has a public character. People visiting the tower must be able to experience the vertical farm and this requires ‘unproductive’ space. The productive space of the vertical farm in this case is 262 m2. Moreover, it is assumed that the vertical farm exists of 4 layers. This is based on pictures of the vertical farm the project is targeting to implement. The number of layers can vary; therefore, it is easy to change it in the model.

Indoor vertical farm			
Surface (m2)	**524**		
Info: Indoor urban vertical farm (IUVF) for leafy greens (lettuce) per m2			
An IUFV is a closed loop system. Plant waste, such as stems, are recycled within the system.			
Initial data			***Sources***
Crop type	Lettuce		
Layer capacity	10		Avgoustaki, D. D., & Xydis, (.
Max yield (kg/m2/year)	100		Avgoustaki, D. D., & Xydis, (.
Energy (kWh/kg dryweight)	247		Graamans, L., Baeza, E., Va .
Water demand per kg (L/kg)	1		Avgoustaki, D. D., & Xydis, (.
Dry weight (%)	7%		Graamans, L., Baeza, E., Va .
Nutrient uptake (kg/kg)	0,11103		Nemali, K (n.d.). Nutrition & Lighting Req
System specific data			
Productive response (%)	50%		
Productive area (m2)	262		
Number of layers	4		*Based on picture of GrowX farm
Yield (kg/m2/year)*	40		
Dry weight yield (kg/m2/yr)	2,8		
Energy (kWh/m2/year)	691,6		
Total per year			
Yield (kg/year)	10480		
Water demand (L/year)	10480		
Energy demand (kWh)	181199		
Nutrient demand (kg)	1164		

Figure 35: Screenshot of the indoor vertical farm settings and outcomes, of the vertical farm tab from Excel. The screenshot shows the initial data, systems specific data and the total supply and demand of FEW per year.

Results from the vertical farm tab

The vertical farm, according to the current settings, produces 10.480 kilograms of lettuce per year. It requires the same amount of water, 10.480 liters per year. Energy required for the production, is 181.199 kWh per year. The nutrients required for the production, is 1.164 kg of nutrients. This will roughly translate to 11.636 kg of nutrient rich sludge of the bio-digester is required.

4.3.3.2 Bio-digester tab

A bio-digester makes use of micro-organisms digesting organic waste in anaerobic circumstances. The process generates a methane rich biogas, which is used to produce electricity and heat. Moreover, the effluent of the process is a nutrient rich sludge which can be used as fertilizer (Curry & Pillay, 2012). A bio-digester requires organic waste as input, and generates electricity, heat, and liquid fertilizer (figure 36).

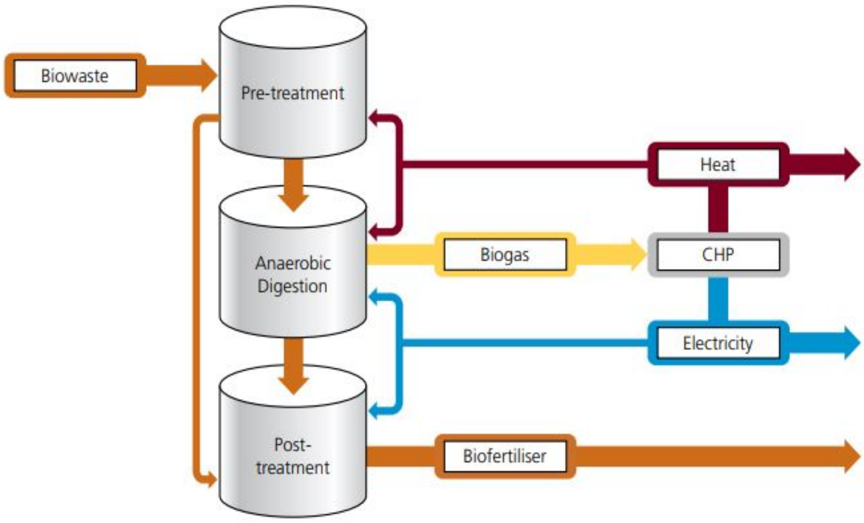


Figure 36: system diagram of an anaerobic digester combined with a CHP engine module (Daly, 2019)

The bio-digester system of the Wastetransformers was used as benchmark for the bio-digester system. The Wastetransformers is a company, that supplies an entire bio-digesting system in a sea container format. They have been mentioned multiple times on the website and in the progress reports of the BK and GT.

Data on the exact demand and supply of a bio-digester unit of Wastetransformers was not publicly accessible. However, an online article from Haven Bedrijf Amsterdam (2019), contained all the information needed to make the equation. It was indicated that a single bio-digester unit, capable of handling 600 kg of organic waste a day, is the size of a sea container. A sea container is approximately 15 square meters. Moreover, estimates of the kWh electricity and kWh thermal energy were given as well. 84% of the input leaves the system as liquid fertilizer. It is assumed that the other 16% is water that evaporates during the process and can be condensated and reused for another purpose. There will also be a weight loss due to the biogas extraction, however, the weight of gas is very low and therefore not considered.

The organic waste used as input for the system comes from the buildings users, and the BK neighborhood's households. The amount of organic waste produced is calculated in two other tabs and will be explained later. The daily input was calculated to be 658 kg of organic waste a day.

The yearly totals of resource production and demand are calculated as follows:

Supply:

$$Total\ organic\ fertilizer\ (kg/year) = organic\ waste\ (kg/year) * conversion\ organic\ fertlizier$$

$$Total\ electricity\ (kWhe/year) = organic\ waste\ (kg/year) * Electricity\ (kWh/kg)$$

$$Total\ heat\ (kWht/year) = organic\ waste\ (kg/year) * Heat\ (kWht/kg)$$

$$Total\ water\ (L/year) = organic\ waste\ (kg/year) * conversion\ water$$

Demand:

$$Organic\ waste\ (kg/year) = organic\ waste\ GT\ (kg/year) * Organic\ waste\ BK\ (kg/year)$$

As the supply of organic waste is more than 1 bio-digester unit can handle, 2 units will be needed. Two units will require 30 m2 of space. 224 m2 floor space is planned for the bio-digesters, which is more than the required space. However, also this system has a public function, the project aims to 'open up' the system and show how the bio-digester works to the public, which will require space. Moreover, the effluents of the bio-digester will have to be stored somewhere, and the organic waste collection also requires space. The section of the bio-digester tab containing the most essential information on the initial values, and supply and demand of FEW by the bio-digester can be seen in figure 37.

Waste transformer		
Surface area	221	
Initial data		
Conversion organic fertilizer (%)	84%	https://www.maritiemne .
Conversion water (%)	16%	
Electricity (kWh/kg)	0,19	https://www.maritiemne .
Heat (KWh/kg)	0,39	https://www.maritiemne .
System specific data		***sources***
Unit(s)	2	
Square meters (m2)	30	
Max input (kg)	1200	https://www.maritiemne .
Organic waste (kg/day)	657,98	
Total per day		
Organic fertilizer (kg/day)	552,7	
Electricity (kWhe/day)	123,8	
Electricity (kWh thermal/day)	258,4	
Water (L/day)	105,3	

Figure 37: Screenshot of the bio-digester data used in the bio-digester tab from Excel. The screenshot shows the initial data, systems specific data and the total supply and demand of FEW per day (which is calculated to supply and demand per year in a different section of the bio-digester tab).

Results from the bio-digester tab

In total, 214.193 kg of organic waste is treated in the bio-digester per year. This generates 40.296 kWh electricity and 84.112 kWh thermal energy (heat) per year. Moreover, 179.922 kg of organic fertilizer is generated, and 34.271 liters of water are separated.

4.3.3.3 PV-Panel tab

A PV-Panel is a panel structure with a photo-voltaic module. The module exists of photo-voltaic cells that transform sun arrays into electrical energy. Solar energy is a renewable source of energy. PV-Panels can be placed on the roofs and facades of buildings. PV-panels require no resource input, just solar radiation. They supply electricity.

The PV-efficiency is the rate at which the PV-panel can transform solar radiation into electricity. The PV-efficiency is determined by multiple factors. The photo-voltaic cells have an engineered efficiency around 20%, depending on the quality of the photo-voltaic cells. The PV-panel loses some performance over time. On average, the system performance lies at about 90% of its optimum. Finally, the orientation at which the panel is situated towards the sun, has a very large effect on the panel's efficiency. Figure 38 is used to determine the orientation efficiency of a PV-panel at various directions and angles. This figure is used to determine the effectivity of the PV-panels related to their orientation. Ideally, PV-panels should be directed perpendicular to the sun. However, as the sun moves throughout the day, this would require the panel to follow the sun. On average, a panel angle of 37° and a panel direction towards the South is the optimum panel orientation in the Netherlands with a panel orientation efficiency of 100%. The least efficient panel orientation is a PV-panel directed to the North at an angle of 90°. PV-panels mounted to the façade of the building are assumed to have an angel of 90° which is less efficient than the optimum, ranging from 70% to 30% depending on the panel direction.

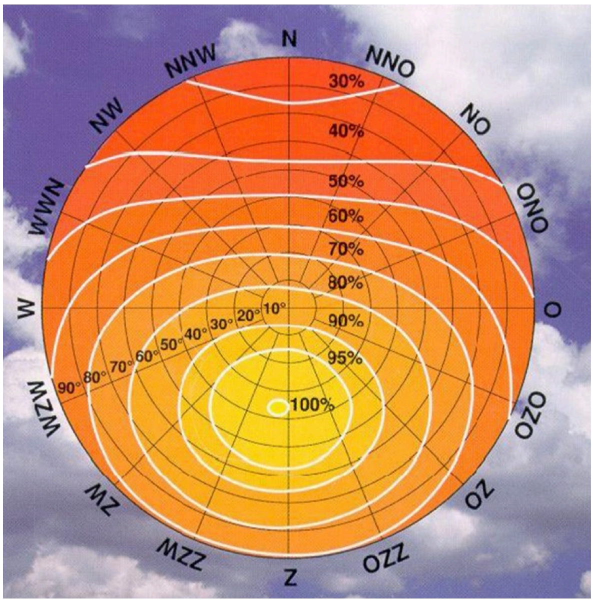


Figure 38: diagram used to determine the efficiency of a solar panel based on the intensity of solar radiation on a surface at various panel orientations (panel direction + panel angle) (source: unknown).

The productive space on the roof is linked to the roof size made available for PV-panels in the program tab, the façade size is linked to the surface area of the facades, which is also indicated in the program tab.

For the model, the following assumption have been made. The PV efficiency is set at 21%. The PV engineered performance is set to 90%. The angle and direction of PV-panels on the roof of a building are set to 37° and South. The angle and direction of PV-panels on the facades of the building are set to 90° and the direction depends on the direction the façade is facing. To calculate the amount of electricity generated by the PV-panels, solar radiation data from the Royal Dutch Meteorological Institute is used. The dataset (KNMI, 2020) includes data on the average solar radiation at various meteorological station around the Netherlands, this data is included in a separate tab: solar radiation data. The data from location Schiphol was selected as it is the closest weather station to the GT.

The electricity generation is calculated separately for every month, as solar radiation greatly differs in summer months compared to winter months. The electricity generation is also calculated for five different surfaces: the roof, façade A, façade B, Façade C and Façade D.

The yearly totals of resource production and demand are calculated as follows:

Supply:

$$Energy\ generation\ (kWh/month) = solar\ radiation\ ((kWh/m2)/month) * productive\ space\ (m2) * engineered\ efficiency * orientation\ efficiency$$

$$Energy\ generation\ (kWh/year) = \mathrm{SOM}(Energy\ generation\ (month\ 1\ ; month\ 12))$$

For all panels, the same type of panel was assumed. The panel efficiency was set to 21%, with a panel performance of 90%. Of the roof space, 109 m2 is available for PV-panels. It was assumed that 90% of the roof space is covered with PV-panels, leaving 98 m2 of productive space. The PV-panel direction is South, and angle is 37°. For the facades, only the top 2 floors are available for PV-panels in the current plans for the GT. The cube shape of the relatively small top two floors is supposed to become a 'solar sculpture'. It was calculated that this space was about 4% of the total façade space on all four facades, translating to 34m2 per façade. It was assumed all panels were placed directly on the façade at an angle of 90°. The direction of the panels differs per façade, being NNW for façade A, ENE for façade B, SSE for façade C and WSW for façade D. Figure 39 shows a screenshot of a section of the PV panel tab showing based on what data the PV panel data is calculated.

PV panels roof	
1 m2	1
Roof space	109
Available for	90%
Panel efficie	21%
Panel angle	37
Panel directi	South
Panel perfor	90%
Orientation	100%
Productive sp	98,10

Roof Energy generation	kWh/m2/mor	kWh/month
January	4	381,1
February	7	690,1
March	15	1431,8
April	23	2261,0
May	30	2925,3
June	31	2992,3
July	30	2976,8
August	25	2472,1
September	17	1637,8
October	10	963,1
November	4	432,6
December	3	283,3
Total	**198,2**	**19447,3**

PV panels facade A	
1 m2	1
Facade spac	850,465
Available for	4%
Panel efficie	21%
Panel angle	90
Panel directi	NNW
Panel perfor	90%
Orientation	30%
Productive sp	34,02

Facade A: Energy generation	kWh/m2/mc	kWh/month
January	1	39,6
February	2	71,8
March	4	149,0
April	7	235,2
May	9	304,3
June	9	311,3
July	9	309,7
August	8	257,2
September	5	170,4
October	3	100,2
November	1	45,0
December	1	29,5
Total	**59,5**	**2023,2**

Figure 39: Screenshot of the calculations of the PV panels on the roof and PV panels on façade A (façade B, C, and D are similar to A) of the PV panels tab from Excel. The screenshots show the system specific data, the initial data and monthly electricity generation per PV panel section.

Results from PV-panel tab

The total electricity generation per year of the five PV-panel surfaces, is 37.794 kWh.

4.3.3.4 Educative Garden

The educative garden is an indoor garden with two functions: education and food production. This means that the garden is purposed to educate visitors on healthy diets and produce food such as vegetables and herbs. Compared to the vertical farm, the productivity of this space will be very low. Moreover, no climate control is needed as the space is in direct contact with outside air. Inputs required for the educative garden are water and nutrients, it supplies the building with a small amount of food. Moreover, most likely lighting is required for plants placed in the core of the building, that are not sufficiently exposed to sunlight. However, for now this lighting demand has not been included as the demand is very uncertain.

For the water and nutrient demand and the food supply, numbers on the average requirements for a vegetable garden were taken. These requirements might be a bit lower than given in the model. This is because the plants are grown inside a building, most likely in pots. In pots no seepage of water or nutrients occurs, creating a lower demand. On the contrary, there is also no precipitation in inside conditions, making the water requirements relatively higher than outside. However, it is assumed that the lack of seepage weighs up to the lack of precipitation.

The yearly totals of resource production and demand are calculated as follows:

Supply:

$$Vegetable\ production\ (kg/year) = \text{production (kg/m2/year)} * productive\ space\ (m2)$$

Demand:

$$Fertilizer\ (kg/year) = \text{Fertilizer (kg/m2/year)} * productive\ space\ (m2)$$

$$Water\ (kg/year) = \text{water(kg/m2/year)} * productive\ space\ (m2)$$

The productive space response was set to 50%, this is due to the educative and thus public function of the educative garden.

Results from Educative Garden tab

The total nutrient demand of the educative garden is 838,5 kg per year and a water demand of 145.340 liters per year. The educative garden produces 559 kg of food per year.

4.3.3.5 Climate Control

Nowadays, there are various sustainable alternatives to using a boiler for central heating and an air-conditioning for cooling. The GT will use a ground coupled heat exchanger, this is a sustainable heating and cooling system. The entire neighborhood, and the GT will be connected through district heating, which distributes the heat and cold generated through the ATES and heat pump. This type of heating systems stores thermal energy in groundwater sources and upgrades the thermal energy through a heat pump. The heat pump requires electricity. Meaning that the heating system requires electricity and produces thermal energy. Moreover, in this tab the electricity for lighting is also calculated.

The GT is a quite unique building in its heating and cooling demand, as a very large portion of the building is exposed to outside conditions. Only 1276 m2 requires climate control, of the total of 7160 m2 total floor space. This will result in a relatively low heating and cooling demand for the size of the building.

For the energy requirements of the spaces that require heating, the BENG-standard is used. This standard is used for all building built after January 1st, 2021. BENG stands for 'Bijna Energie Netruaal Gebouw', which translates to 'Almost Energy Neutral Building'. The standard requires various building types to have a maximum basic energy demand in kWh per m2 per year. Buildings can have the goal to perform a certain percentage better than the standard. The basic energy demand of a building roughly translates to the energy required for heating, cooling, and lighting. The standard used for the Green Tower is 90 kWh per m2 per year.

A well-functioning ATES is in balance, meaning that it requires as much heat in the winter as cold in the summer. Therefore, it is assumed that the heating and cooling in the GT is also in balance. Cooling and heating systems have a COP value, which stands for coefficient of performance. This COP value indicated the balance between the received usable thermal energy and the work energy required. The higher a COP value, the more efficient your heating system is. The Climate control tab includes a table with various COP values for various heating and cooling systems.

The yearly totals of resource production and demand are calculated as follows:

$$Heat\ (kWh/year) = \text{heat demand (kWh/m2/year)} * surface\ area\ (m2)$$

$$Cold\ (kWh/year) = \text{cold demand (kWh/m2/year)} * surface\ area\ (m2)$$

$$Electricity\ lighting\ (kWh/year) = \text{electricity lighting demand (kWh/m2/year)} * surface\ area\ (m2)$$

$$Electricity\ demand\ total\ (kWh/year) = \text{electricity lighting (kWh/year)} + (Heat\ (kWh/year)/\ COP\ heat) + (cold\ (kWh/year)/\ COP\ cold)$$

The heat and cold demand as percentage of the BENG-standard is set to 44% and 44% of the maximum basic energy demand. 11% is set for energy use for lighting. Moreover, the BENG performance percentage (the percentage the building is performing better than the BENG-standard) is set to 25%, this is a well-educated guess. An overview of the data can be seen in figure 40.

Space with climate control		Total Surface	1276
BENG performance (%)	25%		
Beng norm			
Energy demand (kWh/m2/year)	90		
Primary fossil energy use (kWh/m2/year	40		
Percentage renewables (%)	30		
Response			
Cold demand (%)	44%		
Heat demand (%)	44%		
Electricity demand (%)	11%	*Assumed b: .	
Energy demand per m2			
Energy demand total (kWh/m2)	67,5		
Koude vraag (kWh/m2)	30,0		
Hitte vraag (kWh/m2)	30,0		
Electriciteitsvraag (kWh/m2)	7,5		
Total energy demand / production for the building			
Total energy demand (kWh)	86130		
Cold demand (kWh)	38280		
Heat demand (kWh)	38280		
Electricity demand (kWh)	9570		
Total electricity demand		COP	
Electricity demand for cold (kWhe)	6380		6
Electricity demand for heat (kWhe)	7656		5
Electricity demand lighting (kWhe)	9570		
Total electricity demand	23606		

Figure 40: Screenshot of the climate control data and calculation, of the Climate Control tab from Excel. The screenshots show the relative BENG performance, BENG norm, response, energy demand per m2, total energy demand, and total electricity demand.

Results from Climate Control tab

The total heat demand of the building is 38.280 kWh thermal energy per year. The total cold demand of the building is equal, 38.280 kWh thermal energy per year. For lighting, 9.570 electricity is required. In total, 23.606 kWh electricity is required, this includes the electricity needed as work energy for the heating pump.

4.3.3.6 Sanitation

Sanitation facilities are required in every building. However, there are multiple ways of handling the effluents. In conventional practice, urine and feces are discharged in a central sewage system. However, nowadays it is also possible to process these black (flushed feces) and yellow wastewater (flushed urine) flows locally. In the current of plans of the Green Tower, no local wastewater treatment systems are planned. Knowing the amounts of black and yellow wastewater might help in deciding whether adding these local processing systems is useful. Sanitary facilities produce two effluents: black wastewater and yellow wastewater. A demand for sanitation is water, used to flush toilets. In the current system, the water used is fresh water. However, rainwater or previously used filtered water could be also used be used as flushing water. Special infrastructure must be placed for this.

The data was derived from various internet sources. A human defecates on an average of 1,2 times a day, with an amount of 0,128 kg. The urinating frequency is 3,5 times a day, with an average of 1,5 liters.

The yearly totals of resource production and demand are calculated as follows:

Black wastewater:

$$Black\ wastewater\ (L/year) = \text{feces produced (L/year)} + flushing\ water\ (liter/year)$$

$$Feces\ produced\ (L/year) \\ = \text{feces produced by human (L/day)/ 24}\ (hours) * user\ hours\ (hour)$$

$$Flushing\ water\ (L/year) \\ = \text{defecating frequency (times/day)/ 24}\ (hours) * liters\ per\ flush\ (L) \\ * user\ hours$$

Yellow wastewater:

$$Yellow\ wastewater\ (L/year) = \text{urine produced (L/year)} + flushing\ water\ (L/year)$$

$$Urine\ produced\ (L/year) \\ = \text{urine produced by human (kg/day)/ 24}\ (hours) * user\ hours\ (hour)$$

$$Flushing\ water\ (liter(kg)/year) \\ = \text{urinating frequency (times/day)/ 24}\ (hours) * liters\ per\ flush\ (L) \\ * user\ hours$$

The liters per flushed are based on data from international water consumption data. In a table a toilet type can be selected, and the liters per flush copied to the black and yellow wastewater production models. In this case, the eco-flush toilet was selected. It is a dual flush system, where urine and feces are flushed through a separate process. Flushing urine requires 0,3 liters, while flushing feces requires 2,5 liters. As an example, the black wastewater data is shown in figure 41.

Black waste water		
Wastewater produced flushing feces		
Initial data		***Source***
Feces (kg/day)	0,128	https://www.quest.nl/me .
Defecating frequency (x/day)	1,2	https://www.wastewater .
Liters per flush	2,5	https://www.wastewater .
Totals per year		
User hours (hours/year)	920006	
Feces produced (kg/year)	4907	
Water flushed (L/year)	115001	
Black wastewater (L/year)	119907	

Figure 41: Screenshot of the black wastewater data and calculation, of the sanitation tab from Excel. The screenshots show the initial data and totals per year for black wastewater production.

Results from the sanitation tab

The total black wastewater production is 119.907 liters, of which 4907 liters are feces and 115.001 liters is flushing water. The total yellow wastewater production is 97.751 liters, of which 57.500 liters is urine and 40.250 liters is flushing water.

4.3.3.7 City Park

The indoor city park is a public city park, within the GT. It provides leisure for visitors. No climate control is needed as the space is in direct contact with outside air. The city park demands water and nutrients, while not providing any resources.

For the water and nutrient demand, numbers on the average requirements for a vegetable garden were taken. Finding data on indoor city parks was impossible. Also, nonscientific sources have been considered, however browsing through these sources it was realized that there are practically no data available on indoor, multi floor gardens. Therefore, the data for vegetable gardens was regarded to be sufficient. These requirements might be a bit lower than given in the model. This is because the plants are grown inside a building, most likely in pots. In pots no seepage of water or nutrients occurs, creating a lower demand. On the contrary, there is also no precipitation in inside conditions, making the water requirements relatively higher than in outside conditions. However, it is assumed that the lack of seepage weighs up to the lack of precipitation.

The yearly totals of resource production and demand are calculated as follows:

Demand:

$$Fertilizer\ (kg/year) = \text{Fertilizer (kg/m2/year)} * productive\ space\ (m2)$$

$$Water\ (kg/year) = \text{water(kg/m2/year)} * productive\ space\ (m2)$$

The productive space response was set to 33%, the vertical city park is mostly built up of enforced plant pots throughout the building, whilst being large, most space is used for visitors of the vertical city park to reside.

City Park		
System specific data		
Size of city park (m2)	786	
Response (planted space) (%)	33%	
Productive space	259,38	
Initial data		
Fertilzizer (L(kg)/m2/year)	3	https://edep
Water (liter/m2/week)	10	https://edep
Total per year		
Required fertilizer (kg/year)	778,14	
Required water (L/year)	134877,6	

Figure 42: Screenshot of the City Park data, of the City Park tab from Excel. The screenshots show the initial data and totals per year for black wastewater production.

Results from city park tab

The total nutrient demand of the city park is 778 kg per year and a water demand of 134.878 liters per year.

4.3.3.8 Water catchment

The roof of the Green Tower can be used to catch precipitation. This water can be stored within the building and used for watering plants or flushing toilets. In principle, the entire roof space can be used to catch water from.

Data from the Royal Dutch Meteorological Institute is used to estimate the precipitation per month. The average of 20 years (1991-2020) is selected. A separate tab called ‘Rainfall data’ has been added with the average monthly precipitation for various meteorological stations. The data from Schiphol was selected, as this station is closest to the GT.

Rainfall catchment is different from rainfall storage. The water caught on the roof of the GT is not necessarily stored. It is indicated that the basement will potentially hold water storage capacity. The water storage capacity is based on the floor size and height of the potential storage tank.

Another option for rainwater storage, or retention, is the construction of a green roof. A green roof has a storage capacity of about 100 liter per m2.

The yearly totals of resource production and demand are calculated as follows:

Rainwater catchment:

$$Water\ catchment\ potential\ (L/year) = \text{SUM (precipitation ((L/m2/month)} * catchment\ area\ (m2))$$

Rainwater storage:

$$Water\ storage\ capacity\ (L) = \text{Water storage size (m2)} * Water\ storage\ height\ (m) * 1.000$$

Green roof:

$$Green\ roof\ water\ storage\ (L) = green\ roof\ size\ (m2) * green\ roof\ water\ storage\ capacity\ (L/m2)$$

Momentarily, there is 299 m2 of roofs space available for rainwater catchment. There is no green roof planned, or water storage tank.

Results from water catchment tab

The water catchment potential of the GT is 254.239 liter per year. There is no water storage or green roof planned in or on the GT, resulting in a water storage of 0 liters per year.

4.3.3.9 Organic waste BK and GT tabs

All organic waste in BK and the GT is collected for recycling. A quantitative model provided by BKO is used to calculate the amount of organic waste produced by the neighborhood and the building. In the tab organic waste BK, the results from the quantitative model based on the masterplan of BK are given.

The inputs for the quantitative model are among others the number of households, grocery store size, restaurant, and bar sizes etc. The organic waste GT tab includes the quantitative model itself, and the sizes of various functions on which the generated organic waste is based on, are linked to the floor size in the Program tab.

Results from organic waste BK and GT tabs

The GT will collect a total of 214.193 kg of organic waste per year. 208.999 kg organic waste is produced in the BK neighborhood and 5194 kg of organic waste is produced in the GT.

4.3.3.10 Visitors tab

The visitors tab includes all information used to estimate the visitors of the GT. All systems that are public and focused on receiving visitors are added to this tab. Multiple assumptions are used to estimate the occupancy of these systems, this will be explained later. The systems of the GT that are open to visitors are: office space, indoor climbing, restaurant, sports facilities, bar, expo space, education space and the vertical city park. Apart from estimating the occupancy of these systems, the tab is also used to estimate the food consumption for the bar and restaurant based on the 'food consumption data' tab. Moreover, additional electricity and water demand for the office space, bar, and restaurant.

To explain how the visitors, water, electricity, and food data is estimated, the restaurant data will be discussed. In figure 43, a screenshot can be seen of the restaurant tab. The restaurant has a surface area of 301 m2. It is estimated that 50% of this space is used to receive customers, the other 50% is used for the kitchen, walkways, sanitary facilities etcetera. This leaves 151 m2 useable space. A customer requires approximately 1,2 m2. It is assumed a resides in the restaurant for an average on 1,5 hours, being the service time. The restaurant is assumed to be open for 13 hours (9.00 am – 22.00 pm). The visitor capacity of the restaurant is:

$$Visitor\ capacity\ (visitors/day) = (\text{useablespace}\ (m2)/\ space\ per\ visitor\ (m2)) * (opening\ hours\ (hour)\ /\ service\ time\ (hour))$$

The restaurant is assumed to be open for 6 days a week, and thus 313 days a year. The occupancy of the restaurant, meaning how many percent of the capacity is filled on average, is set to 33%. This is an estimate and can be adapted. This results in 359 daily visitors, and 112.219 visitors on a yearly basis. Calculated to visitor hours (the number of hours visitors spent in the system); it is 168.329.

The water use is based on water needed to serve a meal. Preparing a meal and washing dishes, demands water. This number is set to 15 liters. This amounts up to a fresh water use by the restaurant of 1.683.289 liters per year.

The additional electricity use for the restaurant is based on the amount of kWh per m2 per year and is set to 75 kWh per m2 per year, resulting in a total additional electricity use of 22.575 kWh.

Food consumed in the restaurant is based on the time visitors are visiting the restaurant, and the food consumption data from the food consumption data tab. The amount of food and beverages human eats on average, is divided by the time a human can eat a day. This is the time a human is awake and set at 15 hours. The likeliness of someone consuming a part of its daily food consumption in a restaurant or bar is estimated to be twice as likely. Moreover, it is assumed that 40% of a meal served in the GT exists of vegetables or other green that could potentially be produced in the Tower itself. This assumes that the restaurant and bar will only serve plant-based meals, and that most of the used products can be produced in the vertical farm. This is however not a fact yet, so this percentage could be far lower. The total amount of food consumed in the restaurant is 21.546 kg, of which 8.618 kg are vegetables. A total of 45.785 liter of beverages is consumed.

Restaurant						
Surface area (m2)	**301**					
Initial data			***Sources***			
Usable space response (%)	50%	*	.	**Water**		
Useable space (m2)	151			Fresh water use (L/meal)	15	
Space per visitor (m2)	1,2		https://www .	Total fresh water use (L/year)	1683289	
Service time (hour)	1,5	*				
Opening hours (hour)	13,0	*		**Electricity**		
Capacity (visitors)	1086,9			Electricity use (kWh/m2/year)	75	
Opening days (day)	6	*	.	Total water use (kWh/year)	22575	
Yealry days open (day)	313					
				Food consumtion		
Visitors				Beverages consumed (kg/year)	45785	
Occupancy (%)	33%	*	.	.		
Daily visitors	359			Total food consumed (kg/year)	21546	
Yearly visitors	112219			% vegeatables from own farm	40%	
User hours (hour/year)	168329			VF vegetables (kg/year)	8618	

Figure 43: Screenshot of the restaurant section, of the Visitor tab from Excel. The screenshot shows the initial data, visitor data, and FEW data of the restaurant in.

This type of calculation is executed for all system that can receive visitors: office space, restaurant, bar, education space, indoor climbing, sports facilities, expo space, and vertical city park

Results from Visitors tab

According to the estimations, the GT will receive 476.764 visitors per year. These visitors will reside in the building for a total of 920.006 hours. With these numbers it should be noted that they are based on many assumptions. Therefore, they should be treated as estimate and not as definite number of visitors. Moreover, sanitation data and food consumption data are based on these numbers, and thus are as unreliable. A good understanding of how the numbers have come about, is necessary to be able to judge whether the data is accurate enough to be used or not.

4.3.3.11 Food tab

In the food tab, all food and nutrient producing, and consuming systems come together, and their balances are shown. There are four types of balances show: the GT's nutrient balance, the GT's food balance, the external food demand, and the external beverage demand.

On the supply side of the nutrient balance, the nutrients (liquid fertilizer) produced by the bio-digester are included. On the demand side of the nutrient balance, the nutrient (expressed in liquid fertilizer) demand of the vertical farm, educative garden and vertical city park are included. The total nutrient supply is 179.992 kg of nutrients, and the total demand is 13.253 kg of nutrients.

Nutrients								
Nutrient production			*Nutrient demand*					
	Waste transformer (kg)	*Total (kg)*		*Vertical farm*	*Educative ga*	*Vertical city park*	*(kg)*	*Total (kg)*
January	15281	15281	January	988		-		988
February	13802	13802	February	893	-	-		893
March	15281	15281	March	988	-	-		988
April	14788	14788	April	956	-	-		956
May	15281	15281	May	988	-	-		988
June	14788	14788	June	956	-	-		956
July	15281	15281	July	988	-	-		988
August	15281	15281	August	988	-	-		988
September	14788	14788	September	956	-	-		956
October	15281	15281	October	988	-	-		988
November	14788	14788	November	956	-	-		956
December	15281	15281	December	988	-	-		988
Total	179922	**179922**	***Total***	11636	838,5	778,14		**13253**

Figure 44: Screenshot of nutrient demand and supply of the GT, of the Food tab from Excel.

On the supply side of the food balance, the food (vegetables, leafy greens, herbs etc.) produced by vertical farm are included. On the demand side of the food balance, the food (vegetables, leafy greens, herbs etc.) demand of the restaurant and bar are included. The total food produced is 11.039 kg, and the total food demand is 12.477 kg.

Food							
Food production				*Food demand (vegetables)*			
	Vertical farm	*Educative garden (kg)*	*Total (kg)*		*Restaurant*	*Bar (kg)*	*Total (kg)*
January	890	-	890				
February	804	-	804	**Total**	8618	3859	**12477**
March	890	-	890				
April	861	-	861				
May	890	-	890				
June	861	-	861				
July	890	-	890				
August	890	-	890				
September	861	-	861				
October	890	-	890				
November	861	-	861				
December	890	-	890				
Total	10480	559	**11039**				

Figure 45: Screenshot of food demand and supply of the GT, of the Food tab from Excel.

The food producing systems in the GT are not capable of producing all the food required to make a complete meal. Therefore, there will also be a demand for food of external sources. This food demand, according to the model, is 18.716 kg.

External food demand			
Food demand (vegetables)			
	Restaurant	*Bar (kg)*	*Total (kg)*
Total	12928	5788	**18716**

Figure 46: Screenshot of external food demand of the GT, of the Food tab from Excel.

The food producing systems in the GT are not capable of producing beverages, which will also be consumed in the bar and restaurant of the GT. Therefore, beverages will be imported from external sources. This beverage demand, according to the model, is 66.285 liter.

External beverage demand			
Beverage demand			
	Restaurant	***Bar (kg)***	***Total (kg)***
Total	45785	20500	**66285**

Figure 47: Screenshot of external beverage demand of the GT, of the Food tab from Excel.

4.3.3.12 Energy tab

The energy tab includes the supply and demand of energy of the GT. Energy is separated in three types: electricity, hot thermal energy, and cold thermal energy.

The electricity supply is composed of the electricity generation of the PV-panels tab and the bio-digester tab. The demand is composed of the electricity demand of the vertical farm, electricity used for cooling, electricity used for heating, basic electricity demand for lighting and the additional electricity demand of certain visitor systems. The GT produces 78.090 kWh electricity and demands 253.580 kWh electricity.

Electricity										
Electricity generation	in kWhe			**Electricity demand**	in kWhe					
	PV	***Waste transformer***	***Electricity generation***		***Vertical farm***	***Electricity fo***	***Electricity fo***	***Basic Electri***	***Experience f***	***Electricity de***
January	741	3422	4163	January	15390	531,7	638	797,5	4064,6	21421
February	1341	3091	4432	February	13900	531,7	638	797,5	4064,6	19932
March	2783	3422	6205	March	15390	531,7	638	797,5	4064,6	21421
April	4394	3312	7706	April	14893	531,7	638	797,5	4064,6	20925
May	5685	3422	9108	May	15390	531,7	638	797,5	4064,6	21421
June	5815	3312	9127	June	14893	531,7	638	797,5	4064,6	20925
July	5785	3422	9208	July	15390	531,7	638	797,5	4064,6	21421
August	4804	3422	8227	August	15390	531,7	638	797,5	4064,6	21421
September	3183	3312	6495	September	14893	531,7	638	797,5	4064,6	20925
October	1872	3422	5294	October	15390	531,7	638	797,5	4064,6	21421
November	841	3312	4153	November	14893	531,7	638	797,5	4064,6	20925
December	550	3422	3973	December	15390	531,7	638	797,5	4064,6	21421
Total	37794	40296	***78090***		181199	6380	7656	9570	48775	**253580**

Figure 48: Screenshot of electricity supply and demand of the GT, of the Energy tab from Excel.

The heat supply is composed of the heat exchanged for cooling in summer and the heat generation from the bio-digester. The demand is composed of the heating demand for the building's systems in winter. The heating supply is 122.392 kWh thermal energy, and the demand is 38.280 kWh thermal energy.

Heat							
Heat generation	in kWh			Heat demand	in kWh		
	Heat from co	***Waste transformer***	***Total***		***Basic heat d***	***...***	***Total***
Total	38280	84112	**122392**	Total	38280	0	**38280**

Figure 49: Screenshot of heat supply and demand of the GT, of the Energy tab from Excel.

The cold supply is only composed of the cold exchanged for heating in winter. The demand is composed of the cooling demand for the building's systems in summer. The cooling supply is 38.280 kWh thermal energy, and the demand is 38.280 kWh thermal energy.

Cold				
Cold generation	in kWh		Cold demand	in kWh
Cold from heating		Total	Cold demand	Total
Total	38280	38280	Total 38280	38280

Figure 50: Screenshot of cold supply and demand of the GT, of the Energy tab from Excel.

4.3.3.13 Water tab

The water tab includes the water supply and demand of various systems for various types of water. The supply and demand eight different types of water: yellow wastewater, black wastewater, grey wastewater, rainwater, water from bio-digester, fresh water, water for watering, water for flushing toilets.

Yellow wastewater is produced by the visitors of the Green Tower. There are currently no systems planned to process yellow wastewater within the building to retrieve nutrients such as struvite. Based on the current calibration of the model, 97.751 liters of yellow wastewater is produced of which 57.500 liters of urine and 40.250 liters flushing water.

Waste water production			
Yellow wastewater production			
	Urine (L)	*Flushing water (L)*	*Total (L)*
Total	57500	40250	97751

Figure 51: Screenshot of the yellow wastewater production, of the Water tab from Excel.

Black wastewater is produced by the visitors of the Green Tower. There are currently no systems planned to process black wastewater within the building to retrieve nutrients. Based on the current calibration of the model, 119.907 liters of black wastewater is produced of which 4.907 liters of feces and 115.001 flushing water.

Black wastewater production			
	Feces (kg)	*Flushing water (L)*	*Total (L)*
Total	4907	115001	119907

Figure 52: Screenshot of the black wastewater production, of the Water tab from Excel.

Grey wastewater is produced by the restaurant and bar through for instance preparing meals and washing dishes. There are currently no systems planned to process grey wastewater within the building. Based on the current calibration of the model, 2.436.962 liters of grey wastewater is produced.

Grey wastewater production		
	Urine (L)	*Total (L)*
Total	2436962	2436962

Figure 53: Screenshot of the grey wastewater production, of the Water tab from Excel.

Rainwater is caught by the roof of the Green Tower. However, there is no water storage system currently planned. This means the rainwater does flow through the building but is not directly used. If stored, the rainwater produced could be used to flush toilets or water plants. The roof space useable for water catchment allows 254.240 liters of rainwater to be caught per year.

Rain water catchment		
	Roof (L)	*Total*
Total	254240	**254240**

Figure 54: Screenshot of the rainwater production, of the Water tab from Excel.

The bio-digester also produces water, that is distilled from the sludge. This water could also potentially be reused. The amount of water produced by the bio-digester is 38.426 liters.

Water from waste transformer		
	Waste transformer (L)	*Total (L)*
Total	38426	**38426**

Figure 55: Screenshot of the bio-digester water production, of the Water tab from Excel.

Fresh water is used in case there is no other local water source available. The vertical farm, restaurant and bar require fresh water. Their total demand is 2.447.442 liters of fresh water.

Water demand				
Fresh water demand				
	Vertical farm (L)	*Restaurant (L)*	*Bar (L)*	*Total*
Total	10480	1683289	753673	**2447442**

Figure 56: Screenshot of the (fresh) water demand, of the Water tab from Excel.

The indoor gardens, the educative garden and indoor vertical city park, also require water for their plants. This water could be supplied with rainwater, however, if rainwater is not stored in the building, the demand should be met with fresh water. The water demand for watering plants is 280.218 liters per year.

Water demand for watering plants			
	Educative ga	*Vertical city park (L)*	*Total*
Total	145340	134877,6	**280218**

Figure 57: Screenshot of the water for watering demand, of the Water tab from Excel.

Sanitary facilities use flushing water. This water ends up in the yellow and black wastewater streams. It is not necessary to use fresh water for flushing toilets, for instance rainwater could also be used to flush the toilets. The total amount of water required to flush toilets, is 155.251 liters.

Water demand for flushing toilets				
	Feces (L)	*Urine (L)*	*Vertical city park (L)*	*Total (L)*
Total	115001	40250	0	**155251**

Figure 58: Screenshot of the water for flushing demand, of the Water tab from Excel.

4.3.3.14 Dashboard

The dashboard tab is the first and most important tab in the quantitative model. The tab shows all balances of resource flows, divided over the FEW systems. It also shows the number of visitors and space dedicated to them. In figure 59, the dashboard can be observed. The goal of the dashboard is to visualize the resource balances in a way that is easy to interpret.

For every resource the following data is given: the total demand of the resource, the total supply of the resource, the balance between supply and demand given in numbers and the balance between supply and demand given in percentages. A balance score of 0 in kg's or liters and 100% in percentage, indicates that the demand and supply of a resource are in balance. Besides showing the numbers, the data is also visualized in a bar chart, making the difference in demand in supply easier to observe.

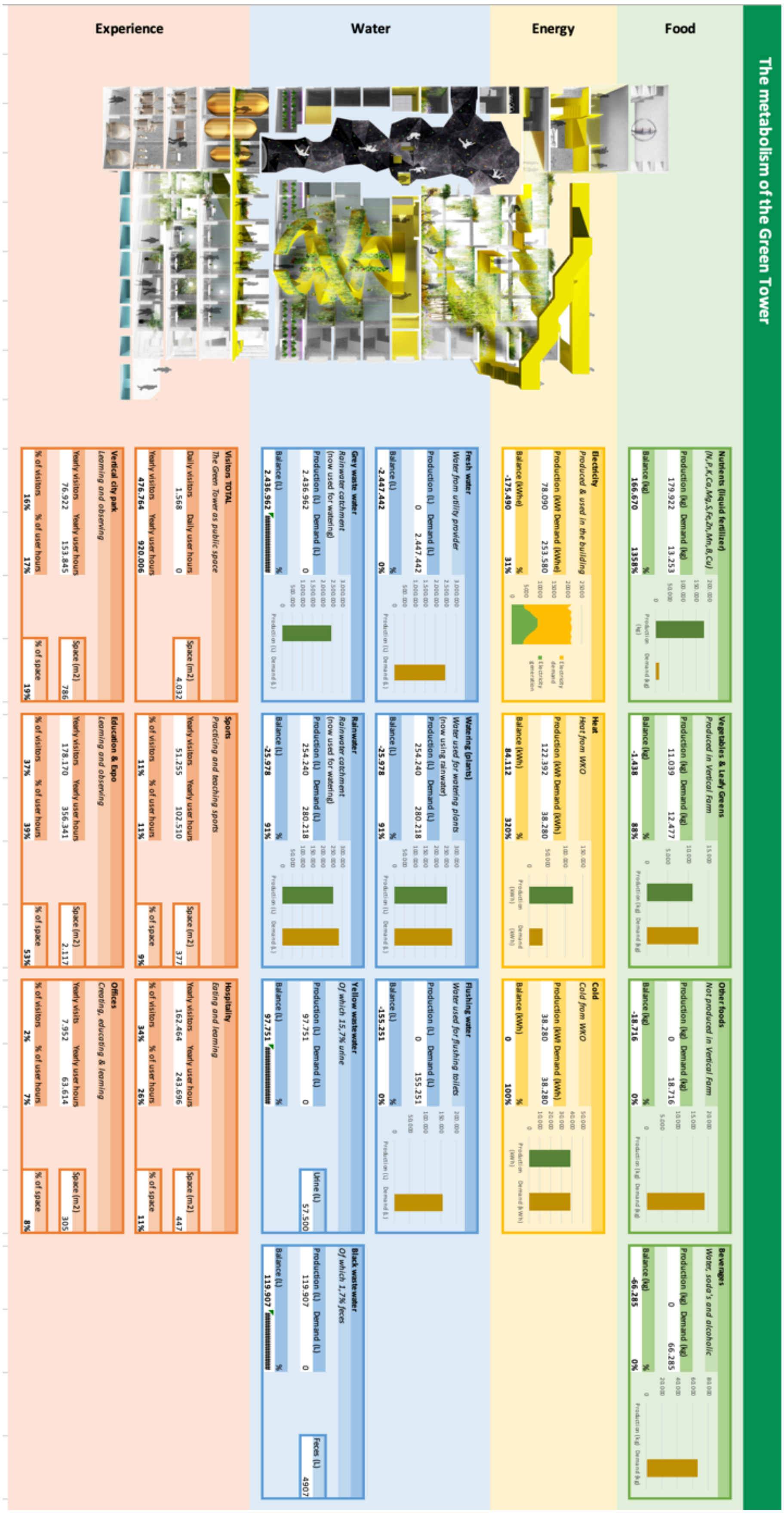


Figure 59: The dashboard of the quantitative model created for this thesis. The dashboard shows resource balances for all resources per food, energy, or water system. Moreover, visitor data is given in the experience section.

Results from dashboard tab

Food
For the food systems of the GT, it can be observed that there is an enormous surplus of nutrients. 13 times more nutrients are produced than the GT requires. The production of vegetables, leafy greens and herbs is lower than the required amount. The GT provides 88% of the required urban farm food. Moreover, there is a large amount of food that requires to be imported, with a shortage of 18.716 kg. The same holds true for beverages, with a shortage of 66.285 liters.

Energy
The GT is not energy neutral or energy positive. The energy production currently produces 33% of the energy demand. Meaning that energy needs to be imported from elsewhere. Moreover, the GT has a heat surplus. The cold supply and demand of the GT is in balance.

Water
In terms of water systems, there are few sustainable practices implemented. The GT has a large demand for fresh water of external sources. It produces none itself. Moreover, for all wastewater streams, there are no local processing facilities. Watering plants could be done with rainwater, and flushing toilets could be done with either gray water or rainwater; however, this is not indicated in the plans.

Experience
In the experience section, most data on visitors can be observed. The model expects that 1.658 visitors will be visiting the GT daily. This amounts up to a total of 476.764 visitors yearly. These visitors spend a total of 920.006 hours in the GT. The visitor numbers are also given per system. The efficiency of the space is also given. For instance, educative spaces amount up to 53% of all space dedicated to visitors, but harbors only 37% of all visitors. On the contrary, the bar and restaurant take up 11% of the total space available for visitors and receive 34% of visitors.

4.3.4 Summary of the quantification of FEW flows in the GT

The most important result of the quantification of FEW flows in the GT are the resources balances of the GT. Below a summary of the resources balances in the GT are given.

Resource type	**Resource flow**	**Supply (per year)**	**Demand (per year)**	**Balance**
Food & Nutrients	Nutrients: liquid fertilizer	179.992 kg	13.253 kg	1358%
	Food: vegetables & leafy greens	11.039 kg	12.477 kg	88%
	Food: non vertical farm food	0 kg	18.716 kg	0%
	Beverages	0 L	66.285 L	0%
Energy	Electricity	78.090 kWh	253.580 kWh	31%
	Heat	122.392 kWh	38.280 kWh	320%
	Cold	38.280 kWh	38.280 kWh	100%

Water	Fresh water	0 L	2.447.442 L	0%
	Water for watering plants	0 L	280.218 L	0%
	Flushing water	0 L	155.251 L	0%
	Rainwater	254.240 L	0 L	~%
	Grey wastewater	2.436.962 L	0 L	~%
	Yellow wastewater	97.751 L	0 L	~%
	Black wastewater	119.907 L	0 L	~%

4.4 Testing the Sustainability Hub Tool

The final step in this research was to put the sustainability hub tool, the system diagram and quantitative model, in practice. All main stakeholders were invited to a co-design session in which sustainability perspectives for the GT were discussed. The sustainability perspectives are based on the results from the first co-design session and the outcomes of the quantitative model. This session was hosted to answer the question: "How do the outcomes of the created tool influence the decision making of stakeholders in the GT project?". Before being able to host this session, a visualization method had to be developed for the data from the quantitative model. The question: "How can the data derived from the tool be presented in a way that is easy to interpret for the stakeholders?". Once the goal of the session and the visualization method were clear, the co-design session was hosted. The session was hosted on May 19, 2021, and the attendees came from AMS Institute, WUR, BKO and FABRICations. The leading question for the session was to find out "How do stakeholders receive the tool and visualization method?". Moreover, a thorough discussion was held on how the tool could be operationalized in the design process of the GT. This chapter will discuss both the outcomes of the session, and a thorough analysis of the process of organizing the session. The process is considered to be valuable data, as it is valuable information on how stakeholders perceive the developed tool.

4.4.1 Preparing the co-design session

Preparing a co-design session is a time-consuming process. At the end of April 2021, the first step was taken in preparing the session. The first step was refining the research goal that was initially formulated. Refining the goal resulted in adding stakeholder specific goals. Afterwards the format and program of the session were formulated, and the stakeholders invited. Once the goals were clear, the format and program were made and the participants were invited, a visualization method was created for the data from the quantitative model.

4.4.1.1 Setting the goals for the session

Two types of goals for the session can be identified; the research goal and the goal as presented to the participants. The research goal of the co-design session is to "find out how the tool and its outcomes can influence the decision making of the stakeholder of the GT.". Moreover, it is researched "if and how the stakeholders see the tool being operationalized in the design process of the GT, or another future project that includes the concept of a neighborhood sustainability hub.".

For the participants of the co-design session, additional goals were set, tailored to the needs of the stakeholders. In a project this size, time is limited for most stakeholders. Specifically, FABRICations and BKO are involved in the design and construction of the entire BK neighborhood. Aligning the goals of the session to their needs without compromising your own research goal, can be beneficial for the stakeholders' will to participate. The goal set, as communicated to the stakeholders, was: "make the sustainability goals of the Green Tower measurable and negotiable.". According to the representative of AMS Institute, making the sustainability goals measurable could help setting the preconditions for sustainability for the GT. At this stage in the project, AMS Institute, BKO and FABRICations were starting conversations for setting the preconditions for sustainability.

4.4.1.2 Format of the co-creation session

The intended format of the session was to discuss different scenarios for the development of the Green Tower based on the sustainability topics of the Green Tower Living Lab. An example for a scenario is "the Green Tower as Nutrient hub", where the productive space planned for the vertical farm is increased, the bio-digester capacity is increased, and many more food and nutrient focused systems were added. The scenarios will be further explained in this paragraph. These scenarios would then be translated to a different floor plan for the GT, which would be inserted to the quantitative model. The results of the quantitative model would be presented as the outcome of the scenario and compared to the current plans. The participants of the co-design session would be presented questions regarding the feasibility of these scenario's and how to operationalize elements of it. However, as the sessions had been canceled, these steps were not executed.

Session set-up 1: CANCELED

The initial plan for the co-design session was to split up the session in three separate sessions, with three different teams working together in each session. Each session focused on a specific cluster of sustainability goals of the Green Tower. Due to a lack of interest of the stakeholders in participating in three separate sessions, and a slight change in the scope of the BK design team, it was decided to cancel the first three planned sessions. The sessions were replaced by one session, in which all three topics were discussed altogether. However, the planning of the first three sessions is closely related to the planning of the final co-design session. Therefore, the preparations for the first sessions will also be discussed, including the reason of cancellation.

The set-up for the first three design session were based on the outcomes of the 'CbD design session BK', hosted by AMS Institute (Appendix 5). In this design session researchers of the Circularity by Design project of the WUR and representatives of BKO and FABRICations collaborated to answer the question: "How can we realize a circular urban agri-food system in the Green Tower in the BK in Amsterdam?". The main result of this session was a diagram with over 120 questions and statements regarding possible experiments that could be set-up in and around the Green Tower, such as a brewery, shared food facilities, urine processing systems, and so forth. Moreover, the sustainability topics for the Green Tower Living Lab were refined using the inputs for experimental set-ups in the GT. The four sustainability topics for the Living Lab, copied from the report on the results of the session, are:

1. "Input Biological cycle: Towards a Closed Biological Cycle: How can the Green Tower function as a Circular Urban Food System in which nutrients and resources from waste produced in the Bajeskwartier can be recovered on the highest circularity level possible?".

2. "Input Material cycle: Towards a Closed Material Cycle: How can the Green Tower become a circular building?".

3. "Input Social: Towards a healthy living environment and Social Acceptance: How can the Green Tower facilitate a Green Vertical Park that contributes to a healthy living environment for the inhabitants of Bajeskwartier?".

4. "Input Sustainability Hub: Towards a replicable Circular Sustainability Hub concept: How can the Green Tower be a fully Circular Building that acts as Sustainability Hub for the Bajeskwartier?".

The four sustainability topics were assessed with a FEW Nexus scope, focusing on their relation to FEW systems. The second topic "material cycle", was not included in the co-design session plan, as this topic focuses on technical materials (construction materials, products, household waste etc.), whereas this research focusses on FEW resource flows. The other topics were transformed to three development scenarios for the Green Tower, given below. Each of these three scenarios served as input for a single co-design session. I will not go too deep into explaining these scenarios, as they were not actually used in the final set-up of the co-design session. The scenarios based on the results of the 'CbD design session Bajeskwartier' were:

1. The Green Tower as nutrient hub (corresponding to topic 1, "Input Biological Cycle"). In this scenario, the Green Tower will function as nutrient hub and focus all its floor space on food production, nutrients recovery and water recycling. Food production would spike, however extremely large amounts of additional water and energy would be required to keep the farm running.

2. The Green Tower as city park (corresponding to topic 3, "Input Social"). In this scenario, the Green Tower will function as city park. The GT will become a location where social interaction, knowledge sharing and (bio)diversity stand central in its design. All its floor space will be public and systems like the indoor vertical city park and educative gardens will fill the building. In this scenario, the Tower loses a part of its FEW processing and production capacity. It generates more human related waste streams, such as black and yellow wastewater, while also requiring more food.

3. The Green Tower as power center (corresponding to topic 4, "Input sustainability hub"). This scenario will optimize the Green Tower's systems to generating, storing, and exchanging as much power as possible. Energy consumption by the tower is minimized. This way the tower can support itself of energy, but also plays a vital role in the energy supply of the BK neighborhood. In this scenario the tower loses a great part of its public function, however, it becomes energy positive and will functions as valuable utility in the neighborhood.

The three scenarios were translated to three separate co-design sessions. The sessions were scheduled and about 10 representatives of the Circularity by Design project, AMS Institute, BKO and FABRICations had been invited per session. Most participants were only invited to one session, which suited best to their expertise. However, only few representatives indicated they would be able to attend. After a few failed attempts to persuade people to attend, it was decided to cancel the session. It was then initiated by a representative of AMS Institute and the Green Tower living lab, to collaborative organize an alternative co-design session.

Session set-up two: CONTINUED

The aim for the new sessions was to only target representatives of BKO, FARBRICations and AMS Institute with a high responsibility level in the GT design. The three scenarios were turned into five design perspectives. These perspectives were closely related to questions the design team of the GT were currently facing. The design perspectives were still largely based on the co-design session held previously, exploring a closed loop urban agri-food system. Therefore, this design session was named "Follow up: Design Session Bajeskwartier (Living Lab). The session was organized together with a representative of AMS Institute and Green Tower Living Lab.

As format, five design perspectives for the GT were discussed (the content of the five perspectives is explained in chapter 4.2). The aim was to get insight in what the priorities of the various stakeholders are, and how the perspectives influence these priorities. For each perspective, three different situations were sketched, backed by data from 3-4 parameters. As an example, in one perspective three situations regarding visitors were sketched: 200.000, 500.000 and 1.000.000 visitors. The perspective was selected to show the effect of the public character of the GT on various balances. The parameters are balances of systems in the Green Tower: vertical farm food, flushing water and nutrients from sanitation. The visitor data of each situation was inserted in the quantitative model, and the values for the parameters extracted. The participants were asked to reflect on these perspectives, with an aim on how it changes their perception of the current design and whether the perspectives would influence the design decisions they made up to now.

The 90-minute session started with an introduction by AMS Institute, on the relevance of the session and its connection to the Green Tower Living Lab and the GT in general. Afterwards, I presented the goal of the session and the program of the day. This was followed by a short presentation on my thesis, the theoretical model and system diagram, and the quantitative model. The quantitative model was explained in about five minutes, so the participants would understand where the data from the perspectives was based on. After the introduction on the session and my thesis, the five design perspectives were presented and discussed for about 10 minutes each. The session ended with a discussion on how the model and data collected for it, could be operationalized in the design of the Green Tower. An overview of the program can be seen in figure 60. The presentation can be seen in Appendix 6.

As stated before, the session was created for representatives of AMS Institute, BKO and FABRICations, with a high level of responsibility in the project. Invitees included the lead architect and owner of FABRICations, the program manager of the GT, the Green Tower Living Lab lead from AMS and five research fellows of AMS Institute specialized in the fields of urban agriculture, nutrient cycles, new sanitation systems, urban energy systems and urban living labs. Organizing the session together with a representative of the design team of the GT, provided extra mandate and resulted in more invitees willing to become attendees.

To summarize, the 90-minute co-design session aimed to discuss five design perspectives backed by data from the quantitative model developed during this thesis and additionally a discussion was planned to discuss the operationalization of the tool and coherent quantitative model.

May 19, 2021

Location: Zoom

Program:

14.30 | Introduction (AMS)	**15.15 |** Perspective 3
14.35 | Thesis Jesse (Jesse)	**15.25 |** Perspective 4
14.45 | Perspective 1	**15.35 |** Perspective 5
14.55 | Perspective 2	**15.45 |** Discussion
15.05 | *brake*	**16.00 |** End

Figure 60: Program of the: “Follow-up Design Session Bajeskwartier (Living Lab)”. In the design session various perspectives were presented based on the quantitative model created in this research. The goal was to test if the model and tool could be used as design tool.

4.4.1.3 Visualizing the design perspectives

While preparing the design session, it was concluded that the data visualization of the dashboard in the quantitative model, was too hard to interpret during a co-design session. The dashboard itself shows many balances, making it even more difficult to quickly assess differences. Therefore, it was concluded that the data required an easy to interpret visualization method.

Visualization method

The design session would be attended by designers, planners, concept developers and researchers. Mainly the designers, planners and concept developers require a visual and easy to interpret method for data visualization. After some discussion with the representative of AMS Institute the session was collaboratively planned with, it was decided that as 'slider' system would work best. By using sliders, it could be easily interpreted whether a system, i.e., parameter, was in balance.

For all parameters except one, the slider indicated if the system had a deficiency, surplus or was in balance (figure 61). The scale of the slider was not given (the values representing the maximum and minimum value of the slider), as it differs for every slider and thus also complicates the interpretation of the slider. However, if the slider is in balance (the dot is in the middle), it can be assumed that the resource balance of the parameter is 0. If the parameter has a deficiency, the dot moves to the left side of the slider and becomes red. If the parameter is in balance, or nearly in balance, the dot moves to the middle of the slider and becomes green. If there is a surplus in the parameter, the dot moves right, and the slider becomes purple. The placement of the dot is not mathematically correct, as it does not automatically move. The dot is placed by the person making the slider, in this case me.

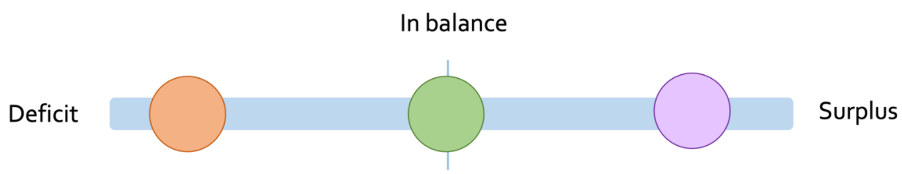


Figure 61: Data visualization method for parameters that can have deficit, surplus, or balance (own illustration).

The one parameter that cannot be represented through the previously explained visualization method, is the combined heat and cold demand/supply of the GT (figure 62). For these systems, there can only be a surplus. Ideally the system is in balance, the heat used in winter is exchanged for the cold of the space that is being heated and vice versa. However, the GT produces additional heat through its bio-digester, which is not compensated by any other system. This leads to a heat surplus. The heat / cold balance is shown in a similar manner as the other balances but differs in the values of its axis. On the left of the slider, a cold surplus is indicated, in the middle of the slider a balance is indicated and on the right of the slider a heat surplus is indicated. The dot is always yellow, as there is no right or wrong in this situation. In principle, you want your heat / cold supply to be in balance, however, in the district heating network there might be another imbalance, compensating the GT's.

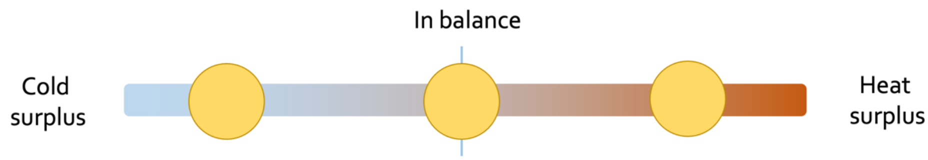


Figure 62: Data visualization method for the heat cold balance of the GT (own illustration).

The outcomes of the quantitative model of the program of the latest known version of the design of the GT were visualized using the sliders. This visualization was also used to show the attendees of the session the current impact of the latest design of the GT on its FEW resources. The visualization, figure 63, only includes some combinations of balances from the dashboard, to keep the visualized data as clean as possible.

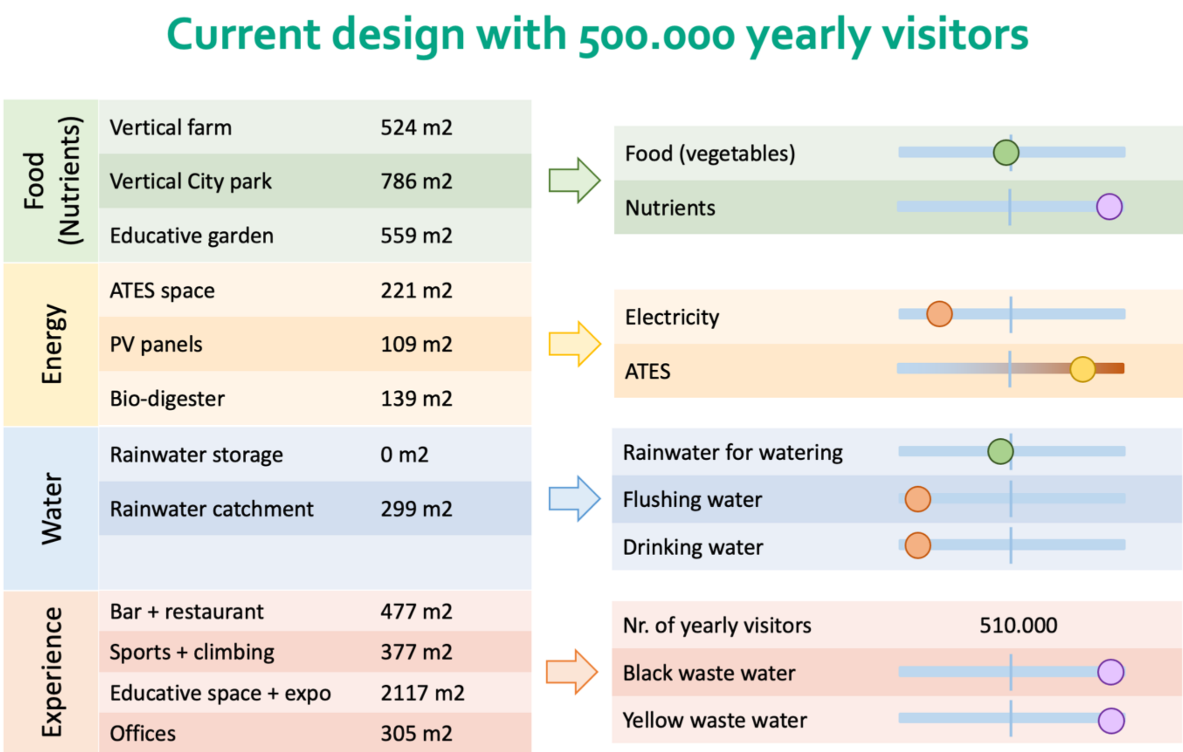


Figure 63: visualization used for the co-design session. It shows the most relevant systems from a FEW Nexus perspective of the GT and their floor sizes (left), and the balances of their related resource flows (right) (own illustration).

The design perspectives visualized

Below, the five design perspectives will be explained. The explanation includes information on where the perspective is derived from, the connected sustainability goal / topic of the Green Tower Living Lab and the used visualization for the co-design session.

Perspective 1: The Green Tower, a place for people

The first design perspective focused on the role of visitor numbers on the balances in food resources, flushing water, and nutrients from sanitation. The perspective connects to the goal of the Green Tower Living Lab to create an educative route where “a space is created space where inhabitants and visitors can interact with the sustainable aspects of Bajeskwartier”. The participants were challenged to think about the effect of attracting visitors to the GT on the sustainability of the building, and thus also the BK. The underlying thought of the perspective was to demonstrate that attracting people to show how sustainable the BK is, potentially makes the BK less sustainable.

The perspective contained three situations, a GT with 200.000, 500.000 or 1.000.000 visitors (figure 64). The parameters chosen where food, flushing water and nutrients from sanitation. The main effect that could be observed, is that increasing the visitors leads to a worsening food balance, a worsening flushing water balance and a surplus of nutrients from sanitation. The latter is an opportunity, however currently the program does not include local wastewater treatment. In general, larger visitor numbers made it harder to balance the resources.

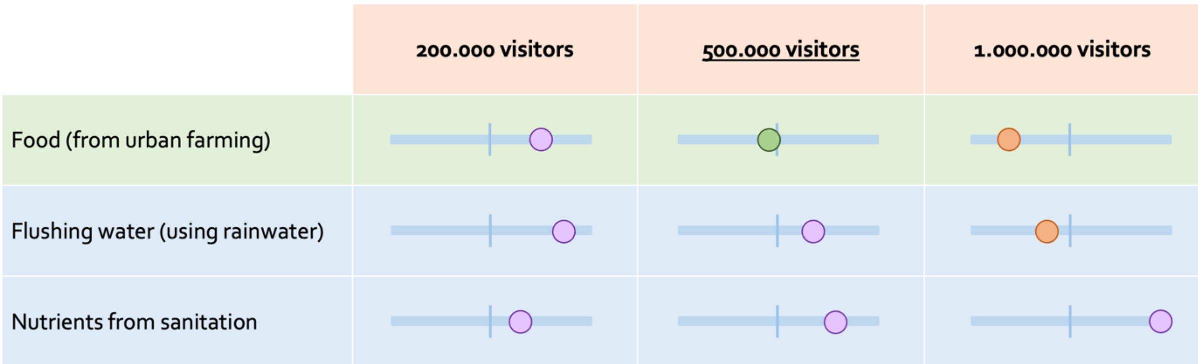


Figure 64: visualization of perspective 1: The Green Tower, a place for people. The visualization shows changing resource balances for food, flushing water and nutrients from sanitation, for various visitor numbers. The numbers are calculated by the quantitative model developed in this thesis (own illustration).

Perspective 2: The Green Tower, supporting the recovery of nutrients

The second design perspective focused on the role of visitor numbers on the balances in waste transformer sludge (liquid fertilizer), yellow wastewater, and black wastewater. The perspective connects to the goal of the Green Tower Living Lab to create a wasteless BK and "support local processing of waste streams and retrieval of nutrients, as effectively as possible.". As displayed in perspective 1, one of the goals of the GT is to attract and educate visitors. Apart from the organic waste collected in the neighborhood for the bio-digester resulting in a nutrient rich sludge, visitors also bring in a valuable resource: urine and feces. Attracting visitors creates the opportunity to retrieve even more nutrients than is already done with the bio-digester. However, there is no direct use for these nutrients. Therefore, the participants were challenged to think about the effects of attracting visitors and the surplus of nutrients it creates

The perspective contained three situations, a GT with 200.000, 500.000 or 1.000.000 visitors (figure 65). The parameters chosen are waste transformer sludge, yellow wastewater, and black wastewater. Increasing visitor numbers, increases the nutrient rich effluents being produced and potentially processed in the building.

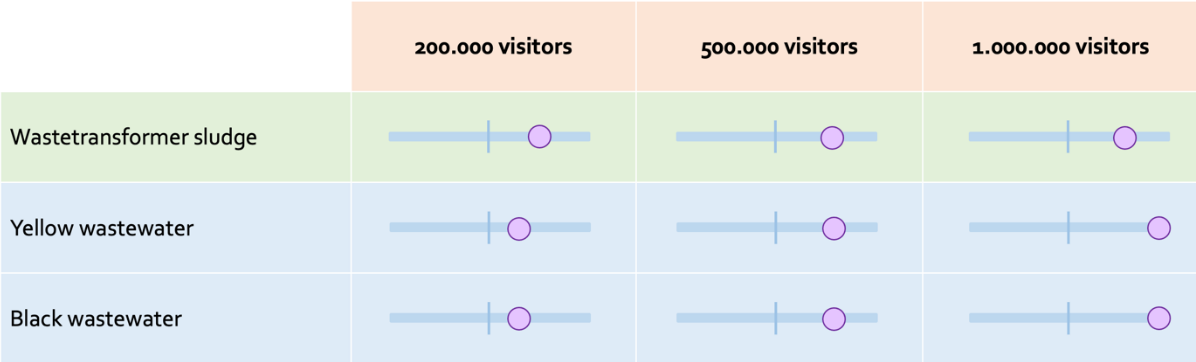


Figure 65: visualization of perspective 2: The Green Tower, supporting the recovery of nutrients. The visualization shows changing resource balances for bio-digester sludge, yellow wastewater, and black wastewater, for various visitor numbers. The numbers are calculated by the quantitative model developed in this thesis (own illustration).

Perspective 3: The Green Tower, maximizing food production

The third design perspective shows the current situation, a situation with increased productivity of the vertical farm and a situation with less visitors and their effects on resource balances in electricity, food, and available food for the fresh market. The fresh market is a new parameter added and calculated specifically for this session, due to a request of the attendees. The perspective connects to the goal of the Green Tower Living Lab to produce as much food locally as possible. The underlying goal is to provide produce for the fresh market in the BK neighborhood. A surplus of food is required to supply food for the fresh market. The fresh market is not part of the GT's systems, therefore all produce that could be used for the market is considered to be a surplus. Two options for improving the food balance are possible: 1) setting the vertical farm's productive space to 100% (originally at 50% due to public character), and 2) Attracting less visitors to the green tower, lowering its internal food demand and creating a food surplus. The participants were challenged to think about compromising the public character of the GT to create a food surplus.

The perspective contained three situations, the current situation, 100% vertical farm productivity and 200.000 visitors (figure 66). The parameters chosen are electricity balance, food, and food for fresh market. The main effect that can be observed is that both situations have a, in this case, positive effect on the fresh market food balance. However, increasing food productivity negatively effects the energy balances, whereas less visitors positively effects the electricity balance.

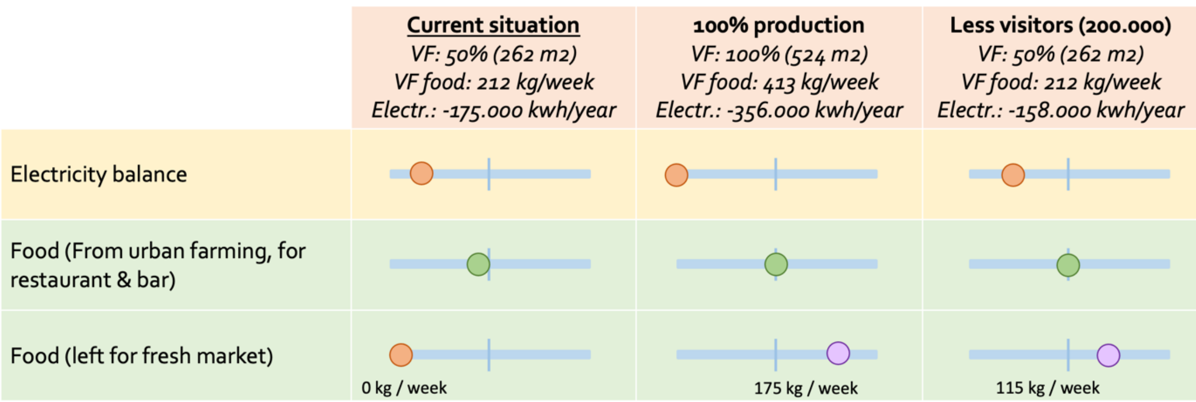


Figure 66: visualization of perspective 3: The Green Tower, maximizing food production. The visualization shows the current situation, changing the productivity of the vertical farm and decreasing the visitor numbers and their effect on the resource balances of electricity, food, and food available for fresh market. As the fresh market is

not within the GT, all food available for it, is indicated as a balance. The numbers are calculated by the quantitative model developed in this thesis (own illustration).

Perspective 4: The Green Tower, reusing rainwater

The fourth design perspective shows the current situation, using rainwater for watering indoor plants, and using rainwater for flushing toilets and their effect on the resource balances of water available for watering indoor plants and flushing water. The perspective connects to the goal of the Green Tower Living Lab to “promote greenery and have the capacity to store 50L of rainwater per m2.”. As there is no storage facility for rainwater planned in the latest design, a storage capacity was proposed. The participants were asked to discuss how and where the rainwater would be stored, and how and where the rainwater would be used.

The perspective contained three situations, the current situation, rainwater primarily used for watering plants, and rainwater primarily used for flushing toilets (figure 67). The parameters chosen are reservoir size, water for watering indoor plants, and water for flushing toilets. The main effect that can be observed is that the potentially stored rainwater can provide all water required for watering plants, but no water is left for flushing toilets. If all water is primarily used for flushing toilets, a small amount of water is also left to flush toilets.

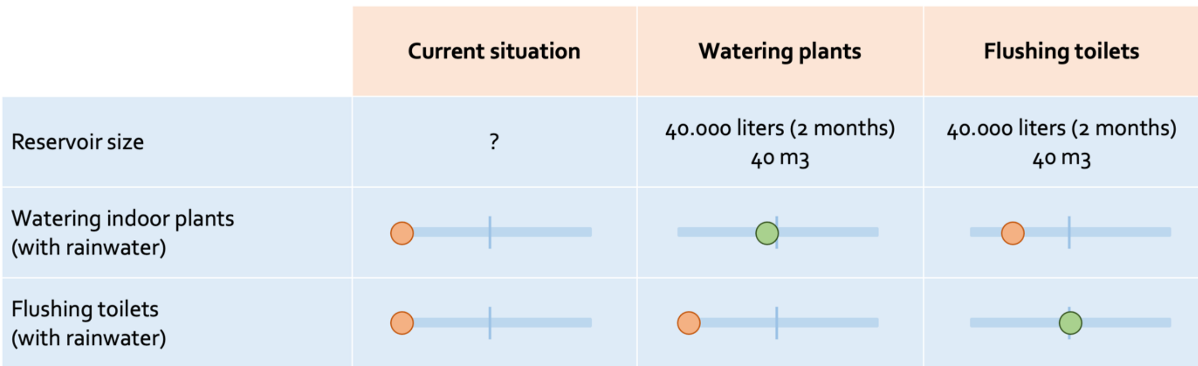


Figure 67: visualization of perspective 4: The Green Tower, reusing rainwater. The visualization shows the current situation, using rainwater for watering indoor plants, and using rainwater for flushing toilets and their effect on the resource balances of water available for watering indoor plants and flushing water. Moreover, a reservoir size is proposed. The numbers are calculated by the quantitative model developed in this thesis (own illustration).

Perspective 5: The Green Tower, energy positive

The fourth design perspective shows the current situation, maximum PV capacity, increasing bio-digester capacity and their effect on the electricity balance, organic waste for bio-digester, ATES and nutrients. The perspective connects to the goal of the Green Tower Living Lab to become energy positive. The participants were confronted with the fact that, according to the model, the GT is energy negative. To become energy positive, two situations are given to do so. However, these situations have a large impact on the building’s infrastructure. Are the participants willing to think in this direction?

The perspective contained three situations, the current situation, maximum PV capacity, increasing bio-digester capacity (figure 68). The parameters chosen are reservoir electricity balance, organic waste for bio-digester, ATES and nutrients. If the roof and all available façade space is filled with PV panels, the GT becomes slightly energy positive, without changing the other parameters. Becoming slightly energy positive by multiplying the bio-digester capacity by six, is also possible.

However, this would result in requiring the organic waste of about 7000 additional households, from other neighborhoods. Moreover, it would increase the heat surplus and nutrient surplus dramatically.

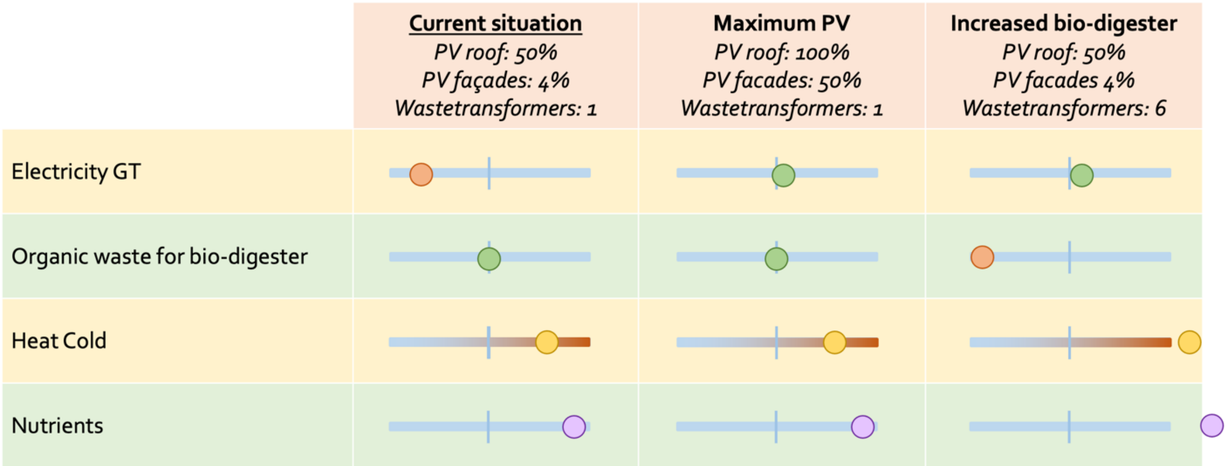


Figure 68: visualization of perspective 5: The Green Tower, energy positive. The visualization shows the current situation, maximum PV capacity, increasing bio-digester capacity and their effect on the electricity balance, organic waste for bio-digester, ATES and nutrients. The numbers are calculated by the quantitative model developed in this thesis (own illustration).

4.4.2 Co-design session outcomes

On May 19, 2021, the design session "Follow-up Design Session Bajeskwartier (Living Lab)" was successfully hosted. The session was attended by five representatives of AMS Institute, BKO and FABRICations. This sub-chapter will dive into the question: "How do stakeholders receive the tool and visualization method?". First, the design session program and planning of the design session will be evaluated. Afterwards, the results of the design session regarding the design perspectives will be elaborated upon. Finally, the feedback given by the participants on how to operationalize the neighborhood sustainability hub design tool will be summarized and evaluated.

The data for this chapter was gathered following these steps: 1) The participants of the co-design session were asked at the beginning of the session if they agreed that the session was recorded, for the purpose of creating a report of the session. The report would be shared with all participants, which in their turn would have to agree with the contents, before the report would be used in this thesis. All participants agreed, and the session recording was started. 2) After the session, the recording was turned into a transcript. The transcript was then turned into a report in which all names were anonymized, and all (possibly harmful) organization specific data was excluded. The recording and transcript were deleted, and the report shared with all participants. 3) The participants accepted the contents of the report.

4.4.2.1 Evaluation: Design session planning and program

The design session was attended by two representatives of AMS Institute, two representatives of BKO and one representative of FABRICations. The representatives of AMS Institute were one scientific program maker, not directly related to the GT project, and one Living Lab expert, also lead of the Green Tower Living Lab. The representatives of BKO were the GT's project manager and lead infrastructural engineer. The representative of FARBRICations is the lead architect of the GT.

Setting a date and time for the sessions was a major struggle with all participants, as all had very busy schedules. The struggle was amplified by the relatively last-minute scheduling, due to the cancellation of the first three sessions and the time pressure of the thesis deadline. Moreover, people seem to be getting tired of ZOOM meetings after more than a year of working from home. If time allowed it, I would have chosen to take more time for scheduling the meeting. Luckily, representatives of all stakeholders were able to join. However, a few representatives that could have given the session greater value, we are not available at the planned time.

The program of the session itself worked out well. The introduction and brief explanation of my thesis and the design tool were received well. The time required per design perspective was enough. However, it should also be noted that the participants were not interested in thoroughly discussing the perspectives, this will be elaborated upon in the next chapter. If the design perspectives would have gained more interest, the 10 minutes per perspective would not have been enough. Discussing the operationalization of the tool was a great success. Participants were very willing to think about operationalization and shared valuable insights.

4.4.2.2 Results: design perspectives as design tool

The design perspectives were not received as hoped for. The main reason for this was that the dilemmas as proposed in the perspectives, had all been decided upon already. This led to the participants not reconsidering their choices but explaining what choices they made and why. Still some valuable insights could be derived from the discussions and are mentioned below.

Perspective 1 'The Green Tower, a place for people', made clear that the Green Tower's public function indeed is leading for design decisions. It was made clear that the primary goal of the GT is to become a public location, where inhabitants of the BK and visitors will find leisure and be educated on sustainable practices. The sustainability of the building itself is very important but comes second.

Perspective 2 'The Green Tower, supporting the recovery of nutrients', resulted in a statement that 'there needs to be a direct demand for a nutrient by the neighborhood, before steps will or can be taken to retrieve it. For organic waste, there is a direct purpose, namely generating electricity and heat in the GT. However, for its effluent, the liquid fertilizer, there is no direct purpose yet. There is no direct demand for nutrients from black and yellow wastewater, therefore it has also not been seriously considered to retrieve nutrients from these waste flows. It was also mentioned that struvite, the main nutrient retrieved from urine, has a very inconsistent quality making it unfavorable in farming practices. This is because an inconsistent quality of nutrients, leads to inconsistent growth of crops. However, applying struvite in city parks can be a viable option, as no stable growth patterns are required in city parks

Perspective 3 'The Green Tower, maximizing food production', discussing the vertical farm it became clear that it was right to assume that 50% of the floor size was used for production. The strong public character of the vertical farm is expressed in the interest for a 'Chef's kitchen', a kitchen where chefs can experiment cooking with vegetables grown in a vertical farm. Regular visitors should also be able to taste vegetables grown in the vertical farm. Moreover, the fresh market will have a floor space of 1200m2 and is supposed to be sell vegetables from the vertical farm. The public character of the vertical farm stands central in its design, so allowing no visitors in the vertical farm, or less visitors in the GT are no viable options.

Perspective 4 'The Green Tower, reusing rainwater', resulted in a discussion about where in the neighborhood water could be stored. An old nuclear bunker seemed to have priority, as it's concrete structure would be effectively reused. Storing water in the GT itself did not really seem to gain traction among the participants. However, it was proposed to create a water square on the square in front of the GT. A water square creates retention capacity for rainwater, no storage for later use.

Perspective 5 'The Green Tower, energy positive, revealed a discrepancy between the energy use data used for the vertical farm in the quantitative model and the data the participants of the session had in mind. In their perception, the vertical farm would be an energy neutral system, generating its own energy by using plants waste such as stems for their own bio-digester. In the quantitative model, the vertical farm is the largest electricity consumer of the building. It was suggested further research on both sides was needed. The energy consumption of the vertical farm in the quantitative model might be too high, while an energy neutral vertical farm might also be too ambitious. The situations sketched in the perspective, were not considered as viable options. Covering the GT in solar panels is too expensive according to the participants and increasing the bio-digester capacity does fit in the GT's goals. Moreover, the heat surplus created by the bio-digester was a valuable insight for the participants. It was explained that the BK neighborhood most likely has a heat surplus as well, due to high isolation standards. Therefore, there is no destination for the heat of the bio-digester, which makes it a waste stream. Looking for nearby parties interested in buying and/or using the heat, is necessary to compensate for this surplus.

4.4.2.3 Results: Operationalization of the neighborhood sustainability hub design tool

The final 20 minutes of the co-design session were dedicated to discussing if and how the tool, quantitative model, and collected data could be used to benefit the GT project. After it was agreed that the tool could be useful in the project, the question asked to the participants was *"how do we make sure that we can transform this tool into something that can be used to support the design of the Green Tower? And what needs to be changed for it to be useful?"*. The feedback given has been clustered in six different topics: assumptions, FEW systems, spatiality of model, visualization, storytelling, and usefulness of the tool.

Assumptions

Participants expressed that they would have liked to know more about the assumptions that had been made in the model. Before interacting with the outcomes, it is very important to them to know what assumptions have been made for the specific balance they are looking at. Therefore, the assumptions should be made clear at the start of a session like the co-design session. A difficulty in this is that many assumptions are made in the model, too many to present in a co-design session. This could be solved by selecting assumptions, that are crucial for understanding the outcomes.

Another point of feedback given that is closely related to assumptions, is the suggestion to add sustainability legislations as basis for the model. Such as the BENG norm (for energy use), isolation norms, or minimum water retention capacity. It was shared, that nowadays there are sustainability requirements for almost anything, especially for energy use and water retention. Making sustainability requirements part of the assumptions, was seen as an option to make the tool even more valuable. Moreover, it was suggested to add a visualization that shows whether the initialized design fulfills the sustainability requirements set in the model.

FEW Systems

The current model only includes systems that are currently planned or were previously suggested for the Green Tower. Of course, there are many more systems that could be implemented in a sustainability hub. It was suggested to add other FEW systems (For instance wind turbines for roofs, struvite retrieval, etc.), and add more types for each system (For instance various types of bio-digesters, PV-panels, etc.). Best would be if these additional systems could be selected through for instance a drop-down menu.

It was also suggested to add information sheets per FEW systems of the quality of resource flows it produces and it requires. Moreover, information could be given on options to process flows. For instance, the sludge produced by the bio-digester, is possibly not ready to use as fertilizer. It requires processing before it can be used. However, the level of processing required might be different for agricultural use or use as fertilizer in city parks. Also, instead of having to search for parties interested in an effluent, a list with options on what type of parties might be interested would be valuable to add. This way, searching for parties will cost less time.

Lastly, the coupling of economic data was suggested as being valuable. This can be done for two things. First, investment costs of certain systems could be added, preferably coupled to the size of the system. Second, economic data could be added to give value to resource flows. Coupling economic data could be benefit the tool to help designers make decisions, however, the risk is created that it diverts the focus on creating FEW systems that are in balance to creating the most economically profitable system. Mostly, sustainable options are not the most economically profitable (in the short term).

Spatiality

It was noticed that some systems of the GT impacted the neighborhood scale and some only the building scale. For the food & nutrient systems, the neighborhood scale is included, while the water and energy systems only focus on the building scale. It was indicated that the tower indeed can be viewed from a neighborhood perspective and a building perspective. The GT is location that processes waste flows and produces resources for the neighborhood. It is also a tower that has users who create all kinds of processes and flows inside the building. However, in the model a clear distinction should be made between wat flows and systems operate at a building scale, and which operate at a neighborhood scale. This is important because the goals for the GT utility for the neighborhood can differ from the goals of the GT as building. One specific system, the ATES, was highlighted as system that cannot be seen separately from the neighborhood, which currently is focused on the building level in the quantitative model.

Visualization

The visualization method in the co-design session (the sliders), was received very positively. It was called “easy to interpret” and suggested to incorporate the sliders in the dashboard of the quantitative model.

The dashboard of the quantitative model was received as being “overwhelming”. There is too much information in the dashboard. The numbers are more informative than the bar charts, however, the numbers are too detailed. It was concluded that the dashboard required simplification.

It was suggested to make a dashboard for the quantitative model using Microsoft Power BI. Power BI is an interactive tool that is used to visualize data. It is used for data analysis and the creation of visual reports. Participants familiar to the Power BI software agreed that using it to create an improved interactive dashboard would be a good option.

Storytelling

Apart from using quantitative model as analytical model for internal use by the designers, it was proposed to use it as a method for storytelling. Knowing, and visualizing the balances in the green tower and comparing them to other situations could be a great way of telling the GT's story. Namely, the GT is not a real sustainability hub yet; the project is focused on showing what is possible in terms of sustainable and local production within a neighborhood. The educative route that flows through the building, is a place where this story can be told, possibly through data derived from this quantitative model. This is a new pathway for the model that had not been explored yet.

More specifically, it was mentioned that comparisons could be made with the model, between the scale of production in the GT, and the scale that is required to feed the neighborhood. For example, currently, the design of the GT harbors two floors with vertical farming of which 50% is used for production. The model could calculate how many floors at 100% production there are needed to feed the BK neighborhood, while also showing its impact on other resource flows. Turning this data into stories and visualizations, can create a different and valuable purpose for the tool.

Usefulness of the tool

The design tool was positively received, and participants showed sincere interest in the possibility to further develop the tool, for use in the Green Tower Living Lab. Some general remarks were given by the participants on how, when, and where to use the quantitative model.

First, it was indicated that the tool could be useful in the initiative phase of designing buildings like the Green Tower. In this phase it could be used to quickly assess if a planned user fits within the building, based on its impact of the building's overall sustainability. Based on the outcome, the design team can decide if a user is allowed in the building or not, or if a proposed system fits within the building or not.

The previously explained function of the tool, using it as assessment tool for allowing systems and users, could also be used in a later stage of designing the building according to the participants. When the design is being crystalized, the model could show if small changes, or last-minute changes in entire systems or users, fit within the building's sustainability boundaries. In this case, the tool must be used and updated during the entire design process, for the data to be as accurate as possible.

Another use for the tool would be to see if certain systems could be downscaled, upscaled, or not necessary at all. If a certain system does not influence the GT in a way that is essential, it could be decided to not implement the system and use the investment for another system. *"Can we remove something and stay in balance?".* An example that was given, is the solar sculpture on the roof of the building. The sculpture has very high investment costs, if it can be concluded that is not essential for being energy neutral, the large investment can better be repurposed.

Lastly, it was stated that we should also not forget to think ourselves. The model is not leading, the model helps you create an assessment framework for making sustainable choices, the choices however, are made by us, the design team.

4.4.3 Summary of testing the sustainability hub tool

If the perspectives would have been better aligned with the current state of design, they would have been more valuable discussion starters. This could have been achieved by setting the assumptions for the perspectives together with the design team. On the other hand, showing them perspectives that were 'out of there comfort zone', was also part of the exercise. The participants were challenged to think about design perspective they might have not considered before. Still, some insights were derived from the discussions of the perspectives. The goal of the GT is not to become 100% sustainable regarding its FEW systems. The tower will showcase the potential of adopting certain innovations in for instance urban farming for creating more sustainable neighborhoods.

Regarding its FEW systems, additional steps in retrieving flows would be considered if there is also a direct demand for these flows. An example is the extraction of struvite from yellow wastewater. Adding black wastewater to the bio-digester is not an option as it negatively effects the bio-digesting process and effluents. The participants did not seem interested in reusing rainwater, which is very surprising. Moreover, the heat the bio-digester generates can become a problem, as the ATES is already ‘overheated’.

5 Conclusions

5.1 Synthesis of the Research Questions

5.1.1 Understanding the current design of the Green Tower

This thesis was based on the indication that the GT would become the ‘sustainable heart’ of the BK, on both a technical and social level. However, while analyzing the program of the GT from a FEW Nexus perspective (chapter 4.1), it was concluded that the systems providing sustainability from a technical point of view had not been planned out properly yet from a FEW Nexus perspective. Therefore, this thesis created a tool that helps understand the relations between FEW, enables the quantification of FEW resource flows, and allows the user of the tool to balance these flows.

During informal conversations, co-design sessions and a focus group, it became evident that the public character of the GT was prioritized over its technical character. It was often explained how public functions had been prioritized over technical sustainability systems, and how all technical systems had a strong public character. This observation became clear while analyzing the FEW systems of the current program by means of a SWOT analysis, from a FEW Nexus perspective. For the food & nutrients systems it is concluded that the GT has two main elements, that can contribute to creating sustainable local food & nutrient loops: organic waste collection and processing, and food production. The vertical city park does not play an obvious role in this cycle, its space and nutrient demand could have better been utilized for food production. Moreover, the Food Recovery Hierarchy should be considered in choosing processing activities for organic waste. Currently, organic waste is instantly processed in the bio-digesters and/or used as compost, options like preventing food waste, feeding the hungry or feeding animals should be considered first. Furthermore, the food production in the GT contributes to the food security in the BK in general terms. However, the system producing food, the indoor vertical farm, will potentially become poorly accessible and inequitable. The energy systems of the GT, the ESCO, bio-digester, Lumniduct and PowerNest, are well aligned in the program of the GT and provide the GT and BK of renewable energy. For the bio-digester, the Food Recovery Hierarchy should be considered as well, this results in preferring feces as input instead of organic waste. However, this would lead to a drastic change of the nutrient composition of the effluent, which requires additional research. A stable performance of the bio-digester is very important as it plays a vital role in the nutrient, electricity and heat supply of the GT and BK. The PowerNest and Lumniduct function are less stable renewable energy suppliers, as their supply depends on the climate. A shortcoming in the design is identified in the Green Tower’s water systems. The only water resource included in the program of the GT is rainwater. Fresh water and wastewater are currently not included in the program of the GT. Moreover, rainwater is not specifically harvested, and the idea of reusing it has not landed in the design yet.

Overall, the separate FEW systems’ have been poorly linked and their impact on other FEW systems, such as the energy required for purifying water or producing food in vertical farms, is lacking.

5.1.2 Visualizing the FEW systems of the Green Tower

Identifying, connecting, and visualizing the FEW resource flows and systems of the GT has helped this research and the stakeholders involved in the one-on-one co-design sessions, to understand their relations. The resource flows identified and used in this research are organic waste, nutrients, food, heat, cold, electricity, yellow wastewater, black wastewater, grey wastewater, rainwater and drinking water. The FEW systems of the GT and their relations as identified in this study gave a more detailed insight than the identification executed by the main stakeholders. The biggest differences in the relations shown in the GT's progress report and the potential relations, are in the water domain. Black and yellow wastewater flows are potentially valuable flows that are not included now.

The theoretical model, based on the visualization, has been developed to help future sustainability hubs and possibly other sustainable buildings to think about their FEW systems and interrelations. The concept of transformation centers was introduced in the visualization and theoretical model in Chapter 4.2. The transformation food, energy, and water center are clusters of systems that enable the generation, distribution, or recycling of resource flows categorized under either food, energy, or water. For example, the energy transformation center includes the PV-panels, ATES, heat pump and bio-digester. The relations between these three FEW transformation hubs show the essentials of FEW Nexus thinking: the relations among FEW systems. As an example, the bio-digester from the energy transformation center, provides nutrients for the food & nutrient transformation center. The food & nutrient transformation center provides plant waste and food waste for the bio-digester in the energy transformation center. However, being able to relate all systems, does not tell the user of the tool anything about the resource ratios or balances they create. The system diagram and theoretical model is therefore complemented by the quantitative tool, solving this limitation of the visualization method(s).

5.1.3 Quantitative model of the FEW flows in the Green Tower

The quantitative model was successful in showcasing potential balances in all identified FEW resource flows. The resource balances showed potential in the food & nutrient domain. The production of nutrients (liquid fertilizer) leaves an enormous surplus after the nutrient demand for the indoor vertical farm, educative gardens and vertical city park are subtracted. Namely 166.739 kilograms of liquid fertilizer, which is about 12,5 times the nutrient demand of the GT itself. A proper destination, preferably in food production, could be found to achieve a balance in nutrients. This way, the nutrients can be kept in the food production loop, reducing the requirement of new nutrients. The current production of vegetables and leafy greens of the GT is calculated to serve 88% of the vegetable & leafy green demand of the GT's restaurant and bar. Furthermore, respectively 18.716 kilograms of other foods and 66.716 liters of beverages will require to be imported from outside the BK.

The electricity balance of the Green Tower is concerning. The model shows that the GT currently can only produce 33% of its electricity demand, resulting in a large deficiency. The major electricity consumer, accounting for 71% of the electricity consumption, is the vertical farm. The GT itself is not in balance in heat and cold supply. The tower produces more heat than it requires, whilst the cooling of the tower is in balance. It should be noted that this disbalance does not indicate the functioning of the BK's ATES, as there are many more buildings connected to its heating grid that potentially influences the overall balance.

The water domain, with the latest program inserted in the quantitative model, does not seem to show any attempt to include processing or (re)using water streams. There might be a direct link from the rainwater catchment on the roof of the GT to the vertical city park or educative gardens. However, no storage capacity has been fitted into the current design, limiting the abilities to use the water within the GT. Moreover, grey, yellow, and black wastewater are discharged on Amsterdam's central sewage system. In case of the yellow and black wastewater, many potentially useable nutrients leave the GT's and BK's boundaries. This also means that all used fresh water from the water authority Waternet, leaves GT and BK again.

5.1.4 The neighborhood FEW design tool in practice

In the focus group it became clear that the priorities of the GT design team are not to create a building with well-balanced resource flows. For them, the goal is to design a well-functioning public building. With well-functioning, they mean it is a pleasant space that can receive a maximal number of visitors. Making sure that resource flows are in balance, came second. The FEW design tool, as presented to the stakeholders in the focus group session, was deemed to be useful in the initiation phase of designing a building like the Green Tower. However, the initiation phase had already passed for the GT design which resulted in the designers explaining the choices they made and how the model could have helped them in an earlier stage. The visualization method for the results of the quantitative model was received positively. Moreover, the focus group concluded that the quantitative model could be a very useful tool in their design journey, if adapted correctly.

These results were expected. The tool and quantitative model were developed to help making decisions in the initiative phase of designing a sustainability hub. When this thesis started, namely fall 2020, the project team was in this initiative phase. However, as time has passed, they have moved beyond this phase, creating a gap between the goals of this thesis and the project. Therefore, the results of the tool were not well aligned with the challenges the design team was facing during the focus group. This discrepancy was inevitable and will be further discussed in the reflection.

5.2 Concluding Remarks

This study shows that, food, energy, and water are underrepresented in the program for the GT, 'sustainable heart' of the BK neighborhood. The food systems underperform in food production and overperform in nutrient production. While potentially improving food security, the current program lacks focus on food accessibility and equitability, providing their produce solely to who can afford to buy it and within the GT. The excess of nutrients in the GT does not directly form a threat, as the surplus could be used for fertilizing (urban) agriculture and city parks. Moreover, the 'Food Recovery Hierarchy' should be considered in finding applications for organic waste before bio-digesting or composting it. In terms of energy systems, the building offers a complete range of electrical and thermal energy generating, storing, and transporting systems. It was calculated that the electricity generating systems within or on the building, as currently planned, will be able provide only 33% of the building's energy demand. Moreover, the building will overproduce heat for the ATES of the BK and thus requires to be balanced somewhere else in the neighborhood. The water systems of the GT have been very poorly defined. The plans only include the (re)use of rainwater within the building. However, the latest program did not include rainwater storage, minimizing the options to direct use during precipitation events. Moreover, no attempt is made to locally produce water, by filtration, nor process grey, yellow, or black wastewater. Processing yellow and black wastewater of the building or the entire neighborhood in the GT is a missed opportunity that would have resulted in local energy, nutrient, and water production. Overall, a shortcoming in focus on the interrelations between FEW systems can be observed in the preliminary design of the Green Tower from a FEW Nexus perspective. For instance, the vertical farm was assumed to be a 'closed loop system', not requiring (considerable) inputs from outside the system. However, a system where you take things out of (food), will logically also require inputs (nutrients, energy & water). Moreover, as the vertical farm does not operate in a vacuum, energy and water losses should also be accounted for. Some literature even indicates that vertical farming has a higher carbon footprint that conventional farming practices, underlining the possible unsustainable character of these urban plant factories (Al-Chalabi, 2015). Improving the understanding of the complex relations between FEW should help the design team in designing a better-balanced GT, without having to compromise the public character of the project.

The performance of the GT's FEW flows has been calculated based on the 'FEW Neighborhood Sustainability Hub Design Tool' developed in this thesis. The tool exists of two elements:

> 1) A visualization method for the FEW systems and relations of the sustainability hub at the building, neighborhood, and city scale level. The visualization method helps designers think about the existing and possible relations in their sustainability hub. And serves as basis for customizing the quantitative tool.
>
> 2) A quantitative model that enables the quantification of the FEW resource flows in the building, by inserting the buildings (floor area) program, and showing the resource balances in its dashboard. By adjusting the floor sizes, or by deleting/adding functions through their floor size, changes in balances can be observed in the model's dashboard.

The data derived from the tool has functioned as interesting material for discussion within the GT project design team. As for the resulting FEW resource balances, it should be noted that they are based on many assumptions. The results are thus also not the only result of this thesis, but the tool itself is a result as well. The primary steps that should be taken to operationalize and improve the tool's quantitative model, for it to provide more reliable and useful data, are: 1) Improving the model's assumptions and cross-check them with stakeholders, as many assumptions of FEW system data have not been (thoroughly) validated. 2) Expanding the options of FEW systems in the model. For instance, adding various types of bio-digesters to be selected by the user of the model. 3) Clarifying the division between building related and neighborhood related systems and flows. In the current model, there is not a clear division between BK and GT related flows, causing confusion on what scale level the tool is targeting. In the current model, it targets some food & nutrient flows at a neighborhood level and targets energy and water flows at a building level. 4) Improving the visualization method for the interactive dashboard. It was indicated that the current visualization of the quantitative model (in the Excel file) was too overwhelming. The slider system, as developed for the presentation, was deemed to be a better option to integrate in the quantitative model. Further development could lead to the tool to be used for: 1) storytelling, 2) decision making framework, 3) system scaling tool. The further development of the tool will be further discussed in Chapter 7, the recommendations.

Important to realize for the further use and development of the 'FEW Neighborhood Sustainability Hub Design Tool', for which an initial development step has been made in this thesis, is that creating resource balances is usually not the primary goal of developing a building and neighborhood. The primary goal of a building of any sort, and thus also a sustainability hub, is to improve the lives of the people that interact with it. In case of the GT this public focus is very strong, resulting in the development of a sustainability hub that primarily focusses on education of the public versus creating sustainable and circular resource loops. But even if the focus was to develop a building solely focused on achieving technical sustainability (sustainability achieved through technical processes, such as recycling FEW flows) for the neighborhood, the aimed for resource balances are still dependent on what is best for the neighborhood. Moreover, residents will have to exercise sustainable practices for the technical sustainable system to operate. For instance, the BK neighborhood might have a perfect food waste recycling system in place, however if the residents do not separate waste accordingly, this system becomes useless. In the real world, 100% circularity is unachievable at a local scale, as losses of food, energy and water are inevitable at this scale. Therefore, clear, and realistic goals for resource balances that serve the purpose of the sustainability hub and surrounding neighborhood should be formulated before, or during the use of the tool by all stakeholders, including the (possibly theoretical) wishes of (future) residents of the neighborhood.

The creation of the tool, both the product and the process, has helped the design team of the GT to become more aware of the FEW resource flows within the building they are designing, and its neighborhood. It was indicated that further development and use of the tool will benefit the design team of the GT. Therefore, it can be concluded that the tool has helped to gain understanding of FEW for designers and will possibly improve this understanding in the future.

6 Reflection

6.1 Reflection on the Process, Methodology & Results

6.1.1 MRQ: Design thinking

Initially I started this thesis thinking that I would combine various methodological approaches as overarching approach, for developing the FEW Neighborhood Sustainability Hub Design Tool. During the thesis, I stumbled upon design thinking as a scientific research method. After familiarizing with the methodology, I realized that the approach I was taking very closely resembled the six steps of design thinking: 1) understand, 2) observe, 3) synthesize, 4) ideate, 5) prototype, 6) test. In this sub chapter I will reflect on how design thinking has been applied, and what could have been done differently.

Jobst & Meinel (2014) describe many examples of research methods that can be applied in design thinking. The ‘understand’ step, has now been executed with a stakeholder power relation mapping and a SWOT-analysis which still very closely resembles examples of analysis methods proposed in design thinking literature, such as stakeholder maps and 360-degree research. In the ‘observe’ phase methods such as expert interviews, extreme users, surveys, and critical function prototype are mentioned. The ‘observe’ phase in this thesis has been conducted through observations from informal conversations and one-on-one co-design sessions, which could be referred to as an expert interview with visual output. This phase could have been executed more thoroughly by executing more expert interviews and participating in more stakeholder meetings. The global pandemic also obstructed the ability to visit the stakeholders and see them collaborate. Other limitations due to the global pandemic will be discussed in chapter 6.2.2. The ‘synthesize’ phase can be conducted by for instance a point of view statement, persona, scenario, process map or Venn-diagram. The visualization produced in this thesis, closely resembles what a process map of the FEW systems of the GT would have looked like. Scenario building, creating various design scenarios for the building, would have been very valuable as well. Then, for the ideation phase various brainstorming setups with the design team, or sub teams are proposed. The one-on-one co-design sessions had the characteristics of a brainstorm session, on how the FEW flows could be related and be best visualized. This phase could have been improved by inviting more representatives to these co-design sessions and planning more of them. In ‘prototype’ various forms of prototyping are proposed: hi-fi prototyping (high quality prototype (mock-ups)), lo-fi prototyping (low quality prototype (mock-ups)), dark horse prototyping (extreme scenario prototype), role plays, system prototyping (software prototype). The executed prototype most closely resembles system prototyping, which is a prototyping method in software engineering. The quantitative model made, can be compared to a small software program, which required testing and development. In hindsight, dark horse prototyping and role plays have also been considered as ways to further test the quantitative model. At first, I wanted to use the model to translate extreme design scenario’s, such as a Green Tower with only food & nutrient systems, to alternative designs for the GT and present these to the stakeholders. Dark horse prototyping is about proposing daring and different ideas, which often turn out to be very close to the best solution (Durão, et al., 2018). As testing methods, interviews, extreme users, questionnaires, and experiments are mentioned. In this thesis, I applied a focus group to test the tool. In hindsight, the applied methods closely resemble the examples named in Jobst & Meinel (2014). Having known about these methods earlier in the process, would have helped improving the methodological approach in how the steps have been executed.

Another useful insight would have been that design thinking is a human centered approach (Jobst & Meinel). At first, I started designing the tool with a more building centered approach, only thinking about how the building could support the best-balanced FEW resource flows. However, at first, I did not emphasize enough that the demand and supply of these FEW resources is defined by the humans interacting with them. During the research this became more evident, and I realized that the aimed for resource balances are defined by the humans interacting with the building. What resource balances benefit the neighborhood, or visitors of the GT most? Also, the tool itself, would be used by designers who have a bigger set of goals for the building than just finding the best resource balances.

In practice, information is often only captured in the products made in the design thinking process. With products for instance the visual presentation of the FEW systems of the GT, or the quantitative model is meant. However, earlier products, their context, dependencies between products, the design rationale and other related details should also be documented. It is important for whoever will use, adapt, or operationalize the tool is that all design activities can be revisited (Jobs & Meinel, 2014). Capturing the design process has been done to a certain extent in this research. However, it was decided to only document the visual outputs of the co-design sessions. In hindsight, a report of which choices were made and why would have been valuable to use for the future development of this tool would have been valuable. The risk now is that whoever further develops the tool, will include, or exclude certain aspects of it, based on their on their own opinion. Without context some crucial elements of a design might be viewed as less important by the person working on it.

As a final remark, having found design thinking as a research method earlier in the process would have given me a bit more confidence in the methods I was applying. For instance, with a background in earth sciences and sustainability studies I was not familiar with the concept of prototyping. During the thesis, just making this tool felt like a bold move. In hindsight, prototyping is a common research method, and being familiar with it would have made just making the tool a bit easier. However, the executed steps closely resemble design thinking and overall, I am very confident about the applied methods.

6.1.2 RQ1: Literature Study & SWOT Analysis

The first research question “What are the strengths and weaknesses of the current design of the Green Tower from a FEW Nexus perspective, and who designed it?” is composed of a stakeholder part and a program part. Both parts have been answered using different research methods. In this sub chapter, I will discuss the research methods applied to answer the first research question, and what I would have done differently.

The stakeholder part answered the questions *“what stakeholders are involved in the design of the Green Tower”* & *“what individual and/or mutual goals do the main stakeholders have and how are they aligned?”.* In the research set-up used for this thesis, stakeholder mapping and power relations have been based on some informal conversations, progress reports and the stakeholder’s websites. In an ideal situation, this step would be executed doing expert interviews with various representatives of each stakeholder. Through these interviews, the stakeholder relations could be researched in a more thorough scientific way. Moreover, expert interviews will give the grounds to do an in-depth analysis of the stakeholder goals, ambitions, and mutual power relations.

In the stakeholder mapping, one important stakeholder is missing, namely the future residents of the BK and future visitors of the GT. Resident profiles, or visitor profiles have not been created yet for the GT or BK. Moreover, the GT project is not in contact with this user group, as they do not exist yet. Including them in the mapping would have been very valuable and could even be viewed as necessary. However, the absence of data on these groups overcomplicated including them. Therefore, it was decided to not include them in the mapping, and just focus on the three main partners involved in designing the GT. Moreover, the tool created will also only be used by the designers, and not the user of the building. The users however are of course the people you are designing for, and therefore including them would have been better.

The GT design program has been analyzed using a SWOT-analysis. A SWOT-analysis is most often applied to analyze the strengths and weaknesses of a company. Using it to assess a design project is also possible. The method served its purpose surprisingly well. At first it was decided to perform a criteria analysis of the strengths and weaknesses of the GT program. However, setting the criteria for the analysis was very difficult due to the lack of literature on good and bad practices in FEW management at a building and neighborhood scale. Therefore, the simplicity of a SWOT-analysis was very suiting for approaching the strengths and weaknesses of the design. Discussing not only the strengths and weaknesses, but also the opportunities and threats, gave a good insight to what could be improved in the design already. However, to gain more depth, a criteria analysis, possibly combined with interviews would have been better.

6.1.3 RQ2: Prototyping & unstructured co-design sessions

Co-design/expert interview sessions were hosted to answer the research question "How can the FEW eco-system and the interrelations of its components of the Green Tower be best displayed?". Whether I have found the 'best' way to visualize the FEW ecosystem and the interrelations of its components will be discussed below. First, the use of MIRO (the online whiteboard tool), the participants of the sessions, and the attempt to add social flows to the visualization will be discussed.

MIRO was used to collaboratively design the connections between FEW systems and create an overview in which the entire FEW ecosystem of the GT and its connections was displayed. MIRO, an interactive white board, was a great tool to collaboratively work in. The tool is used quite a lot in the Metropolitan Analysis, Design & Engineering program and the AMS Institute. In this study, the results of the sessions have also been organized and visualized in MIRO. I was planning on visualizing the system in Adobe Illustrator, however, the visual representation of the diagram created in MIRO was ought to be clear and visually compelling enough to use straight away. This gives an extra dimension to MIRO, not only using it for brainstorming and internal use, but also using it to produce actual results and reporting.

The co-design/expert interview sessions were hosted with two representatives of two of the three stakeholders, FABRICations and AMS Institute. Including the third party, BKO would have improved the validity of the results. Hosting a session with an employee of AM, would have been valuable, as they could have contributed to validating the technical correctness of certain relations.

In the final visualization of the GT FEW system, an 'experience transformation center', was added together with the stakeholders as well. This center provided the theoretical distribution of knowledge flows. The knowledge flows were connected to the GT, as every system in the GT would become part of its educative route. The abstractness of this knowledge concept, lead to not including it in the entire research. The reason why quantifying the knowledge flows posed a problem will be discussed in 6.1.4.

Moreover, the final visualization gives a clear and easy to interpret overview of the systems in the GT and their relations. The visualization can be easily adapted and serves more as a working document than a visualization that is finalized at some point. A major downside of the visualization is that it is very large, and it is not possible to view its contents at a glance. This also posed a problem for explaining the visualization in for instance the focus group and even including it in this thesis.

Therefore, a simplified version of the model has been created. However, this simplified version only shows the idea behind the visualization and does not contain any information on the FEW ecosystem it is used for. Therefore, the visualization method suits as a working document, in which you can keep track of your systems and their (possible) relations, but not as visualization that explains an uninformed individual the FEW system at a glance.

6.1.4 RQ3: Prototyping

The third research question was: "How can food, energy, and water flows be captured in a quantitative model for a sustainability hub?". This was a very guiding research question, which already implicated that a quantitative model was needed. The need for a quantitative model was decided on very early in the project. This decision should have been made from a more user centered approach. From the beginning of the research, it was assumed that a quantitative model would potentially help for the designers to understand the FEW systems in their design. However, there was no an explicit demand from the designers for a quantitative model. The gap in knowledge on neighborhood sustainability hubs from a FEW Nexus perspective was leading in this research. Luckily, the during the research it became clear from a user perspective, that quantifying these flows would help the designers, making the demand a bit more explicit. Some other points to discuss about the developed quantitative model, are the lack of micro-level data on FEW resources, the attempt to capture the social dimension, and the interpretating model outcomes.

The lack of micro-level data (system or resource flow specific data) on FEW resource flows forced me to use data sources to quantify certain flows, that did not correspond to the flow directly. For instance, data on the nutrient demand of a vertical city park is, quite logically, is not widely available. Moreover, data on the nutrient demand of a city park in general is very dependent on the soil type and vegetation. The novelty of the system makes finding key figures for these types of systems very hard. Therefore, the nutrient demand of an average vegetable garden was picked to resemble the nutrient uptake of not only the vertical city park, but also the educative gardens. Moreover, visitor data was not available for the GT either. All visitor data was calculated based on assumptions and can be easily edited in the quantitative model. If I had to make the model more accurate, I would have considered conducting expert interviews to (re)define the data and assumptions used in the model.

When I started this thesis, my idea was to also grasp the social dimension of sustainability in the quantitative model. I wanted to quantify the food, energy, water, and knowledge flows of the GT. This was also specifically mentioned as being valuable for the GT design team. However, after having analyzed multiple ways to capture knowledge generation, it was concluded that this would be extremely hard for the GT. Example of how to capture knowledge, are for instance the number of produced patents or scientific publications. However, the knowledge shared in the GT is not only focused on scientific knowledge, but also knowledge shared with the public. How do you measure whether a visitor of the GT has learned anything? And more specifically, how do you theorize this and put it in a quantitative model? This approach was deemed to be impossible within the timeframe of this thesis. It was also considered to use visitor numbers as indicator for knowledge that could potentially be shared, as all visitors are receptive for the knowledge on sustainability displayed in the building. However, the link between visitors and knowledge was deemed to be too far-fetched. Therefore, a specific focus on knowledge flows has been disregarded. Future research should pick this up, by for instance doing a qualitative assessment of the social impacts of the building's sustainable functions.

Another important thing to acknowledge, is that the data derived from the model, is an indication of what the FEW resource flows of the GT could look like, based on the assumptions and inserted data. The idea of the quantitative model is, that if one has more detailed data, for instance on the energy consumption of the production of 1kg of lettuce, it can be easily edited in the model. All parameters are there, however the data in them can be changed. This also means, that the outcomes of the model can be used as indication on which further design decisions or questions can be made. One cannot assume that the outcomes will represent the actual FEW resource flows of the GT if it was built and therefore, the model cannot be used to make decisions where details are required. The model gives a global idea on how the flows relate and the design team can (or cannot) act upon this indication.

6.1.5 RQ4: Focus group

The final research question "How do the outcomes of the created tool influence the decision making of stakeholders in the Green Tower project?" required the data from the tool to be translated to a simpler visualization and was answered by organizing a focus group.

Organizing a focus group with high ranked representatives of the three main stakeholders was a challenge, as can be read in the results, at first, it was decided to organize three sessions including high ranked representatives and many other professionals related to the project. This was cancelled due to the lack of interest. Afterwards, a focus group was organized including just the high ranked representatives. It was chosen to include only high ranked representatives too make sure the model immediately landed well within the project. Planning this focus group was a big challenge due to busy schedules. If time allowed it, more thorough planning of the focus group itself, and earlier personal invitations would have made the process easier.

The 'wow-effect' of hosting interesting online design / focus group sessions was clearly lost after more than a year of working from home. Participants did not seem to be interested in joining 'another' online co-design session. If COVID-19 regulations would have allowed it, organizing the session in real life would have created great opportunities for other working practices during the focus group. First, being able to host the design group in the building that will become the GT itself would help in envisioning the design perspectives. Second, working in real life versus on MIRO, gives the opportunity to for instance work and draw on printouts of the GT. Helping to visualize where certain systems could be placed, or what changing a certain system's size would do to the design. Organizing the session in real life would have enabled more interaction and more spatial feeling with the design perspectives.

The feedback given on operationalizing the model was very useful. This information has been well documented and can help in the possible further development of the tool. Furthermore, the visualization method used was well received. The 'sliders' should also be incorporated into the dashboard of the quantitative model, through for instance Power BI, to make them interactive. In chapter 7 I will elaborate on the potential development pathways for the tool.

An interesting point that has not been discussed in the focus group, is what additional information is needed to make better informed decisions for FEW systems. It has been thoroughly discussed what extras are needed for the model to work, but not what is needed besides the model. It was mentioned that the model would not be leading in decision making; 'of course we need to keep thinking ourselves'. But about what? I think it is extremely important to get a better understanding of the future residents of BK and the future visitors of GT. Their needs, but also the quantities in which they visit the GT are very important for how the building will be designed.

6.2 Theories Used & Further Research

6.2.1 FEW Nexus

The FEW Nexus supported me well in this thesis, posing an interdisciplinary line of thought about food, energy, and water resources. However, the Nexus does not specifically focus on the scale level my thesis operated at. Nexus thinking is usually conducted at a macro level, looking at the interrelations between FEW policy, FEW governance and FEW management. My research focused on connecting the FEW resource flows physically at a micro scale (building and neighborhood). Limited data was available on FEW Nexus thinking applied at the micro scale. This micro level FEW research focus on for instance the optimization of sustainable FEW systems in a family setting (Karan et al., 2018), or the effects of FEW Nexus oriented policies at household level (Itayi et al., 2018).

Moreover, the policy and governance-oriented nature of FEW Nexus thinking has not been taken strictly in this research. In this thesis, the technical aspects of creating FEW resource balance weighed more than the governance and policy orientation. This is due to the technical nature of the visualization and model developed. The governance aspect has only been discussed in the sense that a certain group of stakeholders are involved in designing the system. Policy has been very poorly discussed. Questions like “who owns the FEW resource flows”, and more specifically “who owns the energy generated from the neighborhood’s organic waste”, and “who decides where resource flows are directed to?” are interesting questions to ask regarding the governing of the FEW resource flows. Policies regarding if, how and where to process certain resource flows would also be interesting to elaborate on. For instance, discussing the required quality of the nutrient rich effluent of the bio-digester could be housed under policy.

6.2.2 Limitations of doing research during COVID-19

The global pandemic has influenced all our lives. The majority in our society works from home, and so did I. Therefore, all meetings with supervisors, design sessions with stakeholders and observations have been executed online. As everything was hosted online, it was easier to join in on sessions to observe. However, every interaction with stakeholders had to be planned. In making a tool the users of the tool are very important, and regular interaction could greatly benefit improving the tool. However, with the current way of working short and informal updates or discussions on whatever you are working is nearly impossible. This has resulted in slower progress of the thesis and a sub-optimal connection with the GT project.

7 Recommendations

The recommendations of this research give insight in how to further develop the tool and specifically the quantitative model, what data is needed fort this, and what development pathways can be chosen. I am sincerely interested in further developing and operationalizing the tool, within the GT project or elsewhere. Therefore, this chapter mainly describes the steps I would have to take to do so.

7.1 Required Data and Research for Finalizing Tool

Additional data and research would greatly benefit the accuracy of the model. While developing the model, it was detected that there was little data available on generic performance indicators for FEW systems. Moreover, during the focus group, it was indicated that it would be valuable to add information on the quality of resource flows, as they exit a system. This mainly holds true for nutrient rich flows, such as black wastewater, or the bio-digester sludge. Furthermore, in the focus group it was noted that adding construction rules and regulations to, such as energy use norms, as a framework to operate within. Indicating whether the design meets these norms. These three types of required additional data and research upon them will be discussed below.

7.1.1 Micro FEW data

As mentioned before, for some FEW resources it was difficult to gather system specific data. This is mainly due to the specificity of the systems, such as a vertical city park. Overall, there was a lack of data on key figures of for instance the energy use of a restaurant. This is most likely due to large variations in energy use of restaurants. This should be solved by hosting expert interviews, with researchers and designers preferably related to the BK project, which can give better assumptions in the figures. This data can and should be frequently updated to keep the model working.

If a generic model is made, that can be used in other settings, expert interviews can also help in defining more generic key figures, that could hold true for other situations as well. If the model is then used in another setting, the process of improving the resource flow figures for that setting specifically, can be started again through case specific expert interviews.

7.1.2 Quality of resource flows

Further research is required on the quality of the resource flows, as they enter and leave a certain system. In the current model, nutrients are just regarded to as nutrients, whilst the composition of the nutrients is very important for its use. There are many types of nutrients, and each system or plant requires a certain composition of these nutrients. Moreover, in what form the nutrients are applied to for instance farming practices is very important as well. This means, that certain nutrients should not be bound to one another as it might impact their usefulness. Knowing this will greatly improve how well the tool can be used in actual design situations. However, it should also be guarded that this data does not become too specific, because that can lead to overcomplicating the tool.

7.1.3 Construction rules and regulations

Having contemporary construction rules and regulations clear, as framework for the quantitative model to work within, would benefit the accuracy and usefulness of the model. For instance, regulations on energy consumption and isolation are very strict. These could be set at the beginning of the model, and an indicator should be included that shows whether these regulations are met.

7.2 Operationalization Pathways for Tool

From the data gathered in the focus group hosted in this thesis, three development paths for the FEW Neighborhood Sustainability Hub Design Tool have been developed. The three paths have been described below.

7.2.1 Performance monitor for the Green Tower

The GT design team has now been familiarized with the design tool and have expressed their interest in potentially using it for the development of the tower. One of the main goals of the tower is to create an educative route, that educates visitors on all the sustainable practices that are undertaken in the GT and BK. The educative route must inform visitors on the sustainable systems in the GT and let them experience food grown in the indoor vertical farm. The concept of the quantitative tool can be the foundation for an interactive dashboard in which real time data of the GT on the functioning of its FEW systems can be shown. The real-life data would for instance show the amount of energy generated by the PV-panels that day, and the amount of food produced. Showing the balances between FEW resources can serve the educative route as well. Seeing in real time that poor weather conditions impact the electricity balance of the building, could be very interesting.

For this development pathway to be executed, conversations should be planned with BKO and FABRICations, who oversee designing the educative route. Moreover, a team of AMS Students is also working on making a concept for this educative route, which should also be involved. An important aspect of using this interactive dashboard would be a compelling design. Also, it should be investigated how real time data of all the systems in the GT could be extracted and processed.

7.2.2 Assessment framework for users of Green Tower

The tool could also be further developed to help the designers of the GT on the back end to make decisions on which parties to accept in the GT. Many systems are already decided upon, however, the parties that will deliver the systems have not been chosen yet. For instance, various vertical farming companies, have various crop outputs and various electricity consumption rates. The model could be used to create a framework, that helps to choose which parties can or cannot be accepted in the GT based on the excessive consumption on certain FEW resources, or limited supply of certain FEW resources.

The tool currently is already able to give data on which a framework like this could be built. Further specifying the key figures in the model would be very important, to make sure parties are not included or excluded based on false assumptions.

7.2.3 Neighborhood sustainable utility design tool

The most difficult but at the same time most rewarding development path for the tool, would be to make it universally applicable to other neighborhoods seeking to implement and scale a neighborhood sustainability hub, or a set of sustainable systems that include food production or food waste processing. The tool can be used in the initiative phase of the hub, for design decisions regarding FEW. In this case, the hub does not have to be bound to a single building, but any space available can be used to plan the systems. For this to work, the key figures and systems require extensive validation. More literature research and expert interviews will have to be conducted. Moreover, various options of each separate FEW system should be included in the model. Making it possible to choose from various systems based on their investment costs and efficiency. The identified available space within the neighborhood, is the maximum available floor area. Each location would be substituted for the floors that are currently used in the model. Moreover, the users of the FEW resources now become the neighborhood. The demand of food, water & energy of the neighborhood should be calculated as well. Possibly another model is required to do this.

Creating this tool would be interesting in terms of research but might also be marketable in the form of a start-up that rents the tool out, together with a work format. AMS Institute provides a solid basis to possibly pursue this route.

8 References

Abergel, T., Dean, B., & Dulac, J. (2017). Towards a zero-emission, efficient, and resilient buildings and construction sector: Global Status Report 2017. UN Environment and International Energy Agency: Paris, France, 22.

Al-Chalabi, M. (2015). Vertical farming: Skyscraper sustainability?. *Sustainable Cities and Society*, *18*, 74-77.

AM. (2021, April 20). *AM | Inspiring Space vastgoed- en gebiedsontwikkelaar stad- en gebiedmaker*. AM | Inspiring space. https://www.am.nl

AM BV. (2019, 8 augustus). *"Een eer dat we deze verandering mogen bedenken en uitvoeren" - Bajeskwartier - Amsterdam*. Bajeskwartier. https://www.bajeskwartier.com/blog/getById?id=1419

AM BV. (n.d.). *Het Plan - Bajeskwartier - Amsterdam*. Bajeskwartier. Geraadpleegd op 11 mei 2021, van https://www.bajeskwartier.com/het-plan/

AMS Institute. (n.d.-a). *Urban Living Labs*. Amsterdam Insitute for Advanced Metropolitan Solutions. Retrieved June 5, 2021, from https://www.ams-institute.org/how-we-work/living-labs/

AMS Institute. (n.d.-b). *What we do*. Retrieved May 21, 2021, from https://www.ams-institute.org/what-we-do/

AMS Institute. (2020). *Bajes Kwartier in Amsterdam gets Green Tower Living Lab gets a test bed for sustainable innovations*. https://www.ams-institute.org/urban-challenges/metropolitan-food-systems/bajes-kwartier-gets-testbed-innovation-urban-living-lab-green-tower/

Andersson, O. (2007). Aquifer thermal energy storage (ATES). In *Thermal energy storage for sustainable Energy Consumption*(pp. 155-176). Springer, Dordrecht.

AT CAPITAL GROUP. (2020). *AT CAPITAL GROUP - Private Equity firm Singapore*. http://atcapital.com.sg/about_us.html

Avgoustaki, D. D., & Xydis, G. (2020, -a). Indoor Vertical Farming in the Urban Nexus Context: Business Growth and Resource Savings. Sustainability, 12(5), 1965.

Avgoustaki, D. D., & Xydis, G. (2020, -b). How energy innovation in indoor vertical farming can improve food security, sustainability, and food safety? Advances in Food Security and Sustainability, 1–51. doi:10.1016/bs.af2s.2020.08.002

Bajes Kwartier. (2020, October 30). *VIDEO: "De Groene Toren maakt de cirkel van deze locatie rond" - Bajeskwartier - Amsterdam* [Video]. Bajeskwartier. https://www.bajeskwartier.com/blog/getById?id=2263

Bajes Kwartier Ontwikkeling. (2020, june). Bajes Kwartier Gedurfde Duurzaamheid Voortgangsrapportage Voorlopig Ontwerp. Fabrications.

Bhattarai, B., Bishwokarma, D., & Legras, M. (2018). Breaking the Bottleneck: Conflicts Metamorphosis of Chure Landscape Management in Federal Nepal. *Journal of Forest and Livelihood*, *16*(1), 71-86.

van Broekhoven, S., & Vernay, A. L. (2018). Integrating functions for a sustainable urban system: A review of multifunctional land use and circular urban metabolism. Sustainability, 10(6), 1875.
Brandt, E. (2007). How tangible mock-ups support design collaboration. Knowledge, Technology & Policy, 20(3), 179-192.

Brunner, P. H. (2007). Reshaping urban metabolism. Journal of Industrial Ecology, 11(2), 11-13.

van Bueren, E. M. (2017). Urban Living Labs: A living lab way of working.

Buur, J., & Bødker, S. (2000, August). From usability lab to “design collaboratorium” reframing usability practice. In Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques (pp. 297-307).

Cai, X., Wallington, K., Shafiee-Jood, M., & Marston, L. (2018). Understanding and managing the food-energy-water nexus–opportunities for water resources research. Advances in Water Resources, 111, 259-273.

CAIRN Real Estate. (2021, March 25). *About*. CAIRN. https://cairn-re.com/about/

Capodaglio, A. G., Callegari, A., Cecconet, D., & Molognoni, D. (2017). Sustainability of decentralized wastewater treatment technologies. *Water Practice and Technology*, *12*(2), 463-477.

Circle Economy & City of Amsterdam. (2020). Amsterdam Circular 2020-2025 Strategy. City of Amsterdam. https://assets.amsterdam.nl/publish/pages/867635/amsterdam-circular-2020-2025_strategy.pdf

Curry, N., & Pillay, P. (2012). Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy*, *41*, 200-209.

Daly, J. (2019, September 23). *Anaerobic Digestion (AD) A Renewable Energy Technology*. Powersystems UK. https://www.powersystemsuk.co.uk/anaerobic-digestion/anaerobic-digestion-renewable-energy-technology/

Dekker, W. (2017, September 12). BAM bouwt Bijlmerbajes om tot groene stadswijk - met 1.350 nieuwe woningen. De Volkskrant. https://www.volkskrant.nl/nieuws-achtergrond/bam-bouwt-bijlmerbajes-om-tot-groene-stadswijk-met-1-350-nieuwe-woningen~bd009a26/

Despommier, D. (2013). Farming up the city: the rise of urban vertical farms. *Trends in biotechnology*, *31*(7), 388-389.

Doughty, M. R., & Hammond, G. P. (2004). Sustainability and the built environment at and beyond the city scale. *Building and environment*, *39*(10), 1223-1233.

Durão, L. F. C., Kelly, K., Nakano, D. N., Zancul, E., & McGinn, C. L. (2018). Divergent prototyping effect on the final design solution: the role of" Dark Horse" prototype in innovation projects. *Procedia Cirp*, *70*, 265-271.

FABRICations. (2018). *GROENE TOREN BAJES KWARTIER – Amsterdam | FABRICations*. https://www.fabrications.nl/portfolio-item/bajes-kwartier-green-tower-groene-toren/

Floyd, C. (1984). A systematic look at prototyping. In *Approaches to prototyping* (pp. 1-18). Springer, Berlin, Heidelberg.

Food and Agriculture Organization of the United Nations (FAO). (2021, February 22). *FAOSTAT*. http://www.fao.org/faostat/en/#data/QC

Geissler, C., & Powers, H. J. (Eds.). (2017). *Human nutrition*. Oxford University Press.

Gelormino, E., Melis, G., Marietta, C., & Costa, G. (2015). From built environment to health inequalities: an explanatory framework based on evidence. Preventive medicine reports, 2, 737-745.

Gumbo, S., Thinyane, H., Thinyane, M., Terzoli, A., & Hansen, S. (2012, May). Living lab methodology as an approach to innovation in ICT4D: The Siyakhula Living Lab experience. In Proceedings of the IST-Africa 2012 Conference (Vol. 24, No. 2013, pp. 29-74).

Graaf, R. D., & Hell, A. V. (2014). Nieuwe Sanitatie Noorderhoek, Sneek: Deelonderzoeken. *Amersfoort, The Netherlands. Rapport*, *48*.

Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. Agricultural Systems, 160, 31-43.

Groene Toren Bajeskwartier in Amsterdam wordt proeftuin duurzame gebiedsinnovaties. (2021, January 21). AM | Inspiring space. https://www.am.nl/groene-toren-bajeskwartier-in-amsterdam-wordt-proeftuin-duurzame-gebiedsinnovaties/

Hamiche, A. M., Stambouli, A. B., & Flazi, S. (2016). A review of the water-energy nexus. Renewable and Sustainable Energy Reviews, 65, 319-331.

Hang, M. Y. L. P., Martinez-Hernandez, E., Leach, M., & Yang, A. (2016). Designing integrated local production systems: a study on the food-energy-water nexus. Journal of Cleaner Production, 135, 1065-1084.

Havenbedrijf Amsterdam. (2019, January 21). *The Waste Transformers zet afval om in schone energie*. Maritiem Nederland. https://www.maritiemnederland.com/nieuws/the-waste-transformers-zet-afval-om-in-schone-energie

Helmreich, B., & Horn, H. (2009). Opportunities in rainwater harvesting. *Desalination*, *248*(1-3), 118-124.

Hoff, H. (2011). Understanding the nexus: Background paper for the Bonn2011 Nexus Conference.

Hox, J. J., & Boeije, H. R. (2005). Data collection, primary versus secondary.

Ishii, S. K., & Boyer, T. H. (2015). Life cycle comparison of centralized wastewater treatment and urine source separation with struvite precipitation: Focus on urine nutrient management. *Water research*, *79*, 88-103.

Itayi, C. L., Mohan, G., & Saito, O. (2021). Understanding the conceptual frameworks and methods of the food–energy–water nexus at the household level for development-oriented policy support: a systematic review. *Environmental Research Letters*, *16*(3), 033006.

Jacobs, D. R., & Tapsell, L. C. (2007). Food, not nutrients, is the fundamental unit in nutrition. *Nutrition reviews*, *65*(10), 439-450.

Jobst, B., & Meinel, C. (2014). How prototyping helps to solve wicked problems. In *Design thinking research* (pp. 105-113). Springer, Cham.

Jørgensen, B. N. (n.d.). *Guide to literature study*. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjB4uemtKHxAhWQnRQKHRhPCxQQFjABegQIBRAD&url=https%3A%2F%2Fwww.sdu.dk%2F-%2Fmedia%2Ffiles%2Fom_sdu%2Ffakulteterne%2Fteknik%2Fphd%2Fansoegskemaer%2Fliterature%2Bstudy%2Btemplate.docx&usg=AOvVaw1UTnWqDh8oKi-L67J1qsjn

Kalmykova, Y., & Rosado, L. (2015). Urban metabolism as framework for circular economy design for cities. In Proceedings of the World Resources Forum 2015.

Karan, E., Asadi, S., Mohtar, R., & Baawain, M. (2018). Towards the optimization of sustainable food-energy-water systems: A stochastic approach. *Journal of Cleaner Production*, *171*, 662-674.

Kjerstadius, H., Haghighatafshar, S., & Davidsson, Å. (2015). Potential for nutrient recovery and biogas production from blackwater, food waste and greywater in urban source control systems. *Environmental technology*, *36*(13), 1707-1720.

KNMI. (2020). *KNMI - Klimaatviewer* [Deze klimaatviewer laat de kaarten, grafieken en tabellen voor het klimaat van nu in Nederland zien. Het KNMI berekent om de tien jaar langjarige gemiddelden ('normalen') voor een groot aantal KNMI-stations. De meest recente langjarig gemiddelden gaan over de periode 1991–2020.]. Ministerie van Infrastructuur en Waterstaat. https://www.knmi.nl/klimaat-viewer/grafieken-tabellen/meteorologische-stations/stations-maand/stations-maand_1991-2020

Kohli, G., Kohli, M., & Galhotra, V. (2014). Diseases among Sewage Workers. *Research & Reviews: Journal of Medical Science and Technology*, *3*(1).

Leck, H., Conway, D., Bradshaw, M., & Rees, J. (2015). Tracing the water–energy–food nexus: Description, theory and practice. Geography Compass, 9(8), 445-460.

Lehmann, S. (2018). Implementing the Urban Nexus approach for improved resource-efficiency of developing cities in Southeast-Asia. City, Culture and Society, 13, 46-56.

Leigh, D. (2010). SWOT analysis. Handbook of Improving Performance in the Workplace: Volumes 1-3, 115-140.

Lele, U., Klousia-Marquis, M., & Goswami, S. (2013). Good governance for food, water and energy security. Aquatic procedia, 1, 44-63.

Lopes, R. A., Martins, J., Aelenei, D., & Lima, C. P. (2016). A cooperative net zero energy community to improve load matching. *Renewable Energy*, *93*, 1-13.

MacArthur, E. (2013). Towards the circular economy. *Journal of Industrial Ecology*, *2*, 23-44.

MIRO. (2021). *About Miro | Meet the team | Our mission*. Https://Miro.Com/. https://miro.com/about/

Morgan, D. L. (1996). Focus groups. *Annual review of sociology*, *22*(1), 129-152.

Nemali, K (n.d.). Nutrition & Lighting Requirements of Lettuce. https://www.purdue.edu/hla/sites/cea/wp-content/uploads/sites/15/2017/04/Nutrition-and-Light-Requirement-of-Lettuce.pdf

Nielsen, B. F., Baer, D., Gohari, S., & Junker, E. (2019). The Potential of Design Thinking for Tackling the "Wicked Problems" of the Smart City. In Proceedings of the 24th International Conference on Urban Planning, Regional Development and Information Society. CORP–Competence Center of Urban and Regional Planning.

Paritosh, K., Kushwaha, S. K., Yadav, M., Pareek, N., Chawade, A., & Vivekanand, V. (2017). Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. BioMed Research International, 2017.

Pedrazzi, S., Santunione, G., Minarelli, A., & Allesina, G. (2019). Energy and biochar co-production from municipal green waste gasification: A model applied to a landfill in the north of Italy. Energy Conversion and Management, 187, 274-282.

Pineo, H. (2020). Towards healthy urbanism: inclusive, equitable and sustainable (THRIVES)–an urban design and planning framework from theory to praxis. Cities & health, 1-19.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., ... & Travasso, M. I. (2014). Food security and food production systems.

Prüss-Üstün, A., Wolf, J., Corvalán, C., Bos, R., & Neira, M. (2016). Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. World Health Organization.

Raworth, K. (2017). Doughnut economics: seven ways to think like a 21st-century economist. Chelsea Green Publishing.

Raworth, K. (2020). The Amsterdam city doughnut–A tool for transformative action. Doughnut Economics Action Lab.

Rijksdienst voor Ondernemend Nederland. (n.d.). *Energy Service Company (ESCO) | RVO.nl | Rijksdienst*. Retrieved June 5, 2021, from https://www.rvo.nl/initiatieven/financieringsvoorbeelden/energy-service-company-esco

Rijksvastgoedbedrijf. (2020, April 14). *Van Bijlmerbajes naar stadswijk: vijf consortia door naar volgende ronde*. Nieuwsbericht | Rijksvastgoedbedrijf. https://www.rijksvastgoedbedrijf.nl/actueel/nieuws/2017/02/01/van-bijlmerbajes-naar-stadswijk-vijf-consortia-door-naar-volgende-ronde

Ritzen, G. (2016, October 4). Bijlmerbajes te koop voor 60 miljoen euro. NRC. https://www.nrc.nl/nieuws/2016/10/04/bijlmerbasis-te-koop-voor-60-miljoen-euro-a1524764

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., ... & Foley, J. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and society, 14(2).

Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., ... & Meinshausen, M. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2 C. Nature, 534(7609), 631-639.

Roggema, R., & Yan, W. (2019). Developing a design-led approach for the food-energy-water nexus in cities. Urban planning, 4(1), 123-138.

Romero-Lankao, P., McPhearson, T., & Davidson, D. J. (2017). The food-energy-water nexus and urban complexity. Nature Climate Change, 7(4), 233-235.

Schulterbrandt Gragg, R., Anandhi, A., Jiru, M., & Usher, K. M. (2018). A conceptualization of the urban food-energy-water nexus sustainability paradigm: Modeling from theory to practice. Frontiers in Environmental Science, 6, 133.

SESYNC. (2018, November 15). *Data to Motivate Synthesis*. https://www.sesync.org/for-you/cyberinfrastructure/research-and-tools/data-to-motivate-synthesis
Steen, K. Y. G., & Van Bueren, E. (2017). Urban Living Labs: A living lab way of working.
United States Environmental Protection Agency. (2021, January 2). *Food Recovery Hierarchy*. US EPA. https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., ... & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223).

Steen, M., Manschot, M., & De Koning, N. (2011). Benefits of co-design in service design projects. International Journal of Design, 5(2).

Turner-McGrievy, G., Wirth, M. D., Hill, K. L., Dear, E. R., & Hébert, J. R. (2021). Examining commonalities and differences in food groups, nutrients, and diet quality among popular diets. *Clinical Nutrition ESPEN*, *41*, 377-385.

UNEP, U. (2011). Towards a green economy: Pathways to sustainable development and poverty eradication. Nairobi, Kenya: UNEP.

United Nations. (2018). World Urbanization Prospects: The 2018 Revision, Key Facts. Technical report.

Vogt, K., Patel-Weynand, T., Shelton, M., Vogt, D. J., Gordon, J. C., Mukumoto, C., ... & Roads, P. A. (2012). Sustainability unpacked: Food, energy and water for resilient environments and societies. Routledge.

Wageningen University & Reseach. (2020). *Flagship 4: Circularity by Design*. WUR. https://www.wur.nl/en/Research-Results/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/Flagship-4-Circularity-by-Design-1.htm

Waternet. (n.d.-a). *Waar komt uw drinkwater vandaan?* Retrieved June 15, 2021, from https://www.waternet.nl/service-en-contact/drinkwater/waar-komt-ons-drinkwater-vandaan/

Waternet. (n.d.-b). *Wat doen wij?* Retrieved June 14, 2021, from https://www.waternet.nl/over-ons/wat-doen-wij-voor-waterschap-amstel-gooi-en-vecht-gemeente-amsterdam/

Wellsun. (2019). *Lumiduct | Wellsun*. https://www.wellsun.nl/lumiduct

Westerlund, B. (2007, March). A workshop method that involves users talking, doing and making. In Proceedings of international conference on human-machine interaction, Human07, IEEE.

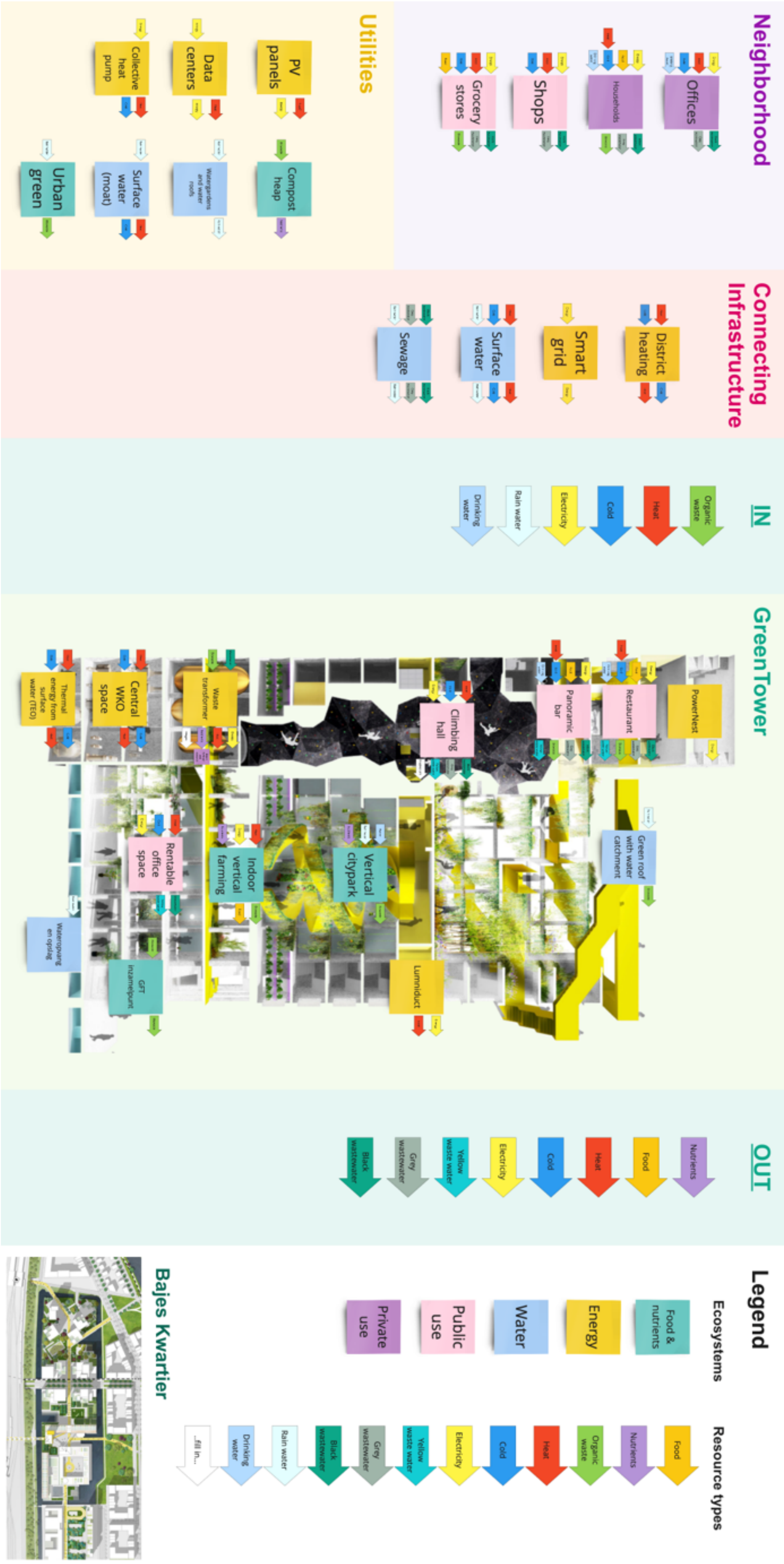
Whatmore, S., Stassart, P., & Renting, H. (2003). What's alternative about alternative food networks?.

Wray, S. (2020, April 15). *Amsterdam adopts first 'city doughnut' model for circular economy*. Smart Cities World. https://www.smartcitiesworld.net/news/news/amsterdam-adopts-first-city-doughnut-model-for-circular-economy-5198

Zhang, J., Gu, D., Chen, J., He, Y., Dai, Y., Loh, K. C., & Tong, Y. W. (2021). Assessment and optimization of a decentralized food-waste-to-energy system with anaerobic digestion and CHP for energy utilization. *Energy Conversion and Management*, *228*, 113654.

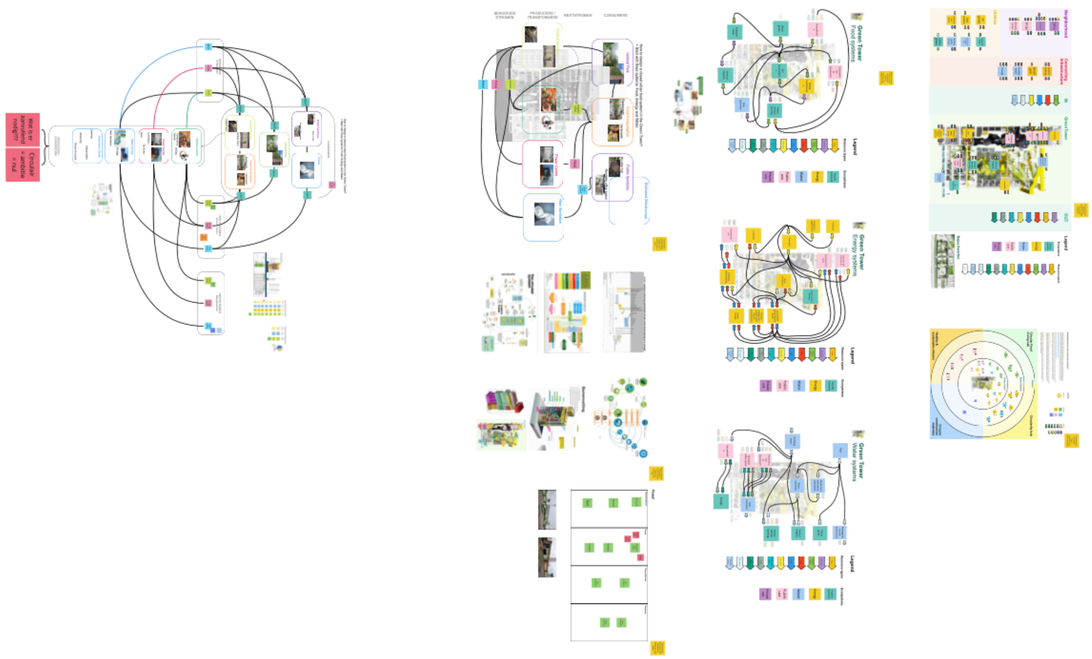
9 Appendices

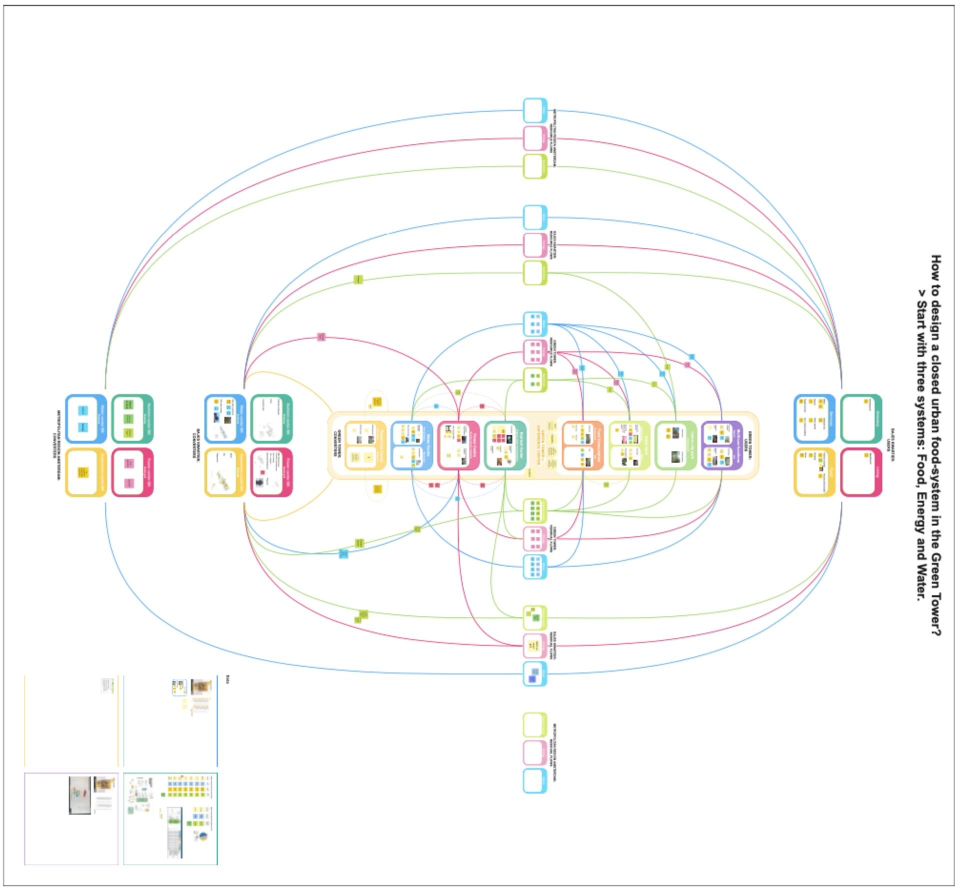
Appendix 1: First mapping of the FEW systems of the Green Tower



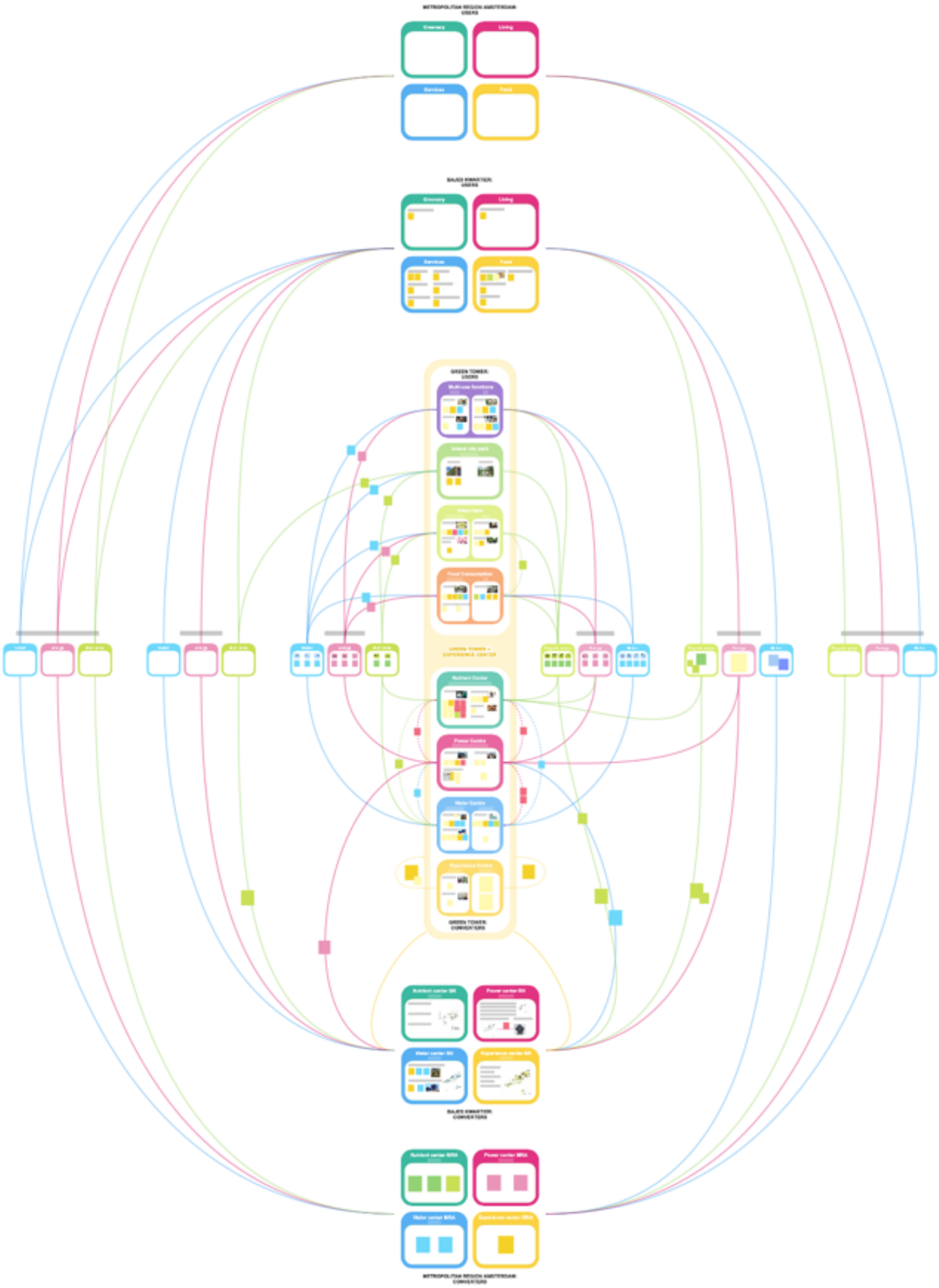
Appendix 2: MIRO board of the process towards creating the visualization of FEW systems for the GT

Link to the board: https://miro.com/app/board/o9J_lXERy2k=/



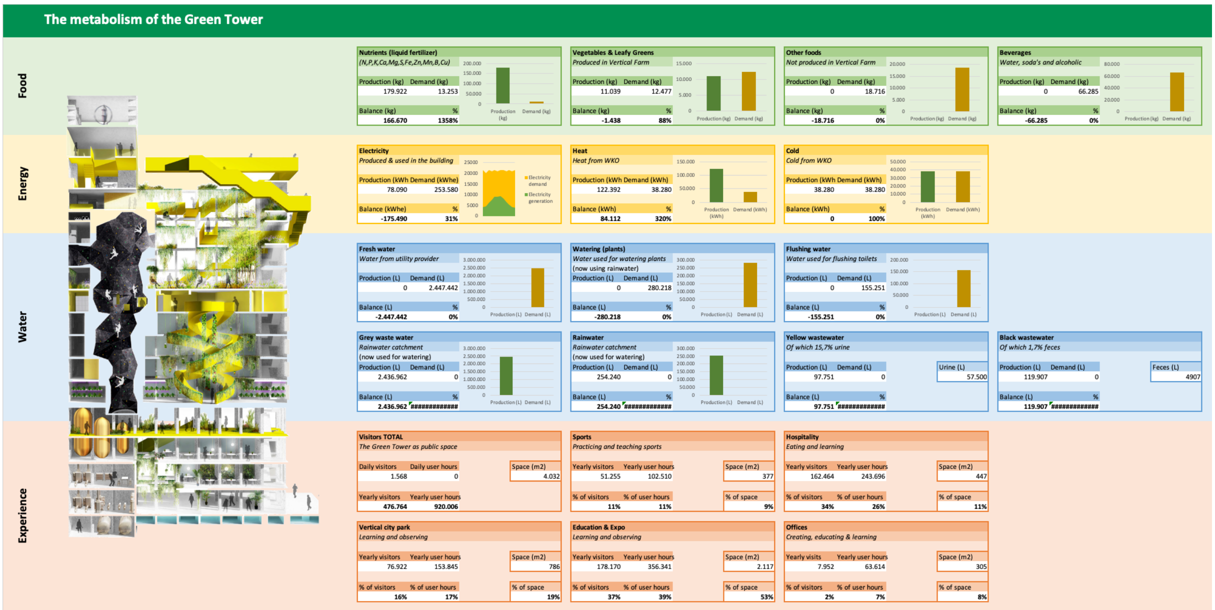


Appendix 3: The visualization of FEW systems for the GT



Appendix 4: The quantitative model of FEW systems for the GT

Dashboard tab



Program tab

BVO	Floor area	Staircase	Unuseable space	Roof Space	Indoor space	Outdoor space	Available indoor	Available outdoor
Access								
Place								
Climate control								
Energy use type								
14	127	18	0	109	0	109	0	-109
13	316	22	104	190	0	190	0	0
12	430	15	7	0	408	0	0	0
11	428	14	85	0	329	0	0	0
10	428	14	148	0	266	0	0	0
9	429	12	128	0	289	0	0	0
8	445	12	157	0	276	0	0	0
7	437	12	87	0	338	0	0	0
6	428	12	79	0	337	0	0	0
5	428	14	71	0	343	0	0	0
4	440	14	47	0	379	0	0	0
3	439	17	0	0	422	0	0	0
2	476	18	54	0	404	0	0	0
1	584	18	105	0	461	0	0	0
0	556	18	0	0	538	0	0	0
-1	769	0	0	0	769	0	643	0
...fill in...								
Total	7160	230	1072		5559	299	643	-109

Space with Climate Control		Space without Climate Control	
Total	1276	Total	4164

Experience	Office space	Indoor climbing	Sports facilities	Expo space	Bar	Restaurant	Education space	...fill in...
Access	Public	Public	Public	Public	Public	Public	Public	...fill in...
Place	Indoor	Indoor	Indoor	Indoor	Indoor	Indoor	Indoor	...fill in...
Climate control	Yes	No	No	No	Yes	Yes	No	...fill in...
Energy use type	Office	Sports	Sports	Office	Gathering	Gathering	Office	...fill in...
14	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
12	0	0	0	0	0	301	67	0
11	61	54	0	91	0	0	79	0
10	61	0	0	0	0	0	76	0
9	61	0	0	0	0	0	72	0
8	61	0	0	0	0	0	78	0
7	61	0	0	0	0	0	101	0
6	0	0	0	0	0	0	72	0
5	0	0	0	0	0	0	76	0
4	0	0	181	0	0	0	94	0
3	0	0	0	0	0	0	83	0
2	0	53	0	0	0	0	139	0
1	0	53	0	126	29	0	171	0
0	0	36	0	0	117	0	167	0
-1	0	0	0	0	0	0	66	0
...fill in...	0	0	0	0	0	0	0	0
Total	305	196	181	217	146	301	1341	0

Nutrients	Vertical farm	Educative garden	Vertical city park	Green roof	...fill in...
Access	Private	Public	Public	Private	...fill in...
Place	Indoor	Indoor	Indoor	Roof	...fill in...
Climate control	Yes	No	No	No	...fill in...
Energy use type	Own	Office	No	No	...fill in...
14	0	0	0	0	0
13	0	0	0	0	0
12	0	0	40	0	0
11	0	0	44	0	0
10	0	81	48	0	0
9	0	78	78	0	0
8	0	40	97	0	0
7	0	0	176	0	0
6	0	179	86	0	0
5	0	181	86	0	0
4	0	0	104	0	0
3	315	0	24	0	0
2	209	0	3	0	0
1	0	0	0	0	0
0	0	0	0	0	0
-1	0	0	0	0	0
...fill in...	0	0	0	0	0
Total	524	559	786	0	0

	Energy: Bio-digester	Energy: WKO space	Energy: PV Panels	Energy: ...fill in...	Water: Rainwater storage	Water: Rainwater catchment	Water: ...Fill in...	Water: ...Fill in...
Access	Private	Private	Private	...fill in...	Private	Private	...fill in...	...fill in...
Place	Indoor	Indoor	Roof	...fill in...	Indoor	Roof	...fill in...	...fill in...
Climate control	No	No	-	...fill in...	No	-	...fill in...	...fill in...
Energy use type	Own	Own	-	...fill in...	-	-	...fill in...	...fill in...
14	0	0	109	0	0	109	0	0
13	0	0	0	0	0	190	0	0
12	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
1	57	25	0	0	0	0	0	0
0	22	196	0	0	0	0	0	0
-1	60	0	0	0	0	0	0	0
...fill in...	0	0	0	0	0	0	0	0
Total	139	221	109	0	0	299	0	0

Food tab

Nutrients

Nutrient production

	Waste transformer (kg)	*Total (kg)*
January	15281	15281
February	13802	13802
March	15281	15281
April	14788	14788
May	15281	15281
June	14788	14788
July	15281	15281
August	15281	15281
September	14788	14788
October	15281	15281
November	14788	14788
December	15281	15281
Total	179922	**179922**

Nutrient demand

	Vertical farn	*Educative ga*	*Vertical city park (kg)*	*Total (kg)*
January	988		-	988
February	893	-	-	893
March	988	-	-	988
April	956	-	-	956
May	988	-	-	988
June	956	-	-	956
July	988	-	-	988
August	988	-	-	988
September	956	-	-	956
October	988	-	-	988
November	956	-	-	956
December	988	-	-	988
Total	11636	838,5	778,14	**13253**

Food

Food production

	Vertical farn	*Educative garden (kg)*	*Total (kg)*
January	890	-	890
February	804	-	804
March	890	-	890
April	861	-	861
May	890	-	890
June	861	-	861
July	890	-	890
August	890	-	890
September	861	-	861
October	890	-	890
November	861	-	861
December	890	-	890
Total	10480	559	**11039**

Food demand (vegetables)

	Restaurant (	*Bar (kg)*	*Total (kg)*
Total	8618	3859	**12477**

External food demand

Food demand (vegetables)

	Restaurant (	*Bar (kg)*	*Total (kg)*
Total	12928	5788	**18716**

External beverage demand

Beverage demand

	Restaurant (	*Bar (kg)*	*Total (kg)*
Total	45785	20500	**66285**

Energy tab

Electricity

Electricity generation

	PV	*Waste transformer*	*Electricity generation*
January	741	3422	4163
February	1341	3091	4432
March	2783	3422	6205
April	4394	3312	7706
May	5685	3422	9108
June	5815	3312	9127
July	5785	3422	9208
August	4804	3422	8227
September	3183	3312	6495
October	1872	3422	5294
November	841	3312	4153
December	550	3422	3973
Total	37794	40296	***78090***

Electricity demand

	Vertical farm	*Electricity fo*	*Electricity fo*	*Basic Electri*	*Experience f*	*Electricity de*
January	15390	531,666667	638	797,5	4064,58333	21421
February	13900	531,666667	638	797,5	4064,58333	19932
March	15390	531,666667	638	797,5	4064,58333	21421
April	14893	531,666667	638	797,5	4064,58333	20925
May	15390	531,666667	638	797,5	4064,58333	21421
June	14893	531,666667	638	797,5	4064,58333	20925
July	15390	531,666667	638	797,5	4064,58333	21421
August	15390	531,666667	638	797,5	4064,58333	21421
September	14893	531,666667	638	797,5	4064,58333	20925
October	15390	531,666667	638	797,5	4064,58333	21421
November	14893	531,666667	638	797,5	4064,58333	20925
December	15390	531,666667	638	797,5	4064,58333	21421
	181199	6380	7656	9570	48775	**253580**

Heat

Heat generation

	Heat from c	*Waste transformer*	*Total*
January	-	7144	7144
February	-	6452	6452
March	-	7144	7144
April	-	6913	6913
May	-	7144	7144
June	-	6913	6913
July	-	7144	7144
August	-	7144	7144
September	-	6913	6913
October	-	7144	7144
November	-	6913	6913
December	-	7144	7144
Total	38280	84112	**122392**

Heat demand

	Basic heat d	*…*	*Total*
January	-	-	0
February	-	-	0
March	-	-	0
April	-	-	0
May	-	-	0
June	-	-	0
July	-	-	0
August	-	-	0
September	-	-	0
October	-	-	0
November	-	-	0
December	-	-	0
Total	38280	0	**38280**

Cold

Cold generation

	Cold from heating	*Total*
January	-	0
February	-	0
March	-	0
April	-	0
May	-	0
June	-	0
July	-	0
August	-	0
September	-	0
October	-	0
November	-	0
December	-	0
Total	38280	**38280**

Cold demand

	Cold demand	*Total*
January	-	0
February	-	0
March	-	0
April	-	0
May	-	0
June	-	0
July	-	0
August	-	0
September	-	0
October	-	0
November	-	0
December	-	0
Total	38280	**38280**

Water tab

Waste water production

Yellow wastewater production

	Urine (L)	*Flushing water (L)*	*Total (L)*
January	-	-	0
February	-	-	0
March	-	-	0
April	-	-	0
May	-	-	0
June	-	-	0
July	-	-	0
August	-	-	0
September	-	-	0
October	-	-	0
November	-	-	0
December	-	-	0
Total	57500	40250	**97751**

Black wastewater production

	Feces (kg)	*Flushing water (L)*	*Total (L)*
January	-	-	0
February	-	-	0
March	-	-	0
April	-	-	0
May	-	-	0
June	-	-	0
July	-	-	0
August	-	-	0
September	-	-	0
October	-	-	0
November	-	-	0
December	-	-	0
Total	4907	115001	**119907**

Grey wastewater production

	Urine (L)	*Total (L)*
January	-	0
February	-	0
March	-	0
April	-	0
May	-	0
June	-	0
July	-	0
August	-	0
September	-	0
October	-	0
November	-	0
December	-	0
Total	2436962	**2436962**

*Lijkt niet in te schatten

Rain water catchment

	Roof (L)	*Total*
January	-	0
February	-	0
March	-	0
April	-	0
May	-	0
June	-	0
July	-	0
August	-	0
September	-	0
October	-	0
November	-	0
December	-	0
Total	254240	**254240**

Water from waste transformer

	Waste transformer (L)	*Total (L)*
January	-	0
February	-	0
March	-	0
April	-	0
May	-	0
June	-	0
July	-	0
August	-	0
September	-	0
October	-	0
November	-	0
December	-	0
Total	38426	**38426**

Water demand

Fresh water demand

	Vertical farm (L)	*Restaurant (L)*	*Bar (L)*	*Total*
January	890	-	-	890
February	804	-	-	804
March	890	-	-	890
April	861	-	-	861
May	890	-	-	890
June	861	-	-	861
July	890	-	-	890
August	890	-	-	890
September	861	-	-	861
October	890	-	-	890
November	861	-	-	861
December	890	-	-	890
Total	10480	1683289	753673	**2447442**

Water demand for watering plants

	Educative ga	*Vertical city park (L)*	*Total*
January	-	-	0
February	-	-	0
March	-	-	0
April	-	-	0
May	-	-	0
June	-	-	0
July	-	-	0
August	-	-	0
September	-	-	0
October	-	-	0
November	-	-	0
December	-	-	0
Total	145340	134877,6	**280218**

Water demand for flushing toilets

	Feces (L)	*Urine (L)*	*Vertical city park (L)*	*Total (L)*
January	-	-	-	0
February	-	-	-	0
March	-	-	-	0
April	-	-	-	0
May	-	-	-	0
June	-	-	-	0
July	-	-	-	0
August	-	-	-	0
September	-	-	-	0
October	-	-	-	0
November	-	-	-	0
December	-	-	-	0
Total	115001	40250	0	**155251**

Visitor tab

Office space

Surface area (m2)	305		
Initial data		*Info*	*Sources*
Usable space response (%)	100%	*Workplace space also inc	.
Useable space	305		
Workplace size (m2)	10		https://www.
Working hours (hours/day)	8	*Based on 9 am - 5 pm w	.
Opening days	5	*Monday - Friday	.
Yealy days open	261		
Employee capactity (employees/day)	30,5		
Employees			
Occupancy	100%		
Employees per day	30,5		
Emplyees visits per year	7952		
User hours (hour/year)	63614		

Water		*Sources*
Fresh water use (L/m2/day)		
Total fresh water use (L/day)		
Electricity		
Electricity use (kWh/m2/year)	50	
Total water use (kWh/day)	15250	

Indoor Climbing

Surface area (m2)	196		
Initial data		*Info*	*Sources*
Usable space response (%)	75%	*	
Useable space (m2)	147		
Space per visitor (m2)	4,0		
Service time (hour)	2,0	*	
Opening hours (hour)	13,0	*	
Capacity (visitors)	239		
Opening days (day)	7	*	
Yealry days open (day)	365		
Visitors			
Occupancy (%)	33%	*	
Daily visitors	79		
Yearly visitors	28772		
User hours (hour/year)	57545		

Restaurant

Surface area (m2)	301		
Initial data			*Sources*
Usable space response (%)	50%	*	.
Useable space (m2)	151		
Space per visitor (m2)	1,2		https://www.
Service time (hour)	1,5	*	
Opening hours (hour)	13,0	*	
Capacity (visitors)	1086,9		
Opening days (day)	6	*	.
Yealry days open (day)	313		
Visitors			
Occupancy (%)	33%	*	.
Daily visitors	359		
Yearly visitors	112219		
User hours (hour/year)	168329		

Water		*Sources*
Fresh water use (L/meal)	15	
Total fresh water use (L/year)	1683289	
Electricity		
Electricity use (kWh/m2/year)	75	
Total water use (kWh/year)	22575	
Food consumtion		
Beverages consumed (kg/year)	45785	
.		
Total food consumed (kg/year)	21546	
% vegeatables from own farm	40%	
VF vegetables (kg/year)	8618	

Sports facilities

Surface area (m2)	181		
Initial data		*Info*	*Sources*
Usable space response (%)	75%	*	.
Useable space (m2)	136		
Space per visitor (m2)	4,0		
Service time (hour)	2,0	*	
Opening hours (hour)	11,0	*	
Capacity (visitors)	186,7		
Opening days (day)	7,0	*	
Yealry days open (day)	365		
Visitors			
Occupancy (%)	33%	*	.
Daily visitors	62		
Yearly visitors	22483		
User hours (hour/year)	44965		

Bar

Surface area (m2)	146		
Initial data			*Sources*
Usable space response (%)	60%	*	.
Useable space (m2)	88		
Space per visitor (m2)	1,2		https://www.
Service time (hour)	1,5	*	
Opening hours (hour)	10,0	*	
Capacity (visitors)	486,7		
Opening days (day)	6,0	*	
Yealry days open (day)	313		
Visitors			
Occupancy (%)	33%	*	.
Daily visitors	161		
Yearly visitors	50245		
User hours (hour/year)	75367		

Water		*Sources*
Fresh water use (L/meal)	15	
Total fresh water use (L/year)	753673	
Electricity		
Electricity use (kWh/m2/year)	75	
Total water use (kWh/year)	10950	
Food consumtion		
Beverages consumed (kg/year)	20500	
Total food consumed (kg/year)	9647	
% vegeatables from own farm	40%	
VF vegetables (kg/year)	3859	

Expo space

Surface area (m2)	217		
Initial data		*Info*	*Sources*
Usable space response (%)	75%	*	
Useable space (m2)	163		
Space per visitor (m2)	6,0		
Service time (hour)	2,0	*	
Opening hours (hour)	9,0	*	
Capacity (visitors)	122		
Opening days (day)	7	*	
Yealry days open (day)	365		
Visitors			
Occupancy (%)	33%	*	.
Daily visitors	40		
Yearly visitors	14702		
User hours (hour/year)	29405		

Education space

Surface area (m2)	1900		
Initial data		*Info*	*Sources*
Usable space response (%)	50%	*	.
Useable space (m2)	950		
Space per visitor (m2)	2,0		
Service time (hour)	2,0	*	
Opening hours (hour)	8,0	*	
Capacity (visitors)	1900		
Opening days (day)	5	*	
Yealry days open (day)	261		
Visitors			
Occupancy (%)	33%	*	.
Daily visitors	627		
Yearly visitors	163468		
User hours (hour/year)	326936		

Sources

Vertical city park — *Data on water & nutrient demand in Vertical Farm tab

Surface area (m2)	786		
Initial data		*Info*	*Sources*
Usable space response (%)	50%	*	.
Useable space (m2)	393		
Space per visitor (m2)	4,0		
Service time (hour)	2,0	*	
Opening hours (hour)	13,0	*	
Capacity (visitors)	639		
Opening days (day)	7	*	
Yealry days open (day)	365		
Visitors			
Occupancy (%)	33%	*	.
Daily visitors	211		
Yearly visitors	76922		
User hours (hour/year)	153845		

Totals

Space	4032		
Daily visitors	1568		
Yearly visitors	476764		
User hours	920006		
	Yealry visitors	**Visitor hours**	**Space**
Sports	51255	102510	377
Food & drinks	162464	243696	447
Education & Expo	178170	356341	2117
City park	76922	153845	786
Offices	7952	63614	305

*Estimates. I do not guarantee the correctness of these numbers.

Food consumption data tab

Food data

Total Food & Beverage consumption (kg)	3	Bron
% Beverage	68%	Bron
Beverage (kg)	2,04	Bron
Solid food (kg)	0,96	Bron
Hours to consume food	15	*If day is 7 AM to 10 PM
Consumption multiplier	2	*Estimate. Person is likely
Food consumption (kg/hour)	0,128	
Beverage consumption per hour (kg/hour)	0,272	

Vertical farm tab

Indoor vertical farm		
Surface (m2)	**524**	
Info: Indoor urban vertical farm (IUVF) for leafy greens (lettuce) per m2		
An IUFV is a closed loop system. Plant waste, such as stems, are recycled within the system.		
Initial data		***Sources***
Crop type	Lettuce	
Layer capacity	10	Avgoustaki, D. D., & Xydis, (.
Max yield (kg/m2/year)	100	Avgoustaki, D. D., & Xydis, (.
Energy (kWh/kg dryweight)	247	Graamans, L., Baeza, E., Vi .
Water demand per kg (L/kg)	1	Avgoustaki, D. D., & Xydis, (.
Dry weight (%)	7%	Graamans, L., Baeza, E., Vi .
Nutrient uptake (kg/kg)	0,11103	Nemali, K (n.d.). Nutrition & Lighting Requir
System specific data		
Productive response (%)	50%	
Productive area (m2)	262	
Number of layers	4	*Based on picture of GrowX farm
Yield (kg/m2/year)*	40	
Dry weight yield (kg/m2/yr)	2,8	
Energy (kWh/m2/year)	691,6	.
Total per year		
Yield (kg/year)	10480	
Water (L/year)	10480	
Energy (kWh)	181199	
Nutrients (kg)	1164	
Liquid fertilizer need		
Is the demand dry or wet?	**Wet**	
If wet, use conversion:		
Fertilizer water content (%)	90%	
Theoretical need of liquid fert	11636	

Production balance					
		Demand			***Supply***
	days	**Water (L)**	**Energy (kWh**	**Nutrients (kg)**	**Yield (kg)**
January	31	890	15389,5	988,3	890
February	28	804	13900,2	892,6	804
March	31	890	15389,5	988,3	890
April	30	861	14893,1	956,4	861
May	31	890	15389,5	988,3	890
June	30	861	14893,1	956,4	861
July	31	890	15389,5	988,3	890
August	31	890	15389,5	988,3	890
September	30	861	14893,1	956,4	861
October	31	890	15389,5	988,3	890
November	30	861	14893,1	956,4	861
December	31	890	15389,5	988,3	890
Total	365	**10480**	**181199**	**11636**	**10480**

Nutrient uptake per kg lettuce			
Source: Nemali, K (n.d.). N .			
	%	**kg**	**Total kg**
N	4,5%	0,045	471,6
P	0,5%	0,005	52,4
K	5,0%	0,05	524
Ca	0,5%	0,005	52,4
Mg	0,3%	0,003	31,44
S	0,3%	0,003	31,44
Fe	0,0015%	0,000015	0,1572
Zn	0,0005%	0,000005	0,0524
Mn	0,0005%	0,000005	0,0524
B	0,0003%	0,000003	0,03144
Cu	0,0002%	0,000002	0,02096
Total	11,1%	0,11103	1164

Educative garden tab

Educative garden		
		Source
Size of picking garden (m2)	559	
Response (%)	50%	
Productive space	279,5	
Fertilzizer (L(kg)/m2/year)	3	https://edep .
Water (liter/m2/week)	10	https://edep .
Food production (kg/m2/year)	2	https://www .
Required fertilizer (kg/year)	838,5	
Required water (L/year)	145340	
Production (kg/year)	559	

Bio-digester tab

Waste transformer		
Surface area	221	
Initial values		***sources***
Unit(s)	2	
Square meters (m2)	30	
Max input (kg)	1200	https://www.maritiemne .
Organic waste (kg/day)	657,98	
Conversion organic fertilizer (%)	84%	https://www.maritiemne .
Conversion water (%)	16%	
Electricity (kWh/kg)	0,19	https://www.maritiemne .
Heat (KWh/kg)	0,39	https://www.maritiemne .
Organic fertilizer (kg/day)	552,7	
Electricity (kWhe/day)	123,8	
Electricity (kWh thermal/day)	258,4	
Water (L/day)	105,3	

Wastetransformer data	Amount	capaciteit	langt	breed	ho	m2
Container	1	600 kg/d	6,06	2,44	3	14,7864
Capaciteit (kg/year)	219000					

Data derived from:
1000kg organic waste turned into 840 litres of organic fertilizer to replace artificial (oil-based) ones
3000kg waste/day generates 206.000 kWh and 430.000 thermal kWh per year

Source
https://www.maritiemnederland.com/nieuws/the-waste-transformers-zet-afval-om-in-schone-energie

System function		Input		Output		
	days	OW BK (kg/month)	OW GT (kg/month)	Electricity (kWh/month)	Heat (kWh/month)	Organic fertilizer (kg/month)
January	31	17751	441	3422	7144	15281
February	28	16033	398	3091	6452	13802
March	31	17751	441	3422	7144	15281
April	30	17178	427	3312	6913	14788
May	31	17751	441	3422	7144	15281
June	30	17178	427	3312	6913	14788
July	31	17751	441	3422	7144	15281
August	31	17751	441	3422	7144	15281
September	30	17178	427	3312	6913	14788
October	31	17751	441	3422	7144	15281
November	30	17178	427	3312	6913	14788
December	31	17751	441	3422	7144	15281
Total	365	208999	5194	40296	84112	179922
		214193				

Organic waste GT tab

Organic waste generated in the Green Tower	
Waste (kg/year)	5.194
Waste (kg/day)	14,23

Organic waste GT monthly data	days	Organic waste GT
January	31	441
February	28	398
March	31	441
April	30	427
May	31	441
June	30	427
July	31	441
August	31	441
September	30	427
October	31	441
November	30	427
December	31	441
total	365	**5194**

Productie Bedrijfsafval

Source: Rekenmodel productie bedrijfsafval BK

aantal m2 bvo: **0**

	Gewenste respons
Restafval	
GF	75,00%
Plastic/verpakkingen	75,00%
Glas	75,00%
Papier	75,00%
karton 25%	75,00%
oud papier 75 %	75,00%
Textiel	75,00%

Output voor gebied

bedrijvighei		Input m2/opp	Uitkomst gebied	Restafval	(papierkarton)	drank	Glas	Textiel	GFT
Werken	Bedrijven	0	0	0	0	0	0	0	0
	Kantoren	305	9.913	4.948	3.024	412	235	0	1.294
Voorzieningen	Supermarkten	0	0	0	0	0	0	0	0
	Dagelijkse voorzieningen	0	0	0	0	0	0	0	0
	Sociale voorzieningen	0	0	0	0	0	0	0	0
	Pharmacy	0	0	0	0	0	0	0	0
	Non-food	0	0	0	0	0	0	0	0
	Fastfood	0	0	0	0	0	0	0	0
	Bar's	146	7.300	2.920	2.190	548	1.095	0	548
	Restaurants	301	28.595	11.099	8.466	2.258	4.797	564	1.411
	Hotel	0	0	0	0	0	0	0	0
	Dienstverlening	0	0	0	0	0	0	0	0
	Tijdelijke initiatieven	0	0	0	0	0	0	0	0
Maatschappelijke voorzieningen	chool/onderwijs	1.341	9.195	5.057	2.207	1.379	0	0	552
	Binnensport	377	29.406	12.203	1.323	14.909	0	0	970
	Kinderen/jongeren centrum	0	0	0	0	0	0	0	0
	Welzijnsvoorzieningen	0	0	0	0	0	0	0	0
	Zorgvoorzieningen	0	0	0	0	0	0	0	0
	Bibliotheek	0	0	0	0	0	0	0	0
	Ruimte voor kunst en cultuur	217	3.656	1.801	890	518	27	0	420
	Totaal per jaar	2.687	88.065	**24.010**	**7.444**	**17.218**	**263**	**0**	**5.194**
	Gemiddelde			1.715	532	1.230	19	0	231

Bronscheiding per stroom / gebied — *in kilogram per jaar*

per day (added dagel

Uitgangspunten afvalproductie

bedrijvighei		Aandeel	Totaalproductie /jaar/100 m2	Restafval	OPK	drank	Glas	Textiel	GFT	Opmerkingen:
Werken	Bedrijven	57,59%	3.900	1.074	1.326	1.131	117	0	252	Bron: BS Standa
	Kantoren	17,28%	3.250	1.080	1.322	180	103	0	566	Bron: BS Standa
Voorzieningen	Supermarkten	2,57%	7.800	499	4.524	718	0	0	2.059	Bron: BS Standa
	Dagelijkse voorzieningen	1,03%	32.288	6.232	7.833	13.419	0	0	4.804	aanname, studi
	Sociale voorzieningen		900	300	200	267	100	33	0	aanname, studi
	Pharmacy		800	320	320	0	0	0	160	aanname, studi
	Non-food		1.421	579	474	53	0	53	263	aanname, studi
	Fastfood		14.667	4.400	7.067	800	0	800	1.600	aanname, studi
	Bar's		5.000	1.000	2.000	500	1.000	0	500	aanname, studi
	Restaurants		9.500	1.750	3.750	1.000	2.125	250	625	aanname, studi
	Hotel		420	89	25	242	25	13	25	aanname, studi
	Dienstverlening	1,03%	0	0	0	0	0	0	0	reinigingsrecht
	Tijdelijke initiatieven	3,80%	0	0	0	0	0	0	0	reinigingsrecht
Maatschappelijke voorzieningen	Basisschool	9,26%	686	274	219	137	0	0	55	Bron: BS Standa
	Binnensport	0,62%	7.800	1.716	468	5.273	0	0	343	Bron: BS Standa
	Kinderen/jongeren centrum	0,13%	3.429	1.371	1.097	583	103	0	274	aanname, studi
	Welzijnsvoorzieningen	1,19%	3.429	662	832	1.425	0	0	510	aanname, studi
	Zorgvoorzieningen	1,54%	1.560	548	162	-139	300	0	688	aanname, studi
	Bibliotheek	2,48%	324	105	105	61	3	0	50	aanname, studi
	Ruimte voor kunst en cultuur	1,49%	1.685	545	547	318	17	0	258	aanname, studi
	Totaal	100,00%	4.943							
	Gemiddelde			1.127	1.614	1.298	195	57	652	

Productie per stroom / per 100 m2

Achtergrond (samenstelling percentage)

		Restafval	OPK	drank	Glas	Textiel	GFT
Werken	Bedrijven	27,5%	34,0%	29,0%	3,0%	0,0%	6,5%
	Kantoren	33,2%	40,7%	5,5%	3,2%	0,0%	17,4%
Voorzieningen	Supermarkten	6,4%	58,0%	9,2%	0,0%	0,0%	26,4%
	Dagelijkse voorzieningen	19,3%	24,3%	41,6%	0,0%	0,0%	14,9%
	Sociale voorzieningen	33,3%	22,2%	29,6%	11,1%	3,7%	0,0%
	Pharmacy	40,0%	40,0%	0,0%	0,0%	0,0%	20,0%
	Non-food	40,7%	33,3%	3,7%	0,0%	3,7%	18,5%
	Fastfood	30,0%	48,2%	5,5%	0,0%	5,5%	10,9%
	Bar's	20,0%	40,0%	10,0%	20,0%	0,0%	10,0%
	Restaurants	18,4%	39,5%	10,5%	22,4%	2,6%	6,6%
	Hotel	21,2%	6,1%	57,6%	6,1%	3,0%	6,1%
	Dienstverlening	14,4%	33,9%	29,4%	19,2%	0,0%	3,0%
	Tijdelijke initiatieven	14,4%	33,9%	48,6%	0,0%	0,0%	3,0%
Maatschappelijke voorzieningen	Basisschool	40,0%	32,0%	20,0%	0,0%	0,0%	8,0%
	Binnensport	22,0%	6,0%	67,6%	0,0%	0,0%	4,4%
	Kinderen/jongeren centrum	40,0%	32,0%	17,0%	3,0%	0,0%	8,0%
	Welzijnsvoorzieningen	19,3%	24,3%	41,6%	0,0%	0,0%	14,9%
	Zorgvoorzieningen	35,2%	10,4%	-8,9%	19,2%	0,0%	44,1%
	Bibliotheek	32,4%	32,5%	19,0%	0,9%	0,0%	15,3%
	Ruimte voor kunst en cultuur	32,4%	32,5%	18,9%	1,0%	0,0%	15,3%

Organic waste BK tab

Organic waste generated in the Bajes Kwartier	Organic waste	Source:
Households (kg/year)	137476,15	Source: Rekenmodel prodı .
Businesses (kg/year)	71523,06	Source: Rekenmodel prodı .
Households (kg/day)	376,65	
Businesses (kg/day)	195,95	
Organic waste (kg/da	572,60	

Organic waste monthly data	days	Households	Businesses	total
January	31	11676	6075	17751
February	28	10546	5487	16033
March	31	11676	6075	17751
April	30	11299	5879	17178
May	31	11676	6075	17751
June	30	11299	5879	17178
July	31	11676	6075	17751
August	31	11676	6075	17751
September	30	11299	5879	17178
October	31	11676	6075	17751
November	30	11299	5879	17178
December	31	11676	6075	17751
total	365	137476	71523	208999

PV panels tab

PV panels total

	kWh
January	740,7
February	1341,2
March	2782,5
April	4394,0
May	5685,1
June	5815,2
July	5785,2
August	4804,3
September	3182,9
October	1871,7
November	840,8
December	550,5
Total	**37794,1**

PV panels roof

1 m2	1
Roof space	109
Available for	90%
Panel efficie	21%
Panel angle	37
Panel directi	South
Panel perfori	90%
Direction per	100%
Productive sp	98,10

Roof Energy generation

	kWh/m2/mor	kWh/month
January	4	381,1
February	7	690,1
March	15	1431,8
April	23	2261,0
May	30	2925,3
June	31	2992,3
July	30	2976,8
August	25	2472,1
September	17	1637,8
October	10	963,1
November	4	432,6
December	3	283,3
Total	**198,2**	**19447,3**

PV panels facade A

1 m2	1
Facade spac	850,465
Available for	4%
Panel efficie	21%
Panel angle	90
Panel directi	NNW
Panel perfori	90%
Direction per	30%
Productive sp	34,02

Facade A: Energy generation

	kWh/m2/mc	kWh/month
January	1	39,6
February	2	71,8
March	4	149,0
April	7	235,2
May	9	304,3
June	9	311,3
July	9	309,7
August	8	257,2
September	5	170,4
October	3	100,2
November	1	45,0
December	1	29,5
Total	**59,5**	**2023,2**

PV panels facade B

1 m2	1
Facade spac	1219,368
Available for	4%
Panel efficie	21%
Panel angle	90
Panel directi	ONO
Panel perfori	90%
Direction per	50%
Productive sp	48,77

Facade B: Energy generation

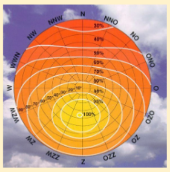
	kWh/m2/mc	kWh/month
January	2	94,7
February	4	171,6
March	7	355,9
April	12	562,1
May	15	727,2
June	15	743,9
July	15	740,0
August	13	614,6
September	8	407,1
October	5	239,4
November	2	107,5
December	1	70,4
Total	**99,1**	**4834,6**

Solar radiation — ***FIND SOURCES***

Location ***Schiphol***

	kWh/m2
January	20,6
February	37,2
March	77,2
April	121,9
May	157,8
June	161,4
July	160,6
August	133,3
September	88,3
October	51,9
November	23,3
December	15,3

Efficiency % at direction & tilt



PV panels facade C

1 m2	1
Facade spac	850,465
Available for	4%
Panel efficie	21%
Panel angle	90
Panel directi	ZZO
Panel perfori	90%
Direction per	70%
Productive sp	34,02

Facade C: Energy generation

	kWh/m2/mc	kWh/month
January	3	92,5
February	5	167,5
March	10	347,6
April	16	548,8
May	21	710,1
June	21	726,4
July	21	722,6
August	18	600,1
September	12	397,6
October	7	233,8
November	3	105,0
December	2	68,8
Total	**138,8**	**4720,7**

PV panels facade D

	1
Facade spac	1219,368
Available for	4%
Panel efficie	21%
Panel angle	90
Panel directi	WZW
Panel perfori	90%
Direction per	70%
Productive sp	48,77

Facade D: Energy generation

	kWh/m2/mc	kWh/month
January	3	132,6
February	5	240,2
March	10	498,3
April	16	786,9
May	21	1018,1
June	21	1041,4
July	21	1036,0
August	18	860,4
September	12	570,0
October	7	335,2
November	3	150,6
December	2	98,6
Total	**138,8**	**6768,4**

Climate control tab

Kantoor functie	Total Surface	**1276**
BENG performance (%)	25%	
Beng-eis		
Energie demand (kWh/m2/year)	90	
Primary fossil energy use (kWh/m2/year	40	
Percentage renewables (%)	30	
Response		
Koude vraag (%)	44%	
Warme vraag (%)	44%	
Electriciteitsvraag (%)	11% Source?	
Energy demand per m2		
Energy demand total	67,5	
Koude vraag (kWh)	30,0	
Hitte vraag (kWh)	30,0	
Electriciteitsvraag (kWh)	7,5	
Total energy demand / production for the building		
Total energy demand	86130	
Cold demand (kWh)	38280	
Heat demand (kWh)	38280	
Electricity demand (kWh)	9570	
Total electricity demand		**COP**
Electricity demand for cold (kWhe)	6380	6
Electricity demand for heat (kWhe)	7656	5
Electricity demand lighting (kWhe)	9570	
Total electricity demand	**23606**	

Energy conversion reference numbers for ZED-course

Space heating system	COP	remarks
Direct electrical heating	1	
Infra red-panel heating	2	Because of zoning and direct effect
Heatpump with source outside air	3	Heating system temperature is 45°C
Heatpump with source ground h.e.	4	Heating system temperature is 45°C
Heatpump with source groundwater	5	Heating system temperature is 45°C
Heatpump with source PVT	6	Heating system temperature is 45°C
Deep geothermal (70-90°C)	10	Electricity for pumps
Heatpump with other sources		Depends on temperature (see Graph)
Electric-boiler (hot water)	1	
Heatpump-boiler (hot water)	3	Source is exhausted ventilation air
Booster heatpump		Depends on the source (see graph)
Cooling system	COP	Remarks
Mobile airco	2	
Airco with outside air (Split-unit)	4	Airco = heatpump
Heatpump with ground source	6	Temperature cooling 12oC
Direct with groundsource	20	Temperature cooling 18oC

Electricity with PV-panels

Watt-piek x 0,9 = optimal kWh/year — South-facing with 40° inclination (slope) = 100 %

Use solar diagram for other inclinations and orientations for the Netherlands

Sanitation tab

Black waste water		
Wastewater produced flushing feces		
Initial data		***Source***
Feces (kg/day)	0,128	https://www.quest.nl/me .
Defecating frequency (x/day)	1,2	https://www.wastewater .
Liters per flush	2,5	https://www.wastewater .
Totals per year		
User hours (hours/year)	920006	
Feces produced (kg/year)	4907	
Water flushed (L/year)	115001	
Black wastewater (L/year)	119907	

Yellow waste water		
Wastewater produced flushing urine		
Initial data		***Source***
Urine (liter/day)	1,5	https://www.gezondheids .
Urination frequency (x/day)	3,5	https://www.wastewater .
Liters per flush	0,3	https://www.wastewater .
User hours (hours/year)	920006	
Urine produced (L/year)	57500	
Water flushed	40250	
Yellow wastewater (L/year)	97751	

Toilet types				
Various types of flushing systems			*source*	https://www .
Normal	Feces: liter per flush	6		
	Urine: liter per flush	6		
Dual flush	Feces: liter per flush	6		
	Urine: liter per flush	2,3		
Eco flush toil	Feces: liter per flush	2,5		
	Urine: liter per flush	0,3		

City Park tab

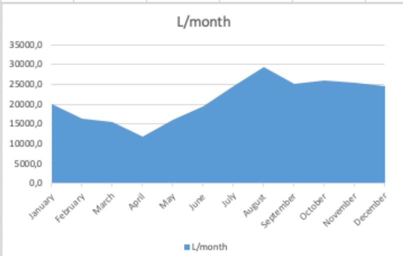
City Park		
Size of city park (m2)	786	
Response (planted space) (%)	33%	
Productive space	259,38	
Fertilzizer (L(kg)/m2/year)	3	https://edep
Water (liter/m2/week)	10	https://edep
Required fertilizer (kg/year)	778,14	
Required water (L/year)	134877,6	

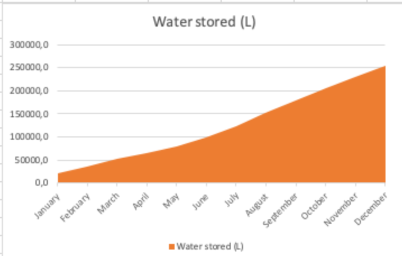
Water catchment tab

Rainwater	
Catchment area (m2 roof)	299
Rainwater catchment (L/year)	254239,7

Rainwater catchment			**Rainwater catchment**			**Rainwater use (NOW INITIALIZED FOR WATERING P**		
	L/m2/month	L/month		Water catchı	Water stored (L)		Water use (L	Storage capacity
January	67	19883,5	January	19884	19883,5	January	23351	-3468,0
February	55	16355,3	February	16355	36238,8	February	23351	-10464,1
March	52	15488,2	March	15488	51727,0	March	23351	-18327,4
April	40	11840,4	April	11840	63567,4	April	23351	-29838,5
May	54	16116,1	May	16116	79683,5	May	23351	-37073,8
June	65	19375,2	June	19375	99058,7	June	23351	-41050,1
July	82	24607,7	July	24608	123666,4	July	23351	-39793,9
August	99	29481,4	August	29481	153147,8	August	23351	-33663,9
September	84	25235,6	September	25236	178383,4	September	23351	-31779,8
October	87	25923,3	October	25923	204306,7	October	23351	-29208,0
November	85	25504,7	November	25505	229811,4	November	23351	-27054,7
December	82	24428,3	December	24428	254239,7	December	23351	-25977,9

Rainwater storage (basin)	
Rainwater storage (m2)	0
Rainwater storage height	1
Rainwater storage capacity (liter)	0
Rain water stored	254239,7





Rainwater storage (Green roof)		
Green roof (m2)	0	
Capacity (L/m2)	100	https://www.nda.nl/groendak-voordelen/
Rainwater storage capacity (liter)	0	
Rain water stored	0,0	

Solar radiation data tab

Globale straling in kJ/cm2

Locatie		jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	jaar
215	Voorschoten	7,7	13,7	28,8	45,7	58,9	60,4	60,0	49,6	32,5	18,9	8,5	5,5	390,2
235	De Kooy	7,2	13,5	28,8	46,3	60,1	60,6	60,7	50,2	32,4	18,7	8,3	5,4	392,2
240	Schiphol	7,4	13,4	27,8	43,9	56,8	58,1	57,8	48,0	31,8	18,7	8,4	5,5	377,6
249	Berkhout	7,3	13,1	28,4	45,2	57,6	58,3	58,6	48,2	31,7	18,7	8,3	5,5	380,9
251	Hoorn Tersch	7,0	13,1	29,5	46,7	60,9	60,3	60,1	49,9	32,7	18,8	8,1	5,3	392,4
260	De Bilt	7,3	12,9	26,7	42,4	54,2	55,1	55,3	46,9	31,4	18,8	8,4	5,4	364,8
267	Stavoren	7,4	13,6	28,6	46,0	58,7	60,0	60,1	50,0	32,9	19,0	8,4	5,5	390,2
269	Lelystad	7,2	13,2	27,5	43,4	55,7	57,0	57,3	47,9	32,0	18,9	8,4	5,4	373,9
270	Leeuwarden	7,0	12,9	27,8	43,7	56,8	56,4	57,1	47,7	31,2	18,3	8,1	5,3	372,3
273	Marknesse	7,3	13,4	27,5	43,8	55,7	57,2	57,8	48,5	32,5	18,9	8,4	5,5	376,5
275	Deelen	7,2	12,8	26,4	41,3	53,1	54,4	54,5	46,1	31,3	18,6	8,4	5,4	359,5
278	Heino	7,1	13,0	26,9	43,0	54,1	56,1	56,6	47,3	32,1	18,9	8,3	5,3	368,7
279	Hoogeveen	6,9	12,6	26,5	42,1	54,1	55,6	56,1	47,2	31,5	18,4	8,2	5,3	364,5
280	Eelde	6,6	12,4	26,2	42,0	54,2	54,7	55,7	47,0	31,2	18,0	7,9	5,1	361,0
283	Hupsel	7,3	13,1	27,0	42,9	54,8	56,6	56,6	47,7	32,3	19,0	8,7	5,5	371,5
286	Nieuw Beert	6,7	12,5	26,5	42,9	55,8	56,4	56,3	46,7	31,1	18,1	7,8	5,0	365,8
290	Twenthe	6,9	12,6	26,4	42,1	53,7	55,6	55,7	46,8	31,8	18,7	8,3	5,3	363,9
310	Vlissingen	8,3	14,4	29,6	46,0	57,9	60,3	59,9	50,8	34,5	20,3	9,5	6,1	397,6
319	Westdorpe	8,0	13,6	27,9	43,5	55,1	57,6	56,2	47,9	32,8	19,8	9,3	6,0	377,7
344	Rotterdam	7,6	13,3	27,6	43,7	56,3	57,7	57,3	48,2	32,0	18,9	8,6	5,6	376,8
348	Cabauw mas	7,9	13,7	28,0	44,5	56,7	57,8	57,8	49,1	33,0	19,7	9,0	5,8	383,0
350	Gilze-Rijen	7,9	13,3	27,3	42,8	54,4	56,3	55,5	47,9	32,7	19,5	9,1	5,9	372,6
356	Herwijnen	7,9	13,6	27,7	43,8	55,7	57,4	56,8	48,5	32,8	19,4	9,0	5,8	378,4
370	Eindhoven	7,9	13,4	27,4	42,9	54,4	56,5	56,0	48,2	33,2	19,8	9,3	5,9	374,9
375	Volkel	7,7	13,3	27,4	43,2	54,8	57,1	56,5	48,1	33,0	19,5	9,2	5,8	375,6
380	Maastricht	8,0	13,5	27,5	43,1	54,7	57,2	56,4	48,6	33,3	19,7	9,5	5,9	377,4
391	Arcen	7,5	13,1	26,9	42,1	53,9	56,1	55,6	47,3	32,3	19,2	9,0	5,6	368,6

OWN TRANSLATION OF DATA TO KWH

Globale straling in kWh/m2

Locatie		jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	jaar
215	Voorschoten	21,4	38,1	80,0	126,9	163,6	167,8	166,7	137,8	90,3	52,5	23,6	15,3	1083,9
235	De Kooy	20,0	37,5	80,0	128,6	166,9	168,3	168,6	139,4	90,0	51,9	23,1	15,0	1089,4
240	Schiphol	20,6	37,2	77,2	121,9	157,8	161,4	160,6	133,3	88,3	51,9	23,3	15,3	1048,9
249	Berkhout	20,3	36,4	78,9	125,6	160,0	161,9	162,8	133,9	88,1	51,9	23,1	15,3	1058,1
251	Hoorn Tersch	19,4	36,4	81,9	129,7	169,2	167,5	166,9	138,6	90,8	52,2	22,5	14,7	1090,0
260	De Bilt	20,3	35,8	74,2	117,8	150,6	153,1	153,6	130,3	87,2	52,2	23,3	15,0	1013,3
267	Stavoren	20,6	37,8	79,4	127,8	163,1	166,7	166,9	138,9	91,4	52,8	23,3	15,3	1083,9
269	Lelystad	20,0	36,7	76,4	120,6	154,7	158,3	159,2	133,1	88,9	52,5	23,3	15,0	1038,6
270	Leeuwarden	19,4	35,8	77,2	121,4	157,8	156,7	158,6	132,5	86,7	50,8	22,5	14,7	1034,2
273	Marknesse	20,3	37,2	76,4	121,7	154,7	158,9	160,6	134,7	90,3	52,5	23,3	15,3	1045,8
275	Deelen	20,0	35,6	73,3	114,7	147,5	151,1	151,4	128,1	86,9	51,7	23,3	15,0	998,6
278	Heino	19,7	36,1	74,7	119,4	150,3	155,8	157,2	131,4	89,2	52,5	23,1	14,7	1024,2
279	Hoogeveen	19,2	35,0	73,6	116,9	150,3	154,4	155,8	131,1	87,5	51,1	22,8	14,7	1012,5
280	Eelde	18,3	34,4	72,8	116,7	150,6	151,9	154,7	130,6	86,7	50,0	21,9	14,2	1002,8
283	Hupsel	20,3	36,4	75,0	119,2	152,2	157,2	157,2	132,5	89,7	52,8	24,2	15,3	1031,9
286	Nieuw Beert	18,6	34,7	73,6	119,2	155,0	156,7	156,4	129,7	86,4	50,3	21,7	13,9	1016,1
290	Twenthe	19,2	35,0	73,3	116,9	149,2	154,4	154,7	130,0	88,3	51,9	23,1	14,7	1010,8
310	Vlissingen	23,1	40,0	82,2	127,8	160,8	167,5	166,4	141,1	95,8	56,4	26,4	16,9	1104,4
319	Westdorpe	22,2	37,8	77,5	120,8	153,1	160,0	156,1	133,1	91,1	55,0	25,8	16,7	1049,2
344	Rotterdam	21,1	36,9	76,7	121,4	156,4	160,3	159,2	133,9	88,9	52,5	23,9	15,6	1046,7
348	Cabauw mas	21,9	38,1	77,8	123,6	157,5	160,6	160,6	136,4	91,7	54,7	25,0	16,1	1063,9
350	Gilze-Rijen	21,9	36,9	75,8	118,9	151,1	156,4	154,2	133,1	90,8	54,2	25,3	16,4	1035,0
356	Herwijnen	21,9	37,8	76,9	121,7	154,7	159,4	157,8	134,7	91,1	53,9	25,0	16,1	1051,1
370	Eindhoven	21,9	37,2	76,1	119,2	151,1	156,9	155,6	133,9	92,2	55,0	25,8	16,4	1041,4
375	Volkel	21,4	36,9	76,1	120,0	152,2	158,6	156,9	133,6	91,7	54,2	25,6	16,1	1043,3
380	Maastricht	22,2	37,5	76,4	119,7	151,9	158,9	156,7	135,0	92,5	54,7	26,4	16,4	1048,3
391	Arcen	20,8	36,4	74,7	116,9	149,7	155,8	154,4	131,4	89,7	53,3	25,0	15,6	1023,9

Source https://www.knmi.nl/klimaat-viewer/grafieken-tabellen/meteorologische-stations/stations-maand/stations-maand_1991-2020

Rainfall data tab

Gemiddelde neerslaghoeveelheid in mm — tijdvak 1991-2020

Locatie		jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	winter	lente	zomer	herfst	jaar
215	Voorschoten	70,00	59,40	52,80	41,60	52,70	62,80	-	-	-	91,10	89,20	83,70	213,10	147,10	-	-	-
235	De Kooy	65,60	50,10	43,70	34,90	42,00	58,70	62,50	89,10	84,70	96,50	83,50	75,30	191,00	120,60	210,30	264,70	786,60
240	Schiphol	66,50	54,70	51,80	39,60	53,90	64,80	82,30	98,60	84,40	86,70	85,30	81,70	202,90	145,30	245,70	256,40	850,30
249	Berkhout	73,30	61,10	51,80	41,30	52,30	58,30	73,50	98,10	84,80	98,60	84,60	86,50	220,90	145,40	229,90	268,00	864,20
251	Hoorn Tersche	65,60	54,10	46,60	33,30	44,50	58,60	67,80	85,70	86,40	95,80	80,30	83,90	203,60	124,40	212,10	262,50	802,60
260	De Bilt	70,80	63,10	57,80	41,60	59,30	70,50	85,20	83,60	77,90	81,10	80,00	83,80	217,70	158,70	239,30	239,00	854,70
267	Stavoren	65,90	51,30	46,70	36,70	49,50	56,50	65,90	90,50	76,20	79,20	67,70	69,10	186,30	132,90	212,90	223,10	755,20
269	Lelystad	67,70	57,20	55,10	42,30	57,20	67,00	91,40	92,10	74,20	76,30	69,70	73,90	198,80	154,60	250,50	220,20	824,10
270	Leeuwarden	68,60	55,50	49,10	39,10	54,50	69,90	77,70	93,70	82,30	79,60	77,90	81,50	205,60	142,70	241,30	239,80	829,40
273	Marknesse	66,80	55,10	49,90	41,20	58,20	77,10	87,00	85,80	71,70	73,20	66,90	71,90	193,80	149,30	249,90	211,80	804,80
275	Deelen	79,50	63,70	60,70	43,80	62,90	69,10	86,50	83,90	73,80	73,30	79,50	91,30	234,50	167,40	239,50	226,60	868,00
278	Heino	66,40	57,00	54,60	40,70	58,40	68,40	81,90	79,80	62,40	67,90	64,80	72,10	195,50	153,70	230,10	195,10	774,40
279	Hoogeveen	73,30	62,90	60,20	44,10	62,60	68,90	89,60	79,70	71,40	73,40	66,80	81,30	217,50	166,90	238,20	211,60	834,20
280	Eelde	72,70	54,70	54,10	41,30	57,90	65,00	85,00	77,80	75,40	71,40	70,00	79,40	206,80	153,30	227,80	216,80	804,70
283	Hupsel	67,10	55,70	55,30	40,30	55,40	64,20	80,50	84,80	67,10	64,70	63,60	76,30	199,10	151,00	229,50	195,40	775,00
286	Nieuw Beerta	66,50	51,60	51,30	37,80	55,90	63,30	84,30	75,10	76,40	66,20	65,10	72,50	190,60	145,00	222,70	207,70	766,00
290	Twenthe	70,80	55,40	58,10	43,70	57,20	64,80	77,60	79,40	67,30	67,50	66,10	76,40	202,60	159,00	221,80	200,90	784,30
310	Vlissingen	58,90	52,80	44,60	35,00	49,40	62,00	72,40	81,80	73,60	73,80	78,90	75,70	187,40	129,00	216,20	226,30	758,90
319	Westdorpe	66,10	59,90	53,80	38,00	55,50	62,50	74,90	80,60	69,50	68,00	73,90	83,30	209,30	147,30	218,00	211,40	786,00
344	Rotterdam	70,80	65,90	56,50	42,10	55,70	68,60	78,60	91,90	90,30	87,30	87,60	86,20	222,90	154,30	239,10	265,20	881,50
348	Cabauw	60,30	55,40	51,30	38,80	53,00	69,60	79,90	78,40	70,30	68,10	70,70	73,90	189,60	143,10	227,90	209,10	769,70
350	Gilze-Rijen	68,00	63,10	54,80	42,50	59,80	66,50	81,40	71,60	65,40	69,90	74,20	81,90	213,00	157,10	219,50	209,50	799,10
356	Herwijnen	67,90	61,30	56,30	39,00	60,00	64,00	74,20	80,10	65,00	70,50	68,20	79,40	208,60	155,30	218,30	203,70	785,90
370	Eindhoven	65,20	60,40	52,00	41,00	56,20	62,60	75,70	73,20	58,90	61,20	67,70	75,40	201,00	149,20	211,50	187,80	749,50
375	Volkel	64,00	58,20	52,70	40,40	57,60	64,10	70,60	73,40	59,40	61,80	64,80	72,20	194,40	150,70	208,10	186,00	739,20
380	Maastricht	63,80	57,60	54,60	41,00	57,70	68,90	72,80	82,80	57,50	63,60	62,20	74,30	195,70	153,30	224,50	183,30	756,80
391	Arcen	62,80	57,50	50,40	40,70	54,60	60,30	71,90	76,80	60,20	63,60	62,90	71,70	192,00	145,70	209,00	186,70	733,40

- geen of te weinig waarnemingen

KNMI, Ministerie van Infrastructuur en Waterstaat — www.knmi.nl/klimaat-viewer

Appendix 5: Results of the for the Design Session Green Tower Challenge

Results
CbD Design Session Bajeskwartier

Date: 16 February 2021, 12:30 – 14:30h
Location: Online via Zoom
Host: Aranka Dijkstra & Ruben Smolders AMS Institute

The diagram on the right is a summary of all the different input we gathered during the online design session about Bajeswartier. The central question was: *"How can we realize a circular urban agri-food system in the Green Tower in the Bajeskwartier in Amsterdam?"*

Multiple researchers part of the Circularity by Design project at Wageningen University and representatives from BKO and FABRICations contributed to the design session. Below the main takeaways from the session are summarized. The input is clustered around the four main topics addressed by the Green Tower Living Lab which are on its turn based on the Ellen McArthur's circularity framework: Input in relation to Biological Cycles, Material Cycles, Social dimensions and input in relations to the Green Tower as an overall general sustainability Hub. Behind some of the takeaways, the names of the participants that are interested in a follow-up on these specific topics are mentioned.

Input Biological Cycle:
Towards a Closed Biological Cycle: How can the Green Tower function as a Circular Urban Food System in which nutrients and resources from waste produced in the Bajes Kwartier can be recovered on the highest circularity level possible?

- Biodiversity & Climate Resilience:
  - Use birds as pestcontrol for the vertical garden; Further research is needed on which crops are suitable. **>> Ciska Nienhuis, Annemarie Mens, Alexander Laarman.**
- Production:
  - Use organic waste for feeding small animals that can produce local food (e.g. chickens for eggs, sheep for wool, etc.). A consequent opportunity is to educate people on on animal welfare, e.g. how to feed the pets in the area? **>> Oona Morrow, Annemarie Mens, Alexander Laarman.**
  - Produce beer from old local bread.
  - Produce soap from used frying oil in the Bajeskwartier.
  - Produce mushrooms on coffee grounds.
  - Produce edible insects on residue waste from fruit and vegetables.
  - Set up an experiment in which different urban food production techniques are compared.
- Consumption:
  - Realise a community fridge in the Green Tower for the Bajeskwartier residents.
- Recycling:
  - Use plants, micro organisms, fish, snails and insects for the conversion of waste streams. **>> Maryia Mishyna, Annemarie Mens, Alexander Laarman.**
  - Recover nutrients from urine and/or feces flows in the Green Tower or borader Bajeskwartier to create fertiliser for local greenery and reduce, or even eliminate, water usage (in broader MRA region). **>> Ciska Nienhuis, Lotte Brouwer**

  - When designing the Green Tower metabolism; consider waste hierarchy (there might be other opportunities for higher value collection) and wider loops (different suitable solutions when looking at different scales). **>> Oona Morrow, Johan van Groenestijn.**
- Heat & Energy:
  - Link food production with surrounding building functions for energy exchange; e.g. link renewable energy over production from the city to Bajeskwartier.

Input Material Cycle:
Towards a Closed Material Cycle: How can the Green Tower become a circular building?

- Think about how resources like plastics, paper, metals and electronics will be re-used or recycled. Use the R-Ladder of Circularity to decide on the best circular solution.

Input Social:
Towards a healthy living environment and Social Acceptance: How can the Green Tower facilitate a Green Vertical Park that contributes to a healthy living environment for the inhabitants of Bajes Kwartier?

- Engaging residents:
  - Interesting research can be conducted on how to realise an inclusive city and district via commons: with shared ownership/stewardship over spaces, innovations, flows. How will decisions be made about the design, use, access, sharing of benefits etc. of these? **>> Oona Morrow, Maarten Markus, Hilke Bos-Brouwers.**
  - Involve residents in food production activities in the Green Tower and/or Bajeskwartier.
- Education through experience for visitors:
  - Create interaction of users/residents/visitors with the demonstrated systems by making them really a part of the system; e.g. by utilising monitoring/tracking their contribution, make the flows visible, compare with mean-'behaviours'., etc. **>> Oona Morrow, Willie van de Broek, Hilke Bos-Brouwers.**

Input Sustainability Hub:
Towards a replicable Circular Sustainability Hub concept: How can the Green Tower be a fully Circular Building that acts as Sustainability Hub for the Bajes Kwartier?

- Get insight in the availability and destination of side flows for alternative uses and explore what would be the best option from a scientific/circular viewpoint. **>> Oona Morrow, Johan van Groenestijn.**
- Explore how the Bajeskwartier can contribute to a more decentralised community based on circular waste/food systems. Research how these can be governed in Amsterdam? **>> Maarten Markus, Ciska Nienhuis, Oona Morrow, Hilke Bos-Brouwers, Alexander Laarman.**

Appendix 6: Presentation for the Follow Up Design Session Bajeskwartier (Living Lab)

Thesis disclaimer

Door mee te doen aan deze sessie **ga je er mee akkoord** dat …:

- … de sessie wordt opgenomen
- … een verslag wordt gemaakt van de opname (waarna de opname wordt verwijderd)
- … na goedkeuring van alle deelnemers, het verslag wordt gebruikt als input voor mijn Master Thesis

De data in het verslag:

- Wordt geanonimiseerd
- 'Gevoelige' informatie wordt niet opgenomen in het verslag, of genuanceerd.

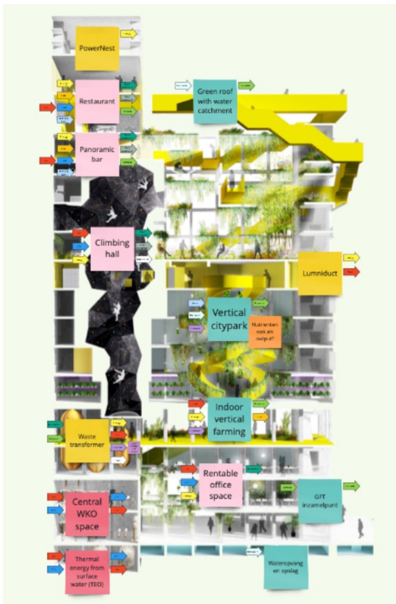
Doel van de sessie

- Duurzaamheid doelstellingen voor de Groene Toren meetbaar en bespreekbaar maken
- Gesprek starten waarin we de duurzaamheid randvoorwaarden voor de Groene Toren verkennen
- Bepalen of en hoe een rekenmodel voor voedsel, energie en water stromen operationeel te maken is

Thesis

"The **goal** of this thesis is to **create a tool** that helps designers make more informed decisions in the concept phase of **designing a sustainability hub** from a food, energy and water perspective"

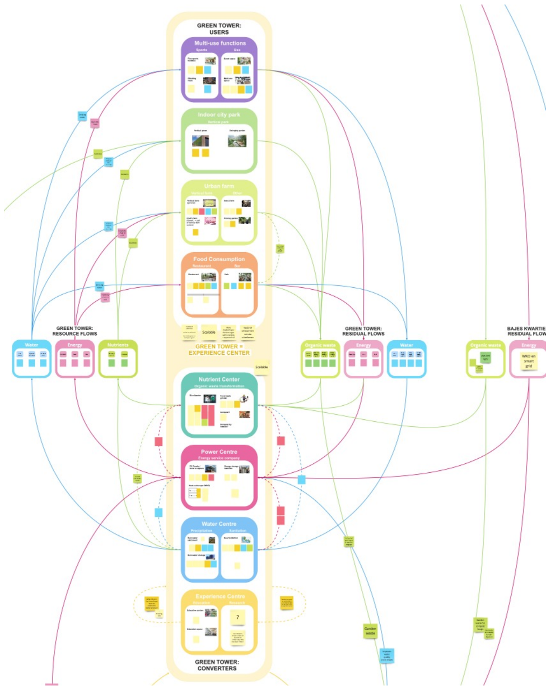
- Groene Toren = Totaal concept
- Food-Energy-Water Nexus
- Onderzoek in 4 stappen
- Tool: Theoretisch model & Rekenmodel



Theoretisch model

Visualiseert

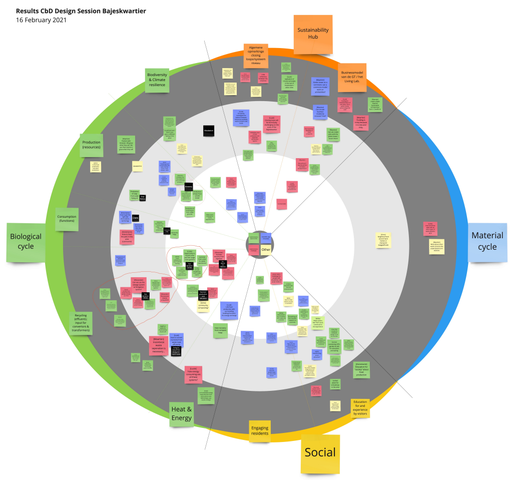
- Voedsel, energie en water stromen & systemen
- Verbindingen en mogelijke verbindingen
- Bruikbaar om eenvoudig een duurzaamheid hub in te visualiseren



Resultaten: ontwerpsessie 1

"How can we realize a circular urban agri-food system in the Green Tower in the Bajeskwartier in Amsterdam?"

- 4 cylci
- Clusters van experimenten:
  - Nieuwe sanitatie
  - Gebruik van insecten & andere dieren
  - Brewery
  - Community koelkast (too good to go)
  - …



Kwantitatief model

Kwantificeert

- Voedsel, energie en water stromen
- Geeft inzicht in overschotten en tekorten

Schaalbaar

- Is schaalbaar d.m.v. functie oppervlaktes (m2)
- Is schaalbaar in bezoekers aantallen

Wat gaan we nu doen?

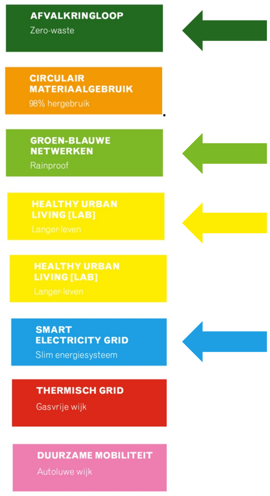
- Met (hypothetische) data zijn een aantal perspectieven voor de GT ruimtelijk en/of meetbaar gemaakt
- Deze ‘perspectieven’ gaan we bespreken

Waar letten we op?

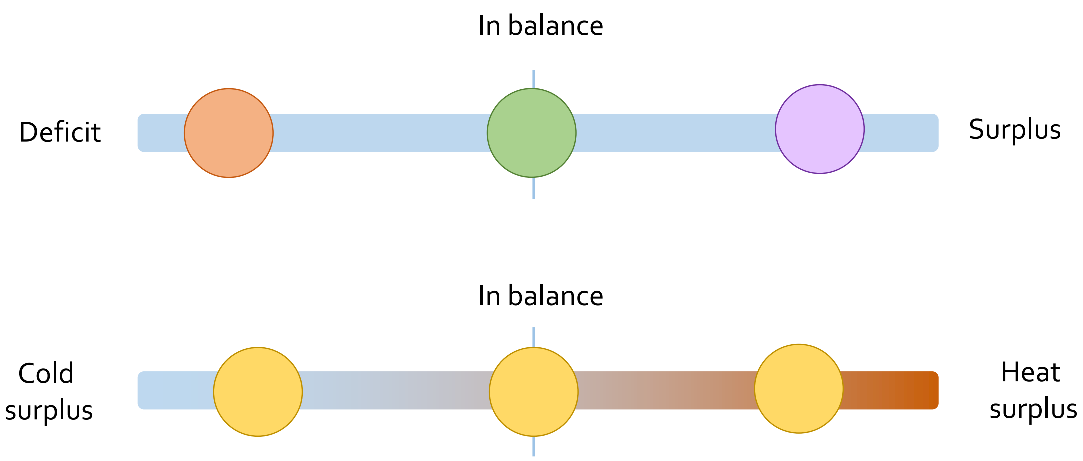
- Welke perspectieven zijn haalbaar en/of wenselijk?
- Hoe kunnen we experimenten koppelen aan de gegeven perspectieven?

De doelen van het Bajeskwartier Living Lab

1. **AFVALVRIJ BAJESKWARTIER (AFVALVERWERKING)**
2. **BIOBASED [EN CIRCULAIRE?] MATERIALEN**
3. **TIJDELIJKE OPENBARE RUIMTE**
4. **EDUCATIEVE ROUTE BAJESKWARTIER**
5. **VEILIG EN VRIJ BAJESKWARTIER**
6. **ENERGIE POSITIEF BAJESKWARTIER**
7. **GASVRIJ BAJESKWARTIER**
8. **AUTOLUW BAJESKWARTIER**



De sliders



Current design with 500.000 yearly visitors

Food (Nutrients)	Vertical farm	524 m2
	Vertical City park	786 m2
	Educative garden	559 m2
Energy	ATES space	221 m2
	PV panels	109 m2
	Bio-digester	139 m2
Water	Rainwater storage	0 m2
	Rainwater catchment	299 m2
Experience	Bar + restaurant	477 m2
	Sports + climbing	377 m2
	Educative space + expo	2117 m2
	Offices	305 m2

Food (vegetables)	
Nutrients	
Electricity	
ATES	
Rainwater for watering	
Flushing water	
Drinking water	
Nr. of yearly visitors	510.000
Black waste water	
Yellow waste water	

Current design with 500.000 yearly visitors

Food (Nutrients)	Vertical farm	524 m2
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Black waste water	
Yellow waste water	

Afval vrij Bajes Kwartier

AFVALKRINGLOOP
Zero-waste

"Op het gebied van **Recycling**: het gescheiden inzamelen en lokaal verwerken van restromen, zoveel mogelijk verwerking en terugwinning van grondstoffen en nutriënten uit voedsel- en afvalresten en uit afvalwater binnen het Bajeskwartier"

	200.000 visitors	500.000 visitors	1.000.000 visitors
Wastetransformer sludge			
Yellow wastewater			
Black wastewater			

Afval vrij Bajes Kwartier

AFVALKRINGLOOP
Zero-waste

"En op het gebied van **Productie**: zo veel mogelijk lokale voedselproductie "

	<u>**Current situation**</u> *VF: 50% (262 m2)* *VF food: 212 kg/week* *Electr.: -175.000 kwh/year*	**100% production** *VF: 100% (524 m2)* *VF food: 413 kg/week* *Electr.: -356.000 kwh/year*	**Less visitors (200.000)** *VF: 50% (262 m2)* *VF food: 212 kg/week* *Electr.: -158.000 kwh/year*
Electricity balance			
Food (From urban farming, for restaurant & bar)			
Food (left for fresh market)	0 kg / week	175 kg / week	115 kg / week

(Tijdelijke) openbare ruimte

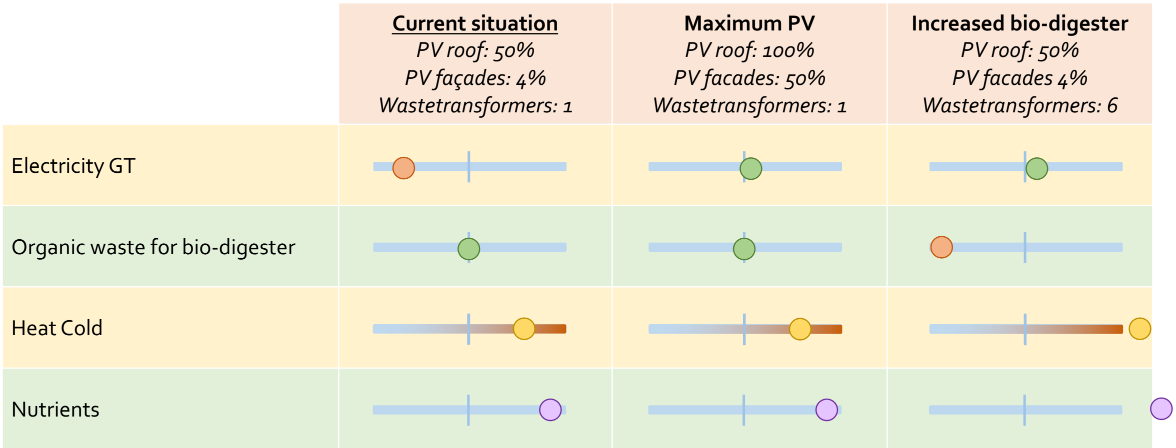
GROEN-BLAUWE NETWERKEN
Rainproof

"*zicht op groen & 50L waterberging per vierkante kilometer*" → wat doen we met het opgeslagen water?

	Current situation	**Watering plants**	**Flushing toilets**
Reservoir size	?	40.000 liters (2 months) 40 m3	40.000 liters (2 months) 40 m3
Watering indoor plants (with rainwater)			
Flushing toilets (with rainwater)			

Energie positief Bajes Kwartier

SMART ELECTRICITY GRID
Slim energiesysteem



Recap

- Lokaal voedsel produceren voor horeca én vers markt is mogelijk, maar:
  - Gaat ten koste van publieke karakter Vertical Farm of Groene Toren
  - Brengt enorme (lokale) elektriciteitsvraag met zich mee
- Een nutriënten overschot uit digestaat, urine & feces is onvermijdelijk
  - Lokaal verder verwerken is mogelijk
- Regenwater inzetten als spoelwater of plantbewatering om het even
- Er zal, hoe dan ook, een warmte overschot ontstaan door de Wastetransformer, slim inzetten!
  - Warmte voor struviet terugwinning?
  - Woningen wellicht warmte tekort in winter?
- Energie neutraal of zelfs positief worden is mogelijk op twee manieren:
  - Gebouw vol zetten met PV Panelen
  - 6x meer GFE afval verzamelen, uit stadsdeel. Ook 5 extra wastetransformers plaatsen

Reflectie op model

- Is dergelijk model bruikbaar in het ontwerp proces?

- Wat is er nodig om dit model operationeel te maken?

Key take-aways

- Formuleer allemaal een of meerdere key take-aways van de sessie!


Einde!

Appendix 7: Results of the Follow Up Design Session Bajeskwartier (Living Lab)

Results

Design session Bajeskwartier (Living Lab)

Date: 19 May 2021, 14.30 – 16.00
Location: Online via ZOOM
Hosts: Aranka Dijkstra & Jesse Bergman (AMS Institute)

The goal of this design session was to "make the sustainability goals of the Green Tower measurable and negotiable". This was done by quantifying the food, energy, and water (from here on: FEW) flows of various design perspectives, based on the outcomes of the previous design session. These perspectives were then used in the session as input to start a discussion on the preconditions for sustainability for the Green Tower (From here on: GT). Moreover, the participants were presented the quantitative model used for quantifying the FEW flows and asked what would be needed to operationalize it within the Bajeskwartier Living Lab.

Summary of outcomes

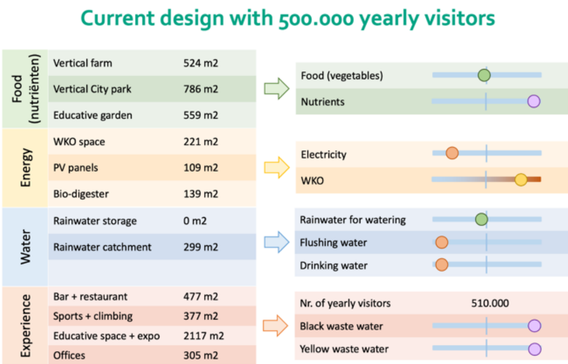
Thesis Jesse

Goal: "**create a tool** that helps designers make more informed decisions in the concept phase of **designing a sustainability hub** from a food, energy and water perspective"

The research was conducted in four steps: 1) Analyzing the FEW systems in the current program of the GT, 2) making a theoretical model that visualizes the FEW systems and their relations, 3) developing a quantitative model that shows balances in FEW and 4) discuss results with and learn from main stakeholders of the GT.

Model outcomes

In the overview on the right, the outcomes of the model can be seen. According to the model, the current program of the GT feeds its visitors (bar + restaurant) with vegetables while ther is a large nutrient surplus. An energy shortage and heat surplus can be observed. Rainwater can be used for watering or flushing. And the visitors generate surpluses of black and yellow wastewater.



Perspectives

If the perspectives would have been better aligned with the current state of design, they would have been more valuable discussion starters. Still, some insights were derived from the discussions of the perspectives. The goal of the GT is not to become 100% sustainable regarding its FEW systems. The tower will showcase the potential of adopting certain innovations in for instance urban farming for creating more sustainable neighborhoods.

Regarding its FEW systems, additional steps in retrieving flows would be considered if there is also a direct demand for these flows. An example is the extraction of struvite from yellow wastewater. Adding black wastewater to the bio-digester is not an option as it negatively effects the bio-digesting process and effluents. Moreover, the heat the bio-digester generates can become a problem, as the ATES is already ‘overheated’.

Tool / model

The model could very well be transformed into a valuable design tool and communication tool. It can help the GT team to create an assessment framework for making sustainable choices. The model could be well used to see whether including or excluding certain systems influences the balance. Moreover, the outcomes could be very well used for marketing and communication purposes and help in finding users that can fix the GT’s surpluses or deficiencies.
Many changes or additions were mentioned for the model. This a summary of the changes to be made:

- Assumptions and lower limits should be clear and set at the front of the model
- Expand the model with more options for the same type of system, giving the freedom to choose a best fit
- Create feedback loops, that allow the user to also scale the model outcomes and showing the effect on floor sizes (Now it is the other way around)
- Make a clear distinction between flows related to the building and flows related to the neighborhood
- Dashboard should be easier to understand, for instance by using Power BI

Furthermore, an alternative sequence for using the tool was proposed:

1) Set starting points and ambitions with stakeholders
2) Create perspectives based on the set starting points and ambitions
3) Choose perspective(s) with stakeholders
4) Quantify perspective(s) with model
5) Act upon surpluses or deficiencies

All outcomes / insights from session

Below, all insights derived from the design session are listed.

Insights derived from discussion on FEW perspectives

Through the prepared perspectives, interesting statements came to the surface regarding FEW systems. *“The Green Tower will be a public building, being in balance in terms of sustainability is not the primary goal of the building.”.* This indicates that the goal of the GT is not to become 100% sustainable regarding its FEW systems. The tower will showcase the potential a building like it, will have for creating more sustainable neighborhoods. Below, the main insights derived from the design session related to FEW are given.

Food | Nutrients
- Struvite has inconsistent quality, making it unfavorable in productive landscapes such as farms. Applying struvite as fertilizer in city parks is a possibility as they do not require stable growth patterns and thus stable fertilizers.

Food | Urban farm
- The vertical farm can only produce vegetables, and more specifically leafy greens. It would be valuable to match the production in volume to the demand in volume of the GT or Bajeskwartier (this is what the model already does, to a certain extent).

- The vertical farm also has a strong public character. For them, it is also a way to show what they do to the public and chefs. And for the public and chefs it is a place to interact with the VF's products. For now, it is right to assume 50% will be used for production and the other 50% for visitors.

- In the main building there will be a 1200 m2 fresh market.

Energy | Electricity
- The vertical farm company involved, claims to offer a system that is in balance. This would mean no additional electricity is needed. Their internal bio-digester should provide the farm from energy. *Validating this claim is of importance, seems unlikely.*

Energy | Thermal energy
- Many vertical farms claim they are in balance. However, this is based on the conversion of electricity to heat through lighting. Heat would need to be captured and reused.

- Due to high isolation standards, there is a heat surplus in the ATES already. If the GT is producing too much heat, it is not favorable.

Water | Sanitation
- There will be limited space assigned to sanitation in the building. View the GT as a public park, there are also limited sanitary options. Moreover, sanitation infrastructure in the building is expensive.

- Linking black wastewater stream to bio-digester is a 'no-go'. There is too big of a chance that detergents will end up in the bio-digester, influencing its performance and the quality of the effluent.

- If black wastewater is added to the bio-digester, it influences the composition of the effluent. If a small percentage of feces is added to the composition, it loses its status as organic fertilizer and becomes a waste stream, making it unmarketable.

- Struvite can be extracted from yellow wastewater. Extraction has a high energy demand. The scale of the GT is relatively small for struvite extraction

Water | Rainwater storage
- Rainwater can be used for both watering plants and flushing toilets.

- Bajeskwartier is obliged to have a storing capacity of 50L/m2 water on the terrain. Surface water cannot be used to store water.

- Reusing the old nuclear bunker in the design cluster as water storage is a viable option (30*6*3,5).

- Water will also be retained by wadis and water squares in the neighborhood*. Idea to display a water square in front of GT?*

Insights on how to operationalize the model
All participants were asked to give feedback on the quantitative model. In general, the feedback was very positive, and it was indicated that further development of the model could be beneficial to the GT and Bajeskwartier stakeholders. The model could be used as design tool, giving guidance for what users are allowed in the building, according to the sustainability goals set by the design team. Moreover, if the dashboard would be improved, it could function as a good communication tool. For instance, in the educative route or in the search for users that could help fix a certain deficiency or surplus. The feedback was mainly focused on setting clear assumptions, starting points and lower limits at the basis of the model. Moreover, the output of the model should be displayed more visually and should be easier to comprehend. Lastly the model mixes building specific flows and neighborhood flows, a clear distinction should be made. Below all insights are given.

Setting up the ecosystem:
- Assumptions should be clear to everyone interacting with the model. Have them clear and make them clear at the start of a session.

- Nowadays, there are many legislations on lower limits for the built environment. For instance, the BENG. Adding these lower limits to the front of the model, would enable you to see if certain choices can or cannot be applied on forehand. Visualize this for instance with a traffic light. This would make the design tool a tool that could actually help you design.

Expanding FEW system options:
- Add quality parameters for flows. Especially interesting for nutrient flows. *An effluent composed of nutrients is not necessarily a fertilizer.*

- Make sure there is a clear distinction between visitor capacity and visitor occupancy in the model (there is).

- Add drop down menus with various systems in every sub-tab (for instance multiple bio-digester systems)

- Optional: create feedback loops. Now you must change the floor size of a function to see how the balance changes, would be interesting to see if it is possible to change the balance and see how it influences the floor sizes. An easier solution would be to show which systems are influencing the disbalance the most.

- Optional: add information sheets of how to handle flows (possible solutions).

- Optional: link economic data. Costs of systems, costs of flows and potential revenues from effluents.

Getting the model spatiality right:
- The building is both a building and a piece of infrastructure. In the current model, some systems affect the building and some the neighborhood. A clear distinction should be made. The GT is a utility for the area, with a few building functions.

- Consider that if the tower has a heat surplus, it does not mean that the neighborhood ATES has a surplus as well. For the ATES, it is important to include the neighborhood in the equation.

- The model shows the supply and demand of the GT itself. It would be valuable to also map the demand of the neighborhood, and link this to the supply of the GT (and vice versa).

Visualizing the outcomes (improving dashboard):
- The 'slider bars', as used in the presentation, could be very well used for communication purposes. They could help in marketing surpluses or deficiencies and finding companies that can offer solutions.

- Make a hufter proof dashboard in Power BI. (This seems like a great option)

- The current dashboard is a bit overwhelming, make it even more visual and easier to interpret.

Using the model for storytelling:
- It is interesting to compare the production capacity of the vertical farm, to the amount of people it can feed expressed in vegetables. This way, one can show that expanding the vertical farm to for instance 4 floors of 100% production, a few housing blocks could be fed. Also link this with the amount of arable land it would save in the countryside. Telling this, is creating stories.

- For now, the GT's goal is not to achieve 100% balance for the neighborhood but showing how it can be reached. Being able to show how scaling up the current systems of the GT could influence the sustainability of the neighborhood, is what makes a model like this interesting.
The data from the model should be useful for developing the educative route. *Link to Young Urban Engineers?*

General remarks on usefulness model:
- The model should not be leading; we should still think ourselves. The model helps you create an assessment framework for making sustainable choices.

- The tool could very well be used to give guidance in the initiative phase of designing a building or neighborhood.

- The tool could be very useful in a later stage as well. When crystalizing the design, it could help decide which systems fit within the system. Once we have chosen a path, does the targeted party conform to the path?

- The model could be well used to see whether including or excluding certain systems influences the balance. This way it can be decided if certain options are essential, or additional. Followingly, it could be decided if the expense on a system could be cut. *Can we remove something, and stay in balance?*

- The model can be used to see which users can be allowed in the building and not. Based on how they influence the balance.

- The flexibility of the model was received positively, being very flexible. Systems can be changed in size or deleted by only adjusting the floor size.

- We want to offer innovative systems a chance in the GT. They do not have to be profitable. However, there should be a reason for us to implement the system. Apart from creating a supply of a resource, there should also be a demand.