Amsterdam University College

BSc Thesis Environmental Sciences

Plan Bee:
Designing the Ideal Bee Habitat in Urban Green Space

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Abstract

If we want to conserve a sufficient part of global biodiversity, we will need to integrate biodiversity conservation in the human environment rather than dedicating these efforts to nature reserves alone. Reconciliation ecology describes how human environments can be adapted to become attractive to a wider variety of non-human species. The divide between nature and humans is often the biggest in cities, because they have been subject of radical land use change. However, this is not a reason to exclude cities from applications of reconciliation ecology. The urban environment provides plenty of opportunities to create habitats for non-human species without inhibiting its use for humans. One of these examples is the construction of planted roofs. These structures have a number of economical as well as environmental benefits for humans, but they can also be a habitat for a variety of species. However, the ecological benefits of planted roofs are not always optimally utilized.

Therefore, this paper provides an example of how planted roofs can be adapted in such a way that they become more attractive for a wider variety of species. This is done by focusing on creating a roof that is especially attractive for a large number of bee species in the city of Amsterdam, the Netherlands. By creating a design for a roof with a species mix based on indigenous plant species, the roof is projected to be more attractive to local bee species than conventional *Sedum* planted roofs. Monitoring the bee visitation rates on the roof over the coming years will give a conclusive answer to this hypothesis.

Keywords: *wild bees, reconciliation ecology, urban ecosystems, planted roofs, indigenous plants*

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Chapter 1 – Reconciliation Ecology in Cities

1.1 Reconciling the city with nature

The combination of unprecedented human population growth and an increase in wealth of many individuals has resulted in a higher average as well as total use of resources by people (Grimm et al. 2015). These increases in consumption and production have brought about enormous changes in land use, which have large effects on different natural phenomena such as biogeochemical cycles and a decrease in global biodiversity (Grimm et al. 2015). To counter this decrease in biodiversity a plethora of biodiversity conservation efforts has been initiated. However, most of these efforts are currently concentrated in dedicated nature reserves and restored nature areas, which are often areas that have been less affected by land use change. Rosenzweig (2003a) argues that these dedicated areas are too small to guarantee the conservation of a sufficient part of biodiversity, especially with global human population projected to grow by another two billion between 2000 and 2030 (Alberti et al. 2003), which is likely to also result in an increase in human-induced land use change.

Consequently, Rosenzweig argues that we need to start integrating nature in human habitats rather than sustaining the current divide between nature and human-used space. This different approach to conservation ecology, called reconciliation ecology, can be defined as “the modification and diversification of anthropogenic habitats to support a greater range of species, without compromising the land use” (Francis & Lorimer 2011, 1429). Instead of setting aside land for other species or restoring land to its previous ecological state, reconciliation ecology works towards creating a new habitat within the existing human habitat to create a win-win situation for all species involved (Rosenzweig 2003b).

Reconciliation ecology is especially applicable to cities, where the divide between nature and humans is often the biggest, partially due to the large difference between the current and the previous land use (Claussnitzer 2014). Additionally, even though urban areas themselves only cover approximately 4% of the terrestrial surface, Goddard et al. (2010) show that the ecological footprints of cities are significantly bigger than their physical area, with 78% of global carbon dioxide emissions originating in cities and 60% of residential water use attributed to cities (Grimm et al. 2015). Yet, this disproportionally large ecological footprint and the fact that urban areas are one of the most intensely used and changed spaces by humans are no reasons to exclude cities from attempts to reconcile humans with nature. Instead, the urban environment provides opportunities to create new habitats for non-human species to compensate for the habitats that have been lost due to the impact of land-use change that has been caused by cities.

1.2 Assessing reconciliation ecology projects; novel ecosystems or habitat analogues?

Implementing projects that incorporate reconciliation ecology and assessing their effectiveness is still challenging for ecologists, because there is no baseline or previous situation that can be set as a threshold or goal for the newly created habitat (Alberti et al. 2003). Rather, ecologists have to assess the biodiversity situation in urban habitats and compare them to similar environments along and outside of the urban gradient to see how the different habitats are performing on the variables they are intending to compare. An example of such an approach is the Cape Town (South Africa) study of Anderson et al. (2014), which measured the ecological outcomes and biological impacts of civic-led interventions of planting indigenous plant species in different green space locations in the city. By comparing planted gardens with indigenous plant species to locations in the cities with no plants and locations outside of the city where those indigenous plants occurred naturally, the study made an estimation of how effective urban gardens were compared to their natural counterparts in terms of attracting more indigenous fauna. They concluded that civic-led gardening projects can reach a similar biodiversity to their natural counterparts outside of the city, as long as they are initiated by people, for these circumstances did not occur naturally without human intervention.

Another experiment, conducted in Leeds (United Kingdom) by Goddard et al. (2010), analysed whether urban gardens that had been retrofitted to include more indigenous plant species rather than exotic species and cultivars would attract a higher species variation of pollinators. The study showed that gardens with more indigenous plant species indeed accommodated a higher animal species diversity.

The difficulty that the studies by Goddard et al. (2010) and Anderson et al. (2014) show is that it is nearly impossible to compare the conditions of the habitat in a city environment to a theoretically similar habitat in a more natural environment. Both studies mention that one of the reasons that this is so difficult is that intensive human interventions and human maintenance are often needed to initiate and maintain the urban habitat projects.

One of the ways in which reconciliation projects can be assessed is within the framework of novel ecosystems. This concept was introduced by Hobbs et al. (2006), who define the category as follows: "… those types of ecosystems containing new combinations of species that arise through human action, environmental change, and the impacts of the deliberate and inadvertent introduction of species from other parts of the world" (Hobbs et al. 2006, 1). Their paper focuses on novel natural ecosystems, such as the San Francisco Bay Area in the United States, which have seen such a tremendous change in species composition due to human interference that the ecosystems now almost entirely consist of exotic species (Hobbs et al. 2006). However, the paper does not go into detail about the externalities of novel urban ecosystems other than that they create dispersal barriers for many species (Hobbs et al. 2006).

Lundholm and Richardson (2010), on the other hand, explicitly address how urban ecosystems can be assessed by ecologists. They argue that human activities can produce habitats that have natural analogues, such as pavements in cities resembling rock walls in mountainous areas. This can be seen as a positive externality of land use change, because humans are inadvertently creating habitats for species in human-used space. However, these habitat analogues also come with the risk of creating a small number of homogenous habitats, such as pavements and walls, and only cater to a small group of widely dispersed species (Grimm et al. 2008). To avoid this risk, the inadvertently created habitats should be adapted in such a way that the area becomes more attractive for a wider variety of indigenous species (Lundholm & Richardson 2010).

In short, it seems to be more effective to assess urban ecosystems as novel ecosystems, rather than comparing them to similar naturally occurring ecosystems outside of the city. The radically different circumstances in the urban environment as compared to more undisturbed nature make them more suitable for the term 'novel ecosystems' than for fitting the definition of a habitat analogue.

1.3 Urban ecosystems: from landscaping accident to reconciliation projects

The transition from inadvertently creating habitats for species to deliberately building structures for species to be used in the city is that it will often require investments. One way to make investing in such projects more attractive for stakeholders is to combine the benefit the structure will have to local biodiversity with an increase in energy efficiency for the structure. This paper provides an example of such a project. It uses research focused on the Netherlands to make and implement a design for a planted roof that has been structured in such a way that it can be an attractive habitat and food source for indigenous bee species of the Amsterdam area in the Netherlands. The market for planted roofs in the Netherlands is very much focused on roofs with *Sedum* plant species, which do not add to the biodiversity of the city environment. Therefore, this papers looks into incorporating more indigenous plant species on the roof to be able to assess how they will perform under the conditions of a planted roof in the future. The results can be used to show rooftop developers that there is a more varied selection of plants available to use on planted roofs, rather than just *Sedum* species.

Additionally, this paper focuses on the conservation of bees in cities for a number of reasons. Bees can be considered to be a flagship species for conservation biology, meaning they are relatively well-studied, compared to other insects, and they have a high potential of positive reception by the public (Claussnitzer 2014). This is mainly because of their important role in the pollination of plants, with which they provide an essential ecosystem service to humanity. Furthermore, their species diversity makes it into an interesting target group if one wants to increase biodiversity and overall species diversity in the city.

Additionally, the paper uses research on reconciliation ecology, urban bee conservation, and planted roofs, both of which will be discussed in the following chapters, to answer the question of how one can design the ideal bee habitat on planted roofs in the urban environment. This question will be partially answered by the research that has already been conducted in this field. Furthermore, the construction of a planted roof in the Science Park neighbourhood of the city of Amsterdam will provide the means to completely answer this research question. Although this assessment will take place in the future, as the plants on the roof grow and develop themselves, this paper provides an overview of the selection of plant species and which bee species are expected to visit the roof. Finally, an overview of theoretical expectations of the efficacy of the planted roof in addition to a list of future research possibilities are provided.

Chapter 2 - Bees in the City

During the past decades, the urban environment in many European and North-American cities has become a relatively safe and attractive habitat for many bee species, compared to other heavily human-influenced areas where bees might occur (Banaszak-Cibicka & Zmihorski 2012). Whereas pesticide use, which has a detrimental influence on bee health (Gallai et al. 2008), is often an omnipresent practice in rural areas, many local governments and municipalities have banned the use of pesticides in residential areas because of their proven health hazards to people (Potts et al. 2016). This decline in pesticide use in cities has been connected to an increase in bee species diversity in cities over the past decades by several studies (Lowenstein et al. 2015; Gunnarsson & Federsel 2014; McFrederick & LeBuhn 2006). However, despite this increase in species diversity, bee species diversity is still suboptimal in many cities (Fetridge et al. 2008). To make the urban environment more attractive for a larger number of bee species, it is important to include indigenous flower species in urban green space. The reason for this is that many plant species have a co-evolutionary history with their pollinators. Therefore, exotic flowers and cultivar species may be less attractive and accessible for indigenous bee species than their indigenous counterparts (Fukase & Simons 2015).

Bees can be distinguished into a group of specialists, which pollinate plants from a particular genus or sometimes even just a single species, and generalists, which pollinate a wider range of flowering species (Nieuwenhuis et al. 2015). Due to co-evolution, specialist bee species are often more effective in pollinating plants than the more generalist species. Generalists visit more different flower species, which results in the risk of pollen of one plant ending up in the flower of a different species (Tonietto et al. 2011). Therefore, it is important to conserve specialist bee species if one wants to conserve the plants they pollinate, and vice versa.

2.1 Honeybees in the city

There has been a recent trend towards researching as well as conserving generalist species, with a focus on *Apis mellifera*, or the western honeybee, in particular. Honeybees can be easily domesticated by humans (Kritsky 2017). Additionally, their eusociality in combination with honeybee colonies living in hives makes them highly efficient as a means to pollinate crops on farms, orchards, and plantations, producing honey as a side-product (Van Engelsdorp & Meixner 2010). All of these facets combined have made the honey industry flourish in many parts of the world over the past decades (More than Honey 2012).

However, this flourishing industry has recently been experiencing a decline in its efficiency due to a relatively high honeybee mortality, caused by Colony Collapse Disorder (CCD) (Van Engelsdorp et al. 2009). The resulting decline in honeybee populations all over the world has alarmed the agricultural industry and ecologists to such an extent that most research on bees is now conducted on honeybees rather than other bee species (Fortel et al. 2014). Additionally, the public popularity of the honeybee due to the widespread media coverage decline because of CCD has resulted in an increase in hobbyist beekeepers in urban environments (Dorrestijn 2016). This increase in honeybee popularity, in the scientific as well as in the societal realm, has created a disparity between the conservation efforts for honeybees and the conservation efforts for other bee species and specialist bee species in particular (Torné-Noguera et al. 2016).

2.2 Urban bee conservation

What is important to take into consideration when thinking about conservation methods for bee species is that when measures catered to specialist bee species are implemented, generalist species often automatically benefit from that as well, because their generalist nature lets them pollinate almost all flowers (Baldock et al. 2015). Therefore, it is probably more beneficial from a conservation biology perspective to focus urban reconciliation projects on the needs of solitary, specialist bees in order to benefit as many species as possible. However, this shared benefit only works for the pollination of flowers. Honeybees, bumble bees, and other generalist and specialist bee species have very different needs when it comes to nesting sites, so that component of creating a successful habitat calls for a more diversified approach. Whereas honeybees live in colonies and use cavities or beehives as living environments, wild bee species often live a more solitary life. Bumble bees live in small colonies during a part of their lifecycle, nesting in dark, dry cavities. However, these colonies rarely exceed 400 individuals, compared to a regular colony size of 40.000 for honeybees (Whitehorn et al.

2012). Solitary bee species make individual nests in different locations, such as holes in wood, hollow twigs, and sandy soils (Van Breugel 2014a). In urban environments, solitary bees adapt to the changed circumstances by digging holes for nests between pavement stones, and holes in wood that is available to them, such as the holes of door handles (Van Breugel 2014a).

In addition to a sufficient number of nesting locations for different bee species, bees should also have access to enough food sources to sustain themselves. Flower availability can sometimes be a problem in the urban environment, but there are many different ways in which the city can be made more attractive for bees in terms of nesting locations and food resources. One way in which a successful urban habitat for bees can be created is by adapting planted roofs in such a way that they become more suitable as nesting locations as well as food resources for a wider variety of bee species.

Chapter 3 – Planted Roofs

Planted roofs can be identified as roofs with plants in their upper layer (Berardi et al. 2014). They are often indicated as a mitigation measure for the environmental problems that occur in heavily urbanized areas (Oberndorfer et al. 2007). One of these problems is the lack of green space in urbanized areas (Berardi et al. 2014). The versatile purposes of planted roofs have also resulted in a wide variety of names for these roofs with plants on them, including green roofs, living roofs, eco-roofs, and roof gardens (Berardi et al. 2014).

3.1 Planted roofs as a city improvement

"As living roofs … essentially create habitat on land that is being directly used by humans as living space, they are a good example of the practice of reconciliation ecology" (Francis & Lorimer 2011, 1431).

Although Francis and Lorimer (2011) argue that the habitat values for non-human species of planted roofs are the main use of these structures, few planted roof engineers would agree with them. The construction rates of planted roofs in cities across the world is not increasing because they are an attractive habitat for non-human species, but because they have multiple other environmental benefits for their surroundings and the building itself. For example, they can store rainwater, decreasing the immediate storm water runoff from buildings, thus relieving stress on the city sewage system during heavy shower events (Berardi et al. 2013). But the main motivation of investors to construct planted roofs is the increased insulation that they provide to the building, resulting in a decrease in temperature variability in the building in addition to a lower energy usage (Berardi et al. 2013) and a decrease in the urban heat island effect (Coutts et al. 2013).

These advantages of planted roofs for the urban environment allow for reconciliation ecology purposes. Ecologists now use the popularity of planted roofs for their economic and environmental benefits to show investors how slight adaptations to the design of the roof can turn the planted roof into a habitat for indigenous species to add to the biodiversity of the city instead of solely adding to the urban green space area (Oberndorfer et al. 2007).

3.2 Varieties of planted roofs

Planted roofs may differ in two aspects, namely the purpose they are made for, and the type of soil they are made with. With respect to their purpose, planted roofs are categorized as intensive or extensive roofs. Intensive roofs often resemble conventional gardens, with a wide variety of high- and low-growing plants, and an emphasis on recreational uses of the roof. Furthermore, intensive roofs tend to have a rather thick substrate, or soil, layer of more than 200 mm to enable the growth of a wide variety of plant species (Francis & Lorimer 2011).

Extensive roofs, on the other hand, have a substrate layer that is usually less than 200 mm. This limits the number of plant species that can adapt to the circumstances on the roof. However, this thinner substrate layer makes it easier to retrofit them on existing roofs because they require a less strong support than intensive roofs. Extensive roofs are predominantly built for biodiversity purposes or to increase the environmental benefits of the building (Francis & Lorimer 2011).

The second aspect in which planted roofs may differ is in the composition of the substrate layer. *Green* roofs have a completely artificial substrate layer that has been carefully landscaped by people (Berardi et al. 2013). Green roofs are mainly constructed to increase the insulation of the building, decrease storm water runoff, and for recreational purposes. A different substrate composition can be found in *brown* roofs, which tend to have a more natural makeup than green roofs (Berardi et al. 2013). The definition of a brown roof originates from the definition of brownfields: “land that was previously developed for housing or industry but has been abandoned and recolonized by different ecological assemblages” (Lorimer 2008). Brown roofs often occur naturally after different kinds of construction debris are left behind on a building and the roof is eventually colonized by indigenous species (Ishimatsu & Ito 2013). Brown roofs therefore often include more native species than green roofs, which are predominantly created for aesthetical purposes, including more cultivar plant species that might not be indigenous to the local ecosystem (Ishimatso & Ito 2013). Because of their minimalistic implementation requirements, brown roofs could function as a very cheap and easily applicable alternative for extensive green roofs. However, this only works if the main goal of the roof is increasing biodiversity, because the other environmental functions that green roofs typically have are not characteristics of brown roofs, because they lack the green substrate layer that facilitates these functions.

3.3 Planted roofs as functional habitats

Even though planted roofs have a high potential as an urban habitat for a wide variety of species, they are most often seen as an engineering challenge rather than a potential ecosystem and urban habitat (Oberndorfer et al. 2007). However, thinking from the perspective of reconciliation ecology, we have to bridge the difference between a planted roof as an engineering challenge and a planted roof as a habitat by reconciling their makeup in such a way that they become beneficial for all stakeholders. What do we want to see in a planted roof if we want it to add to the species diversity of bees in a city?

'Habitat' can be defined as "a place where an organism or biological population normally lives or occurs" (Biology-Online 2017). This means that some species, especially the ones that have low dispersal rates, have to be able to complete their entire lifecycle on the roof for them to be able to call it their habitat. For bees this entails that they should be able to find food, shelter, and a nesting location on the roof or in the close proximity of the roof, depending on the flight range of the species (Van Breugel 2014a).

Many bee species that nest in soil need it to be slightly permeable and not too humid, conditions that can often be found in sandy soils (Colla et al. 2009). Therefore, it is important that the substrate of a planted roof is permeable. Coincidentally a permeable and light substrate is also beneficial for the roof from an engineering perspective, because it will limit the weight of the roof as opposed to using a denser substrate, and permeable substrates also tend to be more useful as insulators (Berardi et al. 2014). Additionally, the depth of the substrate of the roof is also an important factor, as some bees dig their nest tunnels deeper than others (Van Breugel 2014a). Therefore, the roof might not be able to accommodate to the nesting requirements of all local bee species. However, this can be compensated by creating appropriate nesting facilities in the proximity of the roof.

Providing a food supply for bees heavily depends on the species one aims to cater for. Most bee species have an annual lifecycle in which adults gather pollen and nectar for a couple of weeks or months at most (Van Breugel 2014a), which makes it essential that the species have food available during that period. Thus, it is important that a planted roof has a mix of plants with different flowering periods in order to have a variety of flowering plants available for different bee species during the entire growing season. This could entail plant species that cater to specialist bees and therefore provide them with all the food they need, but having different flowering plants available during the entire growing season is also beneficial for generalist species with varying flying periods. Including indigenous plant species in the plant mix for the roof will partially fulfil this requirement for a habitat, because indigenous specialist bee species have co-evolved with indigenous plant species, resulting in flowering periods that are parallel to bee lifecycles (Corbet et al. 2001).

However, not all plants that survive well on planted roofs are attractive to bees. One example of a group of such plants is the *Sedum* genus. This is currently the predominant genus used in extensive planted roofs. *Sedum* species are succulents, allowing them to withstand droughts. This characteristic in combination with their cheap and widespread availability make them a very good fit for planted roofs (Dunnett et al. 2008). However, *Sedum* species are not always the best option if one wants to resemble vegetation based on indigenous plants and animals. Additionally, *Sedum* species have a relatively short flowering period (Bijenplanten 2017), which makes the genus less attractive for providing food for bee species during the entire growing season (Nieuwenhuis et al. 2015).

On the other hand, not all plants that are attractive for indigenous bee species will be able to adapt to the conditions of planted roofs. In a study of the performance of xerophytes, plants adapted to dry climates, and wetland plant species on extensive planted roofs, MacIvor et al. (2010) concluded that planting local wetland plant species combined with *Sedum* species on an extensive planted roof decreases the environmental performance of the roof. However, using these local plant species significantly increased the species variety of the invertebrates visiting and living on the roof. These are all important parameters to take into consideration during the design process of a planted roof.

Chapter 4 – The Science Park Project

4.1 Amsterdam; a biodiversity hotspot for bees?

The city of Amsterdam has seen a 45% increase in species diversity of wild bees between 2000 and 2015, with 45 observed species in 2000 and 64 species in 2015, when Nieuwenhuis et al. (2015) conducted their extensive bee counting observations in different locations in all neighbourhoods of Amsterdam. In a similar study, Fortel et al. (2014) compared the bee species diversity and abundance along the urbanisation gradient of Lyon, France. This study concluded that a high number of wild bee species is a good indicator for having a larger biodiversity in plant, bird, and other insect species. Furthermore, it concluded that the highest species diversity could be found in areas where there was a 1:1 ratio between impermeable surfaces, such as pavements and asphalt, and permeable surfaces, such as gardens and grass fields. Similar results could be found in the Amsterdam study of Nieuwenhuis et al., for the neighbourhoods with more green space had a higher species diversity of bees, whereas the neighbourhoods with a higher ratio of impermeable surfaces, and therefore fewer plants, experienced a relatively low bee species diversity (Fortel et al. 2014).

4.2 The Green Agenda of Amsterdam

The Amsterdam municipality used the results of the study by Nieuwenhuis et al. to assess the tentative effectiveness of their Green Agenda for the years 2015-2018 (Van der Veur & Wijten 2013). The main goal of this agenda is to improve the quality of current urban green spaces. Improving quality of green spaces rather than quantity is important in Amsterdam because the municipality has chosen to let the city grown within its existing borders, rather than expand the city into the surrounding regions. Therefore, the number of parks and gardens in the city is not likely to significantly increase. Van der Veur & Wijten define the improvement of the quality of urban green space as increasing the number of indigenous plant species used, having green space available within walking distance for all citizens, and have the green space be sustainable for intensive recreational use.

The agenda divides the city into four areas along the urbanisation gradient: the centre, the ring around the centre, the city lobes and the city wedges (see sections L and S in figure 1). The centre (Zone C) and the ring (Zone R) are most intensely urbanised, with a high percentage of impermeable surfaces. The city lobes are more recently built neighbourhoods such as the Bijlmer and Nieuw-West. The city wedges are areas where the surrounding green environment enters the city, such as the area surrounding the Amstel river. City wedges have a relatively high percentage of green space, because they have not been developed as intensely as the centre and the ring zones. Each zone requires a different approach towards the management of green space (Van der Veur & Wijten 2013). Whereas the management of the zones C and R will focus more on increasing the number of small patches of plants, with a focus on indigenous plant species, the zones L and S will predominantly see projects to increase the bicycle connectivity with other parts of the city as well as an increase in recreational facilities for residents.

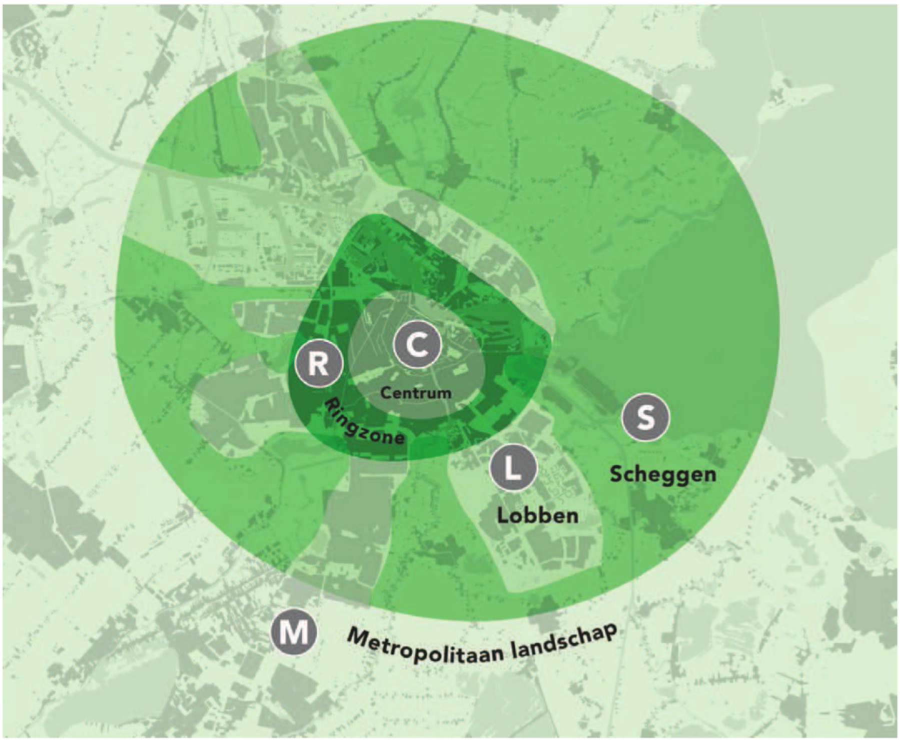


Figure 1. *The five different 'zones of focus' in Amsterdam as indicated by the Amsterdam Green Agenda.*

4.3 Planted roofs in Amsterdam

One of the main goals of the Amsterdam Green Agenda is to increase the area of planted roofs by 50.000 m^2 between 2015 and 2018. This is to be added to the 150.000 m^2 of existing planted roofs in the city. The main benefits of these roofs the municipality expects are a decrease in the urban heat island effect and an immediate take-up of storm water after heavy rainfall (Van der Veur & Wijten 2013). However, if we put these benefits in a reconciliation ecology perspective we should also be able to increase the urban biodiversity by including indigenous plant species in the plant mix on the planted roofs that are to be installed, especially because using indigenous plant species is also a goal of the Green Agenda.

Another municipal regulation that supports the use of a larger variety of plant species on planted roofs is the 'Bomenverordening', or 'tree regulation'. This regulation entails that the number of trees in the city of Amsterdam cannot decrease, so that if one wants to cut a tree, it has to be replanted somewhere in the city (Gemeente Amsterdam 2016). However, the city already counts 400,000 trees (Gemeente Amsterdam 2017a) and with the current density of most parts of the city, it is difficult to replant trees, which is why the municipality is currently looking into replacing cut-down trees with other forms of urban green, such as planted roofs or green walls (Meershoek 2017). Currently, implementing planted roofs is very popular in Amsterdam, especially because their construction is supported and encouraged by the municipality in a variety of ways. Therefore, it is important to raise awareness about the potential benefits planted roofs can have on biodiversity in addition to their other positive environmental effects. This will enable more people to adapt the roofs they are going to build to the requirements that are needed for a planted roof with a potential for a high biodiversity.

4.4 Amsterdam Science Park; a green desert with a lot of potential

One of these city lobes in Amsterdam is the Science Park neighbourhood, a 700.000 m2 area with accommodations for business, science, and housing (Amsterdam Science Park 2017). Many parts of the neighbourhood are currently under development, which is why there still is a large area of undeveloped space. These undeveloped spaces predominantly consist of lawns. The current management of the green space is focusing on a very modern and angular-looking form of urban green space, paying little attention to biodiversity (Personal Observations 2014-2017). If the Science Park area would be maintained in a different, more ecological-focused way, it is likely that the area could cater to a higher biodiversity. Furthermore, the presence of the natural sciences faculty of the University of Amsterdam at the Science Park means that there is a large number of academics who have access to the knowledge to make Science Park a more attractive habitat for a higher number of species. The lack of ecological management and the availability of knowledge make the Science Park neighbourhood a suitable location to implement reconciliation ecology measures, especially to create a more attractive habitat for bee species. There are plenty of potential locations that can be adapted to be more attractive for pollinators; this project only focuses on one location, the so-called Startup village.

4.5 The Startup Village

The Startup Village is an ‘entrepreneurial incubator’ located at Science Park (Startup Village 2017). The organization wants its buildings to be as sustainable as possible, and wants to make an effort to make the buildings and their immediate surroundings a more attractive habitat for a variety of species as well. Their buildings consist of modified sea containers that have been turned into office spaces and one recently constructed co-working space, which is made of wood. Sustainability reasons as well as biodiversity concerns have motivated the developers of the Startup Village to implement planted roofs on some of the sea containers and on the roof of the co-working space. These planted roofs are to be an addition to local habitat provision for pollinator species as well as an insulation layer for the buildings.

4.6 Materials and Methods

4.6.1 Making an inventory of local bee species

To create a roof habitat that caters to local bee species, an overview of local bee species was made. This was done by combining existing research and personal observations from the Science Park neighbourhood. Firstly, the bee map of Amsterdam, created by using the information collected by Nieuwenhuis et al. (2015), was used to make a list of occurring bee species in the Science Park neighbourhood (Gemeente Amsterdam 2017b). However, considering that this list only lists two bee species for Science Park, the bee species occurring in the nearby Flevopark were also added.

Secondly, personal observations were done in the Science Park area to contribute to the list of bee species. These personal observations entailed going out in the field with my supervisor, who could help with species determination. Additionally, a collection of insects collected at the Science Park by students and faculty members from the University of Amsterdam was used as a resource. The inventory of bee species found in the Science Park neighbourhood, a combination of the literature observations and personal observations, can be found in Table 1. In addition to the species names, the flight periods and whether the species is a generalist or specialist species are also indicated (Peeters et al. 2012).

***Table 1.** Overview of occurring bee species in the Science Park and Flevopark areas.*

Bee species Name	Flight Period	Gen. / Spec.	Source
Science Park			
Nomada flavoguttata	March - July	G	Nieuwenhuis et al. (2015)
Andrena flavipes	March - August	G	Nieuwenhuis et al. (2015)
Bombus terrestris	February - September	G	Personal observations (09-05-2017)
Bombus lapidarius	May - September	G	Personal observations (09-05-2017)
Andrena spec.			Personal observations (09-05-2017)
Bombus cf. pascuorum	March - August	G	Insect collection observations (15-07-2015)
Apis mellifera	March - October	G	Insect collection observations (15-07-2015)
Nomada spec.			Insect collection observations (15-07-2015)
Flevopark			
Osmia caerulescens	April - June	G	Nieuwenhuis et al. (2015)
Nomada fuscicornis	June - August	G	Nieuwenhuis et al. (2015)
Andrena minutula	March - July	G	Nieuwenhuis et al. (2015)
Lasioglossum sexstrigatum	April - August	G	Nieuwenhuis et al. (2015)
Lasioglossum calceatum	April - September	G	Nieuwenhuis et al. (2015)
Hylaeus communis	May - September	G	Nieuwenhuis et al. (2015)
Anthophora plumipes	March - May	G	Nieuwenhuis et al. (2015)
Andrena haemorrhoa	March- May	G	Nieuwenhuis et al. (2015)
Osmia bicornis	March - June	G	Nieuwenhuis et al. (2015)
Nomada goodeniana	April - May	G	Nieuwenhuis et al. (2015)
Hylaeus hyalinatus	May - August	G	Nieuwenhuis et al. (2015)
Andrena bicolor	March - July	G	Nieuwenhuis et al. (2015)
Andrena barbilabris	April - June	G	Nieuwenhuis et al. (2015)
Macropis europaea	June - August	S	Nieuwenhuis et al. (2015)

4.6.2 Choosing suitable plants for the planted roof

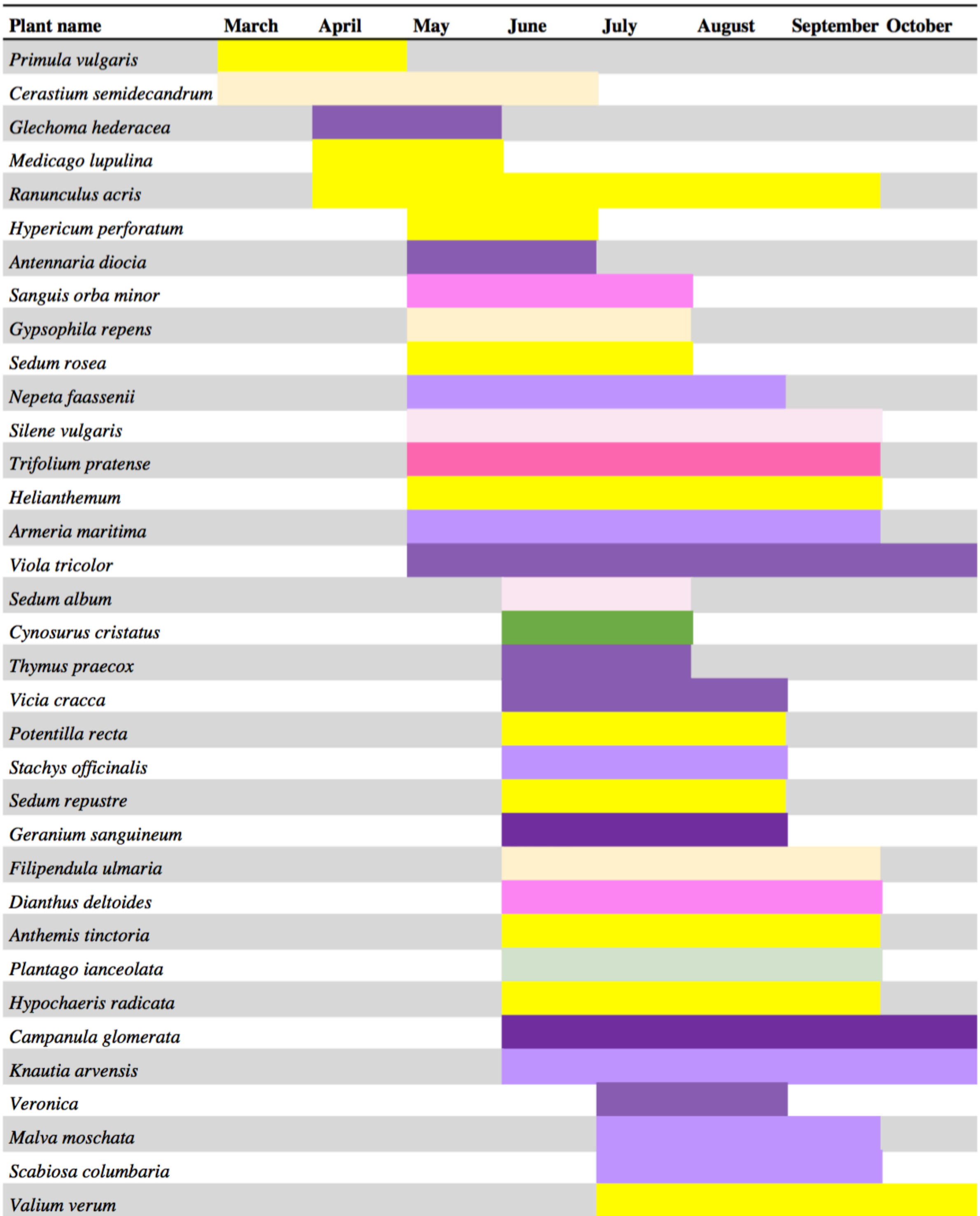
The bee species indicated in Table 1 were used as the foundation of the plant species composition of the planted roof. Most bee species in Table 1 are generalists, which made the selection of specific plants for specialist bee species less of an important factor. However, the varying flight periods of the different bee species was an important factor to take into consideration. Therefore, the selection of plant species is predominantly based on their flowering periods, to make sure that there would be a flowering plant available during the flight period of each bee species.

However, it is important to take into consideration that not all plant species thrive on planted roofs. One has to select species that can adapt to the harsh circumstances of a planted roof. These circumstances entail more wind, longer dry periods, a higher Sun exposure, and a shallower soil layer than non-roof habitats (Grant 2006). Therefore, plants that grow under dry circumstances in a nutrient-poor substrate usually work best on planted roofs. Taking both the preferences of the listed bee species and the adaptability to the circumstances on planted roofs into account, a list of plants was compiled. A variety of sources was used to select the plant species. These sources included the list of wild bees and their preferred plants by Koster (2016), and websites with extensive information such as 'bijenplanten.nl', 'wildebijen.nl', and 'soortenbank.nl'. Bijenplanten.nl maintains an overview of plant species that are attractive for Dutch bee species, including information about their flowering periods, soil preferences, and size. Wildebijen.nl consists of a list of solitary bee species that can be found in the Netherlands, with information about their flight periods, size, and preferred plants. Soortenbank.nl is a very extensive collection of plant species from all over the world, with information about their flowering periods, colour, size, and soil preferences.

Additionally, the website of 'Wildflower Turf', a British company providing ready-made substrate mats for planted roofs in the United Kingdom, was used as a source for wildflower plant species that would grow well on roof substrates (Wildflower Turf 2017). The list of wildflowers they used in their roof turf was checked with Wikipedia to see if all species were also native to the Netherlands, to secure the indigenousness of all plants.

In the end, the plants were selected on their adaptability to the abiotic circumstances on the roof, their flowering periods, their growing height, flower colour, and which bee species would pollinate them. This selection can be found in Table 2, in which the plants are sorted by their respective flowering periods.

Table 2. *An overview of the plant species used on the roof of the Startup Village, with their flowering periods and their flower colours, which is indicated with the colour of the cell.*



4.7 Implementation

For the design of the layout of the planted roof, plant species with different flowering periods and different flower colours were planted next to each other. This way, different parts of the roof will always have at least one plant species flowering during the different months of the growing season.

Figure 2 shows the layout of the co-working space of the Startup Village. Each side of the tilted roof has an area of 69,09 m^2, with a width of 12,45 m and a length of 5,55 m. However, for practical purposes in the design of the roof, an area of 72 m^2 per roof was used to be able to divide the roof into practical squares of 1 m^2.

Figure 2. *The layout of the co-working space of the Startup Village (Source: Geldersche Houtbouw 2017)*

With the area of 72 m^2 per side of the roof, each side was subdivided into 72 clusters of 1 m^2. Each cluster would be planted in such a way that it would contain one plant species. An average of nine plants per m^2 were planted. Some species that have been proven successful on planted roofs were planted in between the clusters to create some continuity between the clusters and to let the roof look more natural. Plants that were known to grow fast, or grow more in width rather than height, were planted in clusters of seven plants per square meter. Slow growing plants, on the other hand, were planted in a higher density of nine plants per square meter. Figure 3 contains the design of the plant distribution for one side of the roof, which was used for both sides of the roof.

Viola tricolor	*Knautia arvensis*	*Medicago lupulina*	*Cerastium semidecandrum*	*Ranunculus acris*	*Dianthus deltoides*	*Sanguisobra minor*	*Sedum repustre*	*Sedum album*	*Gypsophila repens*	*Gypsophila repens*	*Rhodiola rosea*
Cerastium semidecandrum	*Helianthemum*	*Trifolium pratense*	*Scabiosa columbaria*	*Vicia cracca*	*Festuca ovina*	*Veronica*	*Glechoma hederacea*	*Viola tricolor*	*Hypochaeris radicata*	*Medicago lupulina*	*Thymus praecox*
Knautia arvensis	*Armeria maritima*	*Campanula glomerata*	*Thymus praecox*	*Armeria maritima*	*Plantago ianceolata*	*Nepeta faasenii*	*Potentilla recta*	*Geranium sanguineum*	*Primula vulgaris*	*Antennaria diocia*	*Sedum album*
Geranium sanguineum	*Primula vulgaris*	*Antennaria diocia*	*Sedum album*	*Hypericum perforatum*	*Silene vulgaris*	*Filipendula ulmaria*	*Festuca rubra*	*Knautia arvensis*	*Armeria maritima*	*Campanula glomerata*	*Thymus praecox*
Viola tricolor	*Hypochaeris radicata*	*Medicago lupulina*	*Thymus praecox*	*Stachys officinalis*	*Vicia cracca*	*Anthemis trinctoria*	*Galium verum*	*Cerastium semidecandrum*	*Helianthemum*	*Trifolium pratense*	*Scabiosa columbaria*
Sedum album	*Gypsophila repens*	*Gypsophila repens*	*Rhodiola rosea*	*Ranunculus acris*	*Malva moschata*	*Cynosorus cristatus*	*Sedum repustre*	*Viola tricolor*	*Knautia arvensis*	*Medicago lupulina*	*Cerastium semidecandrum*

Figure 3. *The plant distribution for one side the planted roof of the co-working space of the Startup Village.*

This plant mix, which consists of indigenous plants from the Netherlands with different flowering periods, has not been used on a planted roof before. Therefore, it might be very interesting to monitor the development of the plants on the roof over the years. If this roof were to perform well in the Netherlands, this plant mix will be a good alternative to the conventional *Sedum* roofs.

However, the novelty of this plant mix also means that the current planted roof industry, or market, is not very familiar yet with constructing roofs with a plant mix of indigenous plants rather than *Sedum* species. This was one of the reasons why the construction of the planted roof of the co-working space can turn out to be twice as expensive as covering the same roof area with *Sedum* mats. The cost of the roof could double in expenses compared to a *Sedum* roof if the Startup Village decides to place an irrigation system on the roof if the conditions turn out to be too harsh for the plants. The average price of a *Sedum* roof is €80,- per square meter (Ishimatsu & Ito 2013), whereas the planted roof of the co-working space cost €154,- per square meter (Van Maanen 2017).

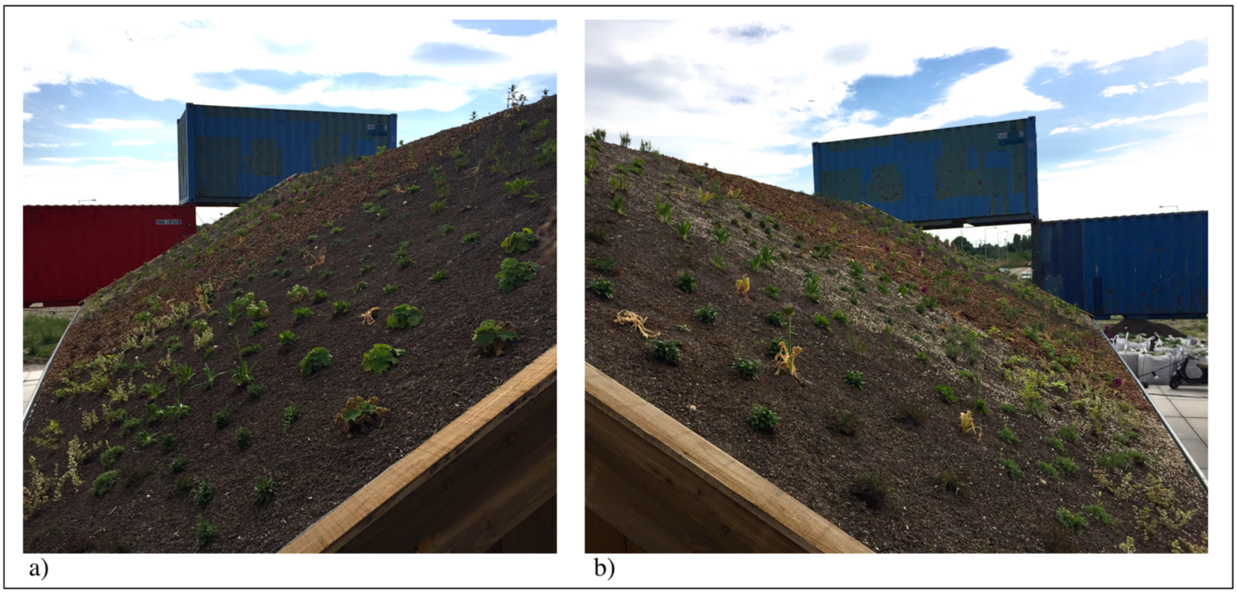


Figure 4. *Pictures of each side of the planted roof one month after planting. The southern side is pictured in figure 4a whereas the northern side is pictured in figure 4b.*

4.8 Additional pollinator facilities at the Startup Village

One of the requirements for a planted roof to be a successful habitat for bees, alongside providing enough floral resources, is providing shelter and nesting facilities near the roof. Solitary bees have a foraging range between 150 and 600 meters (Gathmann & Tscharntke 2002), and the foraging range increases with body size (Greenleaf et al. 2007). Therefore, it is important to have nesting facilities for solitary bees in the Startup Village itself, as this is currently surrounded by open fields that do not necessarily provide preferable nesting locations.

Open fields can provide nesting locations for some bee species nesting in sand, for the open fields around the Startup Village have a soil with a high sand content. However, it is more difficult for other bee species that prefer nesting in dead wood or reed to find a nesting location. To solve this lack of shelter, so-called pollinator hotels were built into large flower pots located around the Startup Village. These pollinator hotels were built following the recommendations and guidelines of Van Breugel (2014b). In addition to providing nesting locations for bee species, these pollinator hotels also raise awareness for solitary bee species, as their otherwise barely visible nesting locations are now visible for people.

4.9 Assessing the efficacy of the Startup Village as a bee habitat

Due to the short-term scope of the capstone project, which is four months, the results of the efficacy of the Startup Village as a bee habitat cannot be incorporated in this paper. The efficacy of the Startup Village as a bee habitat can only be assessed after the planted roof has experienced an entire bee season. Taking into consideration that the roof was planted mid-April, this would mean that continuous bee observations for each month between April 2017 and April 2018 would allow us to make an inventory of the bee species that can be found on the roof year-round. Fortunately, the Science Park Project will continue over the coming three to five years, so the development of the Startup Village as a bee habitat will be studied in the future.

Nonetheless, criteria to assess the project in the near future can be written in advance. The first three chapters of this thesis describe the different factors that come into play when one wants to make the urban environment a more attractive habitat for humans, plants, and animals, with bees in particular. However, section 1.2 explains the difficulties that can occur when assessing a reconciliation ecology project, for there is no natural habitat that can be used as a baseline for the research. Therefore, this paper uses the bee species inventory for the city of Amsterdam that was created by Nieuwenhuis et al. in 2015. Sixteen bee species were observed in the public park adjacent to the Science Park and about 1000 meters away from the Startup Village (Google Maps 2017). This is quite a large distance for most solitary bee species, but the flowerbeds that are located between the park and the Startup Village will make it more likely for the bee species to disperse to a new location.

Thus, the attractiveness of the Startup Village as a bee habitat can be proven if the Startup Village would have a similar bee species diversity as the Flevopark. However, the plants on the planted roofs and in the flower pots need time to grow and flower, and the bee species themselves need time to find the newly created habitat. Several academics stress the importance of the development of a planted roof as an ecosystem over the years, and how there currently is a lack of long-term planted roof assessments for most roofs have only been installed recently (Dunnett et al.

2008; Bates et al. 2013). To conclude, continuous observations have to be done at the Startup Village to assess the colonization by bee species of the area over the coming year.

Chapter 5 – Limitations and future research

5.1 Limitations

Several limitations were identified during the research, the writing, and the implementation of this project-based paper. This section will succinctly describe them and section 5.2 will propose how they can be overcome in the future during continuing research.

The first limitation that returns in almost every aspect of the Science Park Project is time. Section 1.2 already identified the difficulties of assessing projects that incorporate reconciliation ecology. Since my project needed completion in less than half a year, it was not possible to include results of how successful the Startup Village will be as a bee habitat. However, section 4.9 includes a estimation of how successful the bee habitat can be, based on literature and personal observations.

Additionally, the accessibility of the roof of the co-working space will make future observations of bee species on the roof more difficult. The steepness of the roof and its height make it hard for people to do close-up observations of bees visiting plants on the roof. These close-up observations are often needed to be able to determine a species. Fortunately, the continuous development of the Startup Village as a bee habitat will provide us with easier ways to determine which bee species use it as a habitat. In addition to the planted roofs, flower beds will be planted around the offices of the Startup Village and 40 large flower pots with bee-friendly plants and built-in pollinator hotels will be placed on the premises as well. Bees visiting the planted roofs are likely to also visit the flower beds and flower pots, allowing for an easier species determination.

Furthermore, the Startup Village will construct planted roofs with the same plant species mix on the roofs of the container offices. These roofs are more easily accessible than the roof of the co-working space, which will make the species determination of bees and the observation of plants easier.

Finally, it is challenging to make this setup of a planted roof, in which each plant is manually planted in the substrate, financially competitive with the conventional *Sedum* roofs in the Netherlands. I want to stress the importance of the Netherlands in the previous sentence, for the market for planted roofs in this country is predominantly built around having *Sedum* roofs as extensive green roofs. However, in other countries, such as the United Kingdom with companies such as Wildflower Turf and Norway, using other plant mixes for planted roofs occurs more regularly (Bakhtina 2016). Constructing extensive roofs with more than just *Sedum* species seems to already be a regular practice in other countries. Therefore, it should also be possible for the planted roof industry in the Netherlands to adapt to using a wider variety of plant species in their plant mixes. Even more so because the two countries with successful diverse planted roof industries have a very similar plant makeup and climate to the Netherlands, showing that there is a plethora of learning opportunities there.

5.2 Directions for future research

The Science Park Project as has been described in this paper is part of a larger project, carried out by Amsterdam Green Campus, which includes educational research on urban sustainability and urban green space in Amsterdam. Therefore, this section discusses how the Science Park Project could be continued in the future within the frame of the 'Systems Approach to Urban Green' project of Amsterdam Green Campus (Van Maanen 2017).

Firstly, as has been mentioned in section 4.8, the plants on the planted roof will develop, grow, and attract a changing variety of species over the years. The plant mix that is used on the planted roof of the Startup Village has not been used on a roof before, which makes it interesting to study how the different plants will perform and develop over the years. This will enable one to confirm or oppose the theory-based expectations that were stated in this paper. One could research how the plant species composition will change over the years.

Secondly, the plants of the co-working space roof were planted in three different substrates. Even though the substrate did not play a significant role in the research of this paper, future research can include an assessment of how the different plant species perform in the different substrates. It could be possible that plant competition is different in the different substrates, for instance.

Additionally, the planted roofs will probably have to be irrigated over summer as they include a number of plant species that need more water than the conventional *Sedum* roof species do. The necessary water quantities and how this influences the growth process of the planted roof as a whole can be observed and the results can prove to be a useful resource to take into consideration when using the same plant mix on other roof locations.

Thirdly, one can research how using a bee-friendly plant mix for a planted roof can be made more economically competitive with *Sedum* roofs by analyzing how bee-friendly plant species can be included in pre-fabricated plant mats that can be rolled out over roofs to cut back on the costs, similar to the work that is currently being done by Wildflower Turf in the UK (Wildflower Turf 2017).

Fourthly, it is especially important to monitor which bee species will end up visiting the roof. One could study how the species variety of bees visiting the roof changes over the years, for instance. It might be interesting to see whether the Startup Village will attract different bee species than Flevopark and Science Park themselves. Additionally, one could monitor whether the bee species on the planted roof are just visiting the Startup Village for pollination purposes, or whether they also nest in the pollinator hotels and the sandy soils around the Startup Village. If the roof of the Startup Village were to attract a variety of bee species similar to that of Flevopark and Science Park, it could be used as an argument to use the plant-mix proposed in this paper on other locations in the city.

Finally, it is important to reach out to a wider audience about the improved ecological values of the roofs of the Startup Village by choosing plant species that are especially attractive for bees. Most people will not be able to notice the difference that the current plant mix can make on an ecological level. Therefore, expanding the available educational resources by organizing excursions with reading material and visual posters with information about the plant species and local bee species can aid the environmental sciences education of students on all levels of education. Additionally, the entrepreneurial purpose of the Startup Village lends itself for businesspeople to be inspired by the sustainability of their working environment to include it in their own projects as well.

Chapter 6 – Conclusion

This paper and its corresponding implemented project aim to create the ideal bee habitat in urban green space. The design of the planted roof, the first step towards an effective bee habitat in this project, was underpinned with the theories behind reconciliation ecology, research on planted roofs in an ecological context, and bees in an urban environment. Additionally, the design and implementation process of the roof was explained to enable others to take a similar approach towards adapting their planted roofs to the needs of bees.

The theoretical effectiveness of the planted roof of the Startup Village is supported by the arguments provided in the first three chapters of this paper. However, the practical efficacy of the bee roof remains to be proven in the future, once bees start to find their way to the Startup Village and the plants firmly root themselves into the substrate.

Nevertheless, this does not mean that the research question of this paper: "How does one design the ideal habitat in urban green space?" remains unanswered. Rosenzweig (2003a) describes reconciliation ecology as a form of 'win-win ecology', in which humans and non-human species benefit from the outcomes of a project. With the construction of the planted roof at the Startup Village the insulation and storm water catchment abilities of the roof have increased, which is beneficial for humans. Additionally, the use of indigenous plant species has significantly increased the food supply for bee species in the area of the Startup Village, for the surface used to be an empty sand plain. Therefore, we can conclude that both parties, humans and bees, have definitely won. The question that is to be answered over the course of the development of the roof as an ecosystem, though, is exactly how many bee species will be part of this win-win situation.

However, because of the fact that we are talking about a win-win situation, regardless the end results of this project, there is no reason to delay using this design or similar designs in other locations to increase the potential of planted roofs as habitats for bees across the city of Amsterdam.

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Appendix 1 – Overview of rooftop plant species

Scientific Name	Flowering Period	Growing Soil	Flower Colour	Height (cm)	# Clusters
Glechoma hederacea	April-May	Humid to dry, very versatile	Purple	15-60	2
Sedum rupestre	June-August	Sandy soil	Yellow	<35	2
Sedum album	June-July	Dry, nutrient-poor, stony and sandy soils	White-Red	<15	8
Potentilla recta	June-August	Dry, moderately nutrient-rich, open, sunny	Yellow	30-70	2
Anthemis tinctoria	June-September	Dry, open, nutrient-poor to moderately nutrient-rich	Yellow	30-60	2
Thymus praecox	June-July	Dry, nutrient-poor, very versatile	Purple	5-10	8
Cerastium semidecandrum	March-June	Sandy, nutrient-poor	White	10-20	8
Geranium sanguineum	June-August	Sandy, dune areas	Purple	10-50	4
Campanula persicifolia	June-August	Nutrient-rich	Purple	10	
Antennaria dioica	May-June	Sandy, stony	Purple-Pink	15	4
Armeria maritima	May-September	Stony, nutrient-poor	Light Pink	5-50	6
Dianthus deltoides	June-September	Dry, moderately nutrient-rich	Purple	20-40	2
Gypsophila repens	June-September	Dry, versatile, calcium-rich	White	10-20	8
Sedum rosea (Rhodiola rosea)	May-August	Dry, versatile	Yellow	20-30	4
Veronica	July-August	Sunny slopes, dry	Purple	20-50	2
Nepeta faassenii	May-August	Drought resistant, very versatile	Purple-Blue	30-60	2
Helianthemum	May-September	Dry	Yellow	10-40	4
Silene vulgaris	May-September	Drought resistant, dry	Grey	30-60	2
Primula vulgaris	March-April	Nutrient-rich, moist	Yellow	10	4
Galium verum	July-October	Average, dry to medium moisture	Yellow	15-100	2
Filipendula ulmaria	June-September	Dry to medium moisture, sunny	White	60-200	2
Hypericum perforatum	May-June	Medium moisture, sunny	Yellow	20-85	2
Plantago ianceolata	June-September	Very versatile	White	50	2
Vicia cracca	June-August	Humid, nutrient-rich	Purple	<200	4
Trifolium pratense	May-September	Humid, nutrient-rich	Red	15-50	4
Medicago lupulina	April-September	Dry to moist, sunny	Yellow	5-50	8
Viola tricolor	May-October	Dry, moderately nutrient-rich, sandy	Purple	30	8
Stachys officinalis	June-August	Moderatly humid, calcium-rich	Pink	30-90	2
Hypochaeris radicata	June-September	Dry to humid, nutrient-rich, open	Yellow	20-60	4
Knautia arvensis	June-October	Humid, calcium-rich, sandy	Pink	15-60	8

Ranunculus acris	April-September	Humid, nutrient-rich, sandy	Yellow	<100	4
Malva moschata	July-September	Humid, nutrient-rich	Pink	30-70	2
Sanguisorba minor	May-July		Pink	60	2
Campanula glomerata	June-October	Humid, calcium-rich, sandy	Purple	30-60	4
Scabiosa columbaria	July-September	Moderately humid, calcium-rich	Purple	30-90	4
Cynosorus cristatus	June-July	Humid, moderately nutrient-rich	-	20-60	2
Festuca ovina	May-June	Acidic, stony	-	15-70	2
Festuca rubra	May	Dry to humid, versatile	-	50	2