Thesis Report Msc. Industrial Ecology

Extending bee habitat in urban area

- *How green roofs can foster bee populations in the Netherlands*

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Samenvatting

Dit onderzoek draagt bij aan de oplossing van het vergroten van gezonde bijen populaties in Nederland. Het onderzoek is gericht op wilde bijen en gedomesticeerde honingbijen in stedelijk gebied. Het biedt richtlijnen voor het aanleggen van groene daken en groene gevels op verschillende schaalniveaus en voor de relatie tussen deze schaalniveaus. Deze levels zijn een individueel dak of individuele gevel (micro-schaalniveau) en een collectie daken/gevels verspreid over een stad (macro-schaalniveau). Belangrijke onderzochte factoren op micro-schaalniveau zijn het constructiesysteem, voor groene daken in het specifiek de substraatlaag en de drainagelaag, fysieke eigenschappen, klimatologische omstandigheden, het type vegetatie en daarbij het beheer van de vegetatie, aanvullende voorwerpen op het dak/aan de gevel en de mate van luchtvervuiling van omringende lucht. Op het macro-schaalniveau is de aanwezigheid van bestaande voedselbronnen en nestplaatsen op maaiveldniveau, bestaande groene gevels en groene daken en de afstand tussen deze belangrijk.

Geconcludeerd kan worden dat de twee essentiële factoren voor het creëren van habitat voor bijen zijn voedselvoorziening en nestgelegenheid. De drainagelaag en de substraatlaag bepalen het microklimaat van een groen dak en daardoor de geschiktheid voor drachtplanten om hier te groeien. Het microklimaat in de substraatlaag is ook direct van belang voor de geschiktheid voor bijen om in deze laag te nestelen. Een andere belangrijke factor om rekening mee te houden is de wind. Een bijenhabitat op een groen dak of aan een gevel moet beschermd zijn tegen harde wind. Bij harde wind is het ongunstig voor bijen om uit te vliegen omdat dit dan veel energie kost. Een windluwe habitat kan gecreëerd worden door bijvoorbeeld het planten van vegetatie. Bovendien zijn nestplaatsen het meest geschikt op warme zonnige plekjes. Luchtvervuiling is van invloed op het foerageergedrag van bijen en daarom moeten habitats in de ideale situatie op enkele tientallen meters van drukke verkeerswegen af gecreëerd worden.

Op het macro-schaalniveau is het belangrijk om habitat 'stapstenen' te creëren. Deze stapstenen moeten voedselbronnen en nestgelegenheid bieden. In steden kunnen de stapstenen aanwezig zijn op maaiveldniveau of ze kunnen gecreëerd worden op groene daken/aan groene gevels. De minimale foerageerafstand van bijen voorkomend in stedelijk gebied is 100 meter, dit is dus de minimale afstand tussen de stapstenen.

De uitkomst van het onderzoek is samengevat in twee checklijsten waarin alle belangrijke parameters staan. Om het gebruik van de checklijsten te illustreren en om de functionaliteit van de lijsten te testen zijn case studies uitgevoerd op een groen dak op de Vrije Universiteit Amsterdam en in de omliggende woonwijk de Zuideramstel. In deze case studies zijn de

huidige stapstenen in kaart gebracht en is er een advies uitgebracht is over waar en hoe de huidige stapstenen aangevuld kunnen worden.

Executive summary

This research contributes to the solution for enhancing healthy bee populations in the Netherlands. The research covers habitat creation for both wild bees and domesticated honey bees in urban areas. It provides guidelines for the construction of green roofs and façades on different levels of scale and on the relation between these scales. These levels of scale are a single roof or façade (micro-scale) and a collection of green roofs and façades distributed over a city (macro-scale). Important researched parameters on a micro-scale are the construction system, for green roofs in particular the substrate layer and drainage systems, physical properties, the climatic properties, the type of vegetation and its management, additional objects on the roof and the level of air pollution of environmental air. Concerning the macro-scale the presence of existing food sources and nesting spaces, existing green façades and green roofs and the distance between these is important.

It can be concluded that the two essential factors for creation of bee habitat is food provision by pollen and nectar supplying plants and the availability of nesting spaces. The drainage layer and the substrate layer of a green roof determine the microclimate and therefore the suitability for bee attractive plants to grow. The micro-climate also determines the suitability for ground nesting bees to nest in the substrate. Another environmental factor important to consider is the wind force. Bee habitat on a green roof or façade should be protected from strong winds. It is too energy intensive for bees to fly out in cases of strong winds. Protected habitats can be created by for example planting vegetation. Additionally, nesting spaces are ideally created on warm and sunny places. Air pollution negatively affects forage behaviour of bees and therefore nesting spaces should be created a few dozens of meters away from heavy traffic roads.

On the city scale it is important to create habitat 'stepping stones'. These habitat stepping stones should contain food provision and nesting spaces for bees. In cities, these stepping stones can be available on ground level or have to be created on green roofs or green façades. The minimum forage distance of bees present in urban areas is 100 meters, so this is the maximum distance in between these stepping stones.

The outcome of the research is summarized in two checklists including all the important parameters on both levels of scale. To illustrate the use of the checklist and to test the functionality of the checklist case studies are carried out on a green roof on the VU Amsterdam and in the surrounding district the Zuideramstel. In these case studies the current stepping stones are mapped and the and an advice is provided on where and how the current stepping stoned can be complemented.

Preface

This research is the final project of my master of science studies Industrial Ecology at TU Delft and Leiden University. The project has gained me a lot of new knowledge and insights, but overall a lot of joy and excitement also. However, I would not have been able to finish this project without the help of some people, therefore I would like to thank them. At first I want to thank my supervisors Arjan van Timmeren and Marc Ottelé for guiding me through the research process, always with a lot of enthusiasm. Secondly, I want to thank the experts Arie Koster and Pieter van Dugteren for sharing me their knowledge about bees and beekeeping. Thirdly, I want to thank founder of the company 'Solar Sedum' Matthijs Bourdrez for his interest in my research, helping me with a brainstorm and for sharing me his network. Fourthly, I want to thank the Stadsdeel Amsterdam-Zuid and Ellen Koningen, project manager Campus Development of the VU University for providing me relevant information for my research and for showing interest in my results. Finally, I want to thank my family and friends for their interest in my research, for their good questions and critical remarks, but overall for their unlimited support!

Marloes Gout,

January 2014

Contents

Table of figures

Cover page: Municipality of Rotterdam via www.degroenestad.nl (and own adjustments), 2008

Table of tables

Glossary

1) *Bumblebees* – bumblebees are a remarkable group of wild bee species. They are bigger and hairier than other wild bee species and they fly out more frequently. They make a low humming noise while flying (Koster, A., Adviesgroep Vegetatiebeheer, 2013,wildebijen.nl, 2013).
2) *Cuckoo bees* – cuckoo bees live solitary, but they invade nests of other bees. They do not collect their own pollen and nectar, but obtain it from the host species (Peeters, Raemakers & Smit, 1999; Westrich 1996).
3) *Extensive green roof* – *'or vegetation roof usually consists of moss, sedum, succulents and herbs. This type of roof does not require much maintenance.* This roof, often limited accessible for people (only for maintenance purposes), has usually a lower carrying capacity than intensive green roofs (Groendak.info, 2013).
4) *District council; or 'Stadsdeel'*– the latter is a Dutch word to describe both a governed area as well as the institution itself which forms the legal governing the area. This area is a part of a city, the district council or Stadsdeel is part of a city municipality (Van Dale, 2013).
5) *Foraging* – Collecting food (Soortenbank.nl, 2013).
6) *Green façade*- is used to describe any type of façade with vegetation attached to it
7) *Green Roof* – *'The term 'green roof' describes both intensive, ornamental roof gardens and extensive, roofs with more naturalistic plantings or self-established vegetation, p. 66* (Kadas, 2006).*'*
8) *Honey bees* – The honey bee is the most well-known bee species (Koster, A., Adviesgroep Vegetatiebeheer, 2013,wildebijen.nl, 2013). The species is almost extinct in the Netherlands, but bee-keepers held in total circa 63.000 colonies in 2009 (van der Sluijs, 2011, referring to NCB, 2011). Usually when people talk about bees they mean honey bees.
9) *Intensive green roof* – *'also called roof gardens. They are comparable to normal gardens, in regards to view, use and maintenance. The vegetation exists of grasses, herbs, bushes and sometimes even trees* (Groendak.info, 2013). This type of green roof, often accessible for people, requires a high carrying capacity of the building structure below the roof (Groendak.info, 2013).
10) *Monophagous* – Bee species which only forage on one particular plant species (Koster, 2000).

11) *Pollination* – pollination is the transfer of pollen from an anther to the stigma of a flower (Praktijkonderzoek plant & Omgeving Wageningen UR, 2004). Bees are important pollinators.

12) *Polyphagous* – Bees which fly out on multiple plant species (Koster, 2000).

13) *Social bee* – social bees show more social interaction than solitary bees. At the most basic form of social behaviour multiple bees live in the same nest. The most complex social behaviour can be found among honey bees and bumblebees (Peeters, Raemakers & Smit, 1999).

14) *Solitary bees* – The female of this species makes her own nest, obtains supply for the breed cell and lays one egg per cell (Peeters, Raemakers & Smit, 1999).

15) *Stepping stone* – bee habitat, in terms of food sources and nesting spaces, on ground level and on roofs and façades. The stepping stones should create a bee habitat network on the city scale.

16) *Urban area* – a city or town and their surroundings consisting of suburbs. The urban area has a high density of human structures (National Geographic, 2013).

17) *Urban bees* – bees which often occur in urban area. A complete list is shown in appendix 0.

18) *Urban green* – Unless described differently it refers to green roofs and green façades

19) *Wild bees* – The Netherlands counts next to the domesticated honey bees approximately 350 wild bee species (van der Sluijs, 2011; (Koster, A., Adviesgroep Vegetatiebeheer, 2013,wildebijen.nl, 2013). Examples of wild bee species are Sand bees (*Andrena)*, Bumblebees *(Bombus)* and Mason bees (*Osmia)*.

1 Introduction

Globally the honey bee population has been steeply going down in the last 10 years (van der Sluijs, 2011). Especially in the Netherlands the bee population is decreasing. A survey carried out by in 2008-2009 by the scientific network COLOSS shows that most European countries (Austria, Switzerland, Germany, Poland, Denmark, Norway and Sweden) had colony losses of up to 15 percent in the same year. Among these countries Norway and Denmark had experienced the lowest losses with 7.1 percent and 7.5 percent respectively. The Netherlands and Ireland were found to be the countries with the highest losses; both 21.7 percent. They were followed by Belgium, 18 percent, and the United Kingdom, 16 percent. In the year 2009-2010 the losses were even higher and in this year in the Netherlands measured the highest decrease. The country lost almost one third of its honey bee colonies: 29.3 percent, followed by Belgium with a 26 percent drop (OPERA, 2013). Figure 1 shows an overview of the winter bee colonies' losses in Europe in the year 2009-2010.

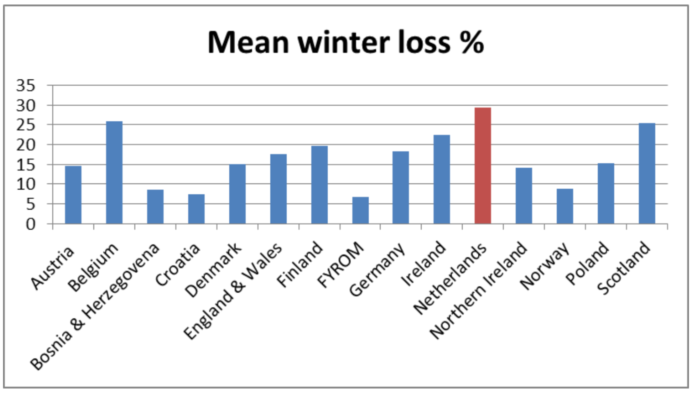


Figure 1 Overview winter bee colonies' losses year 2009-2010, Source: Opera, 2013

For wild bees, amongst other bumblebees, this trend of decline in population exists for a longer period. In the Netherlands more than 50% of the circa 350 bee species present is on the so called 'Red List', which means they are under the threat of extinction or have disappeared (van der Sluijs, 2011).

This decline of bee populations is influencing ecosystems since bees represents an important functional group within an ecosystem (Steffan-dewenter and Leschke, 2002 referring to LaSalle and Gauld, 1993 and Tscharntke et al., 1998). Conserving biodiversity within ecosystems is important for several reasons. The diversity of genes, species and ecological processes is essential for the provision of ecosystem services. Ecosystem services are services provided by ecosystems, these services range from the supply of clean water to wood supply and agricultural crop production. The major ecosystem service bees provide is pollination (Fischer et al., 2006 referring to Daily, 1999). Different bee species pollinate plant species, which means they secure the survival of various plant species. Therefore securing diversity of bees leads to more resilience of the ecosystem (Fischer et al., 2006 referring to Walker, 1995).

The decline of bees brings far-reaching consequences for humans. Bees pollinate plants from which we derive our food. Pollination can also be done by wind, but the major share of plants is pollinated by animals. About 80 percent of all existing plants depend on pollination by the estimated 20.000 different bee species. Our agricultural crops heavily depend on pollination by animals, especially on the pollination by domesticated honey bees and bumblebees. They account for 80 to 90 percent of the biotic pollination. The other 10 to 20 percent is carried out by wild pollinators (van der Sluijs, 2011). About 90 types of agricultural crops depend on biotic pollination; this comprises approximately one-third of the global food provision. These crops among others are fruits like apples, cherries, mangos, peaches, lemons and oranges and vegetables and nuts like eggplants, aubergines, cucumber, tomatoes, almonds and cashew nuts. Coffee, cacao and cotton plantations also heavily depend on the pollination by honey bees and bumblebees. Moreover crops grown for animal feed, for example the crop alfalfa also depend on pollination done by bees (Rabobank, 2011).

Because of the importance of pollinators, more and more attention is drawn to the extinction of bee populations. In 2008, the European Parliament adopted a resolution to perform research on the reasons of the decline of bee populations (Blitterswijk et al., 2009). The exact reason for the bee population losses is difficult to determine. It can be concluded from many studies that the explanation lies in a combination of factors (Reemers & Peeters, 2003; Blacquière, 2009; OPERA, 2013;). These are often summarized under the name of the Colony Collapse Disorder (CCD) (van Engelsdorp et al, 2009). These reasons include the deterioration of nature, a decrease of biodiversity of plants and therefore a lack of food and nesting possibilities. Also the homogenization and the up scaling of agriculture have led to a unilateral supply of nectar and pollen, a supply, which is also not equally distributed over the forage season of bees. Another reason causing honey bee distinction is the rise of the varroa-mite and the accompanied diseases. Furthermore the increased use of toxic pesticides negatively affects the bees by weakening their immune system (van der Sluijs, 2011; Blacquière, 2009).

Our human population is still growing, leading to urban space expansion, which often comes at the expenses of green area. The financial crisis had put a hold on large-scale construction projects and fostered the development of innovative business models addressing low budget building transformation and sustainable area development. This provides many opportunities for the creation of new green urban areas. Urban agriculture is one of the options for the development of these areas.

Big cities like Amsterdam and Rotterdam prove this point: a number of think tanks and projects are already initiated and are being implemented in different parts of the cities. Examples of such projects are 'De Dakakker' (eng. = *agricultural field roof*, Rotterdam), 'Uit Je Eigen Stad' (*eng.= From Your Own City*, Rotterdam), 'Farming the City' (Amsterdam) and 'Food Village' in Amsterdam-North. These projects are attractive and successful due to a number of reasons. Firstly, there is increased awareness of climate change and the need for food security (Creative City Lab, 2013; Farming the city 2013; Dakakkers.nl, 2013). Secondly, health problems among consumers related to unhealthy food consumption urges the adoption of more healthy life-styles, of which a change of diet is a key one. Thirdly, people suffer from more food intolerances and allergies in which the negative role of E-numbers is under question E-numbers (Creative City Lab, 2013). Fourthly, urban agriculture projects can also serve as a tool to stimulate social cohesion among citizens (Farming the city; 2013). And finally, people are more and more alienated from food production. Urban agriculture can play a significant role in addressing some of these problems. It is a way to educate people, to reconnect them with the entire food production chain (Dakakkers.nl, 2013).

The biggest uncovered surfaces in cities are rooftops and that offers a great potential for urban agriculture development. New York is an example of a city where many related projects have already been implemented. The Brooklyn Grange, a rooftop farm business in Long Island is one of them. A few projects also exist in the Netherlands. De Dakakker in Rotterdam and Zuidpark in Amsterdam represents the most successful examples.

Figure 2 Brooklyn Grange, urban agriculture on a rooftop in Long Island City, New York City. Source: cityfarmer.info, 2013

Figure 3 De Dakker, Source: ivn.nl, 2013

Figure 4 Zuidpark Amsterdam, Source: amsterdamology.com, 2013

The presence of bees plays an essential role in the success of urban farms. Without bees plants cannot be pollinated and will thus not produce vegetables, fruits or nuts. But bees are not only important for food production in cities. Most of the wild plants also need pollination, about 80% of the species (Blacquière, 2009). This pollination is mainly done by

wild bees, only a small share of these plants (around 15%) is pollinated by honey bees. Wild bees are thus very important for our diversity of plants.
In general natural area is the most appropriate environment for bees' habitat (v. Dugteren, 2012), however urban area is also an appropriate environment, since it has a beneficial microclimate and contains a broad diversity of plants with different supply of pollen and nectar throughout the flight season (Blaqcuière, 2009; v. Dugteren, 2013). The worst environment for bees is agricultural area, because of unilateral supply and high concentration of pesticides.
Thus, the focus of this research is to determine how the large unused surface areas in cities, the roofs and façades of buildings, can be used to extend and improve the urban environment for bee habitat.

1.1 Background

Studies performed in Basel and in London have proven that green roofs can provide new habitats for rare and endangered animal species affected by land-use changes (Brenneisen, 2006; Kadas, 2006). Wild bees are one of these species which make use of the replaced habitat on buildings (Kadas, 2006). However, which roof properties determine whether a species establishes is not yet precisely known (Brenneisen, 2005). In 2005 Brenneisen conducted a research on the effect of different types of green roof substrates, vegetation and structural diversity in relation to the potential for bees to establish on the roof. The research was carried out in two different locations in Switzerland; Basel and Luzern. The investigation showed that a green roof with substrates from the region was about as suitable for habitat creation of wild bees as natural areas on ground level. They found that the variety of substrate levels in combination with diverse vegetation had more visits from bees, probably because these roofs had a longer flowering season, so more food provision for bees (Brenneisen, 2005).
In 1999 Koster examined the effect of urban green management on honey bees and wild bees in urban areas in the Netherlands. The scope of the project comprised all kinds of public green spaces, for example green along bicycle lanes, graveyards and streets, but green roofs were not included. Based on this study was concluded that ecological green management was the key factor for bees to establish. When green areas were ecologically managed and when they provided nectar and pollen during the forage season, bees were found in the areas (Koster, 1999).
This research builds further on these existing studies. It examines how green roofs(facades) can foster healthy bee populations in cities. Although for economic reasons we mainly need bees to pollinate our crops on agricultural land, with the upcoming trend of urban agriculture the need for bees in cities enhances. Also, the floral diversity of our public and

private green is mostly secured by pollination by wild bee species, therefore conserving the diversity of bees is essential. Besides, when honey bee and bumblebee populations are growing in cities they will probably also spread over the agricultural field outside the city.

This research is written from the perspective of Industrial Ecology which aims '*to move towards integrated ecological-industrial systems that eliminate waste products and maximize energy capture over the entire life cycle of materials, p.831 (Oberndorfer et al. 2007 referring to Korhonen, 2005)'* Green roofs can contribute to this goal by creating solutions for multiple environmental problems. Green roofs for example can be applied to reduce storm water run-off in cities, but they can at the same time enhance biodiversity in cities. This research focuses on increasing biodiversity with as main focus bees, but at the same time other environmental problems like air pollution will be reduced. Therefore green roofs can be seen as a tool to apply the concept of Industrial Ecology to practise.

The current study will explore more parameters than covered in the studies by Kadas, Koster and Brenneisen. These additional parameters are for example climatic properties as sun, wind and rain. Also air pollution and the presence of additional measures is explored. All this information is combined and processed and based on this recommendations are provided on how green roofs should be designed both on the level of the individual roof and how they should be spread over the city.

1.2 Problem statement and scope

Bees are keystone species in ecosystems and therefore conservation of them is of crucial importance. They provide a key ecosystem service, pollination, and are thus of major importance for our food provision. Nowadays bee populations are globally in decline, particularly in the Netherlands. Green roofs have proven to offer suitable habitat for bee populations, which increases the chances for populations flourish. Therefore this research aims to provide practical information like which properties and parameters of green roofs are important for healthy bee populations' growth in the Netherlands. Since vertical green spaces (green walls and green façades) are very similar to green roofs, important environmental parameters for creating a bee habitat by constructing green facades is also discussed in this research. However, the technical details about green façades are not studied in detail, because the main focus is on the development of green roofs. In the research both honey bees and wild bees are considered. Koster examinded which wild bees are currently mainly present in urban area. This list is used as a basis for studying the parameters that are important for creating a bee habitat. However this research provides general guidelines for green roof development in urban area, which would benefit all types of bees, including those species which are not present in urban areas yet. The research provides practical information for both policymakers and citizens with ownership of roof areas on how to transform their roofs into green roofs.

1.3 Research questions

The problem statement results in the following research question and sub-questions:

Research question:

> *How can green roofs (façades) in the Dutch built environment increase healthy bee populations, which measures on different scales can be taken and how are they interrelated?*

Sub-questions:

1) *What factors are crucial for bee populations to flourish?*
2) *What are the current problems in the Netherlands that cause bee populations to decline?*
3) *Which bees are present in Dutch urban areas?*
4) *How can green roofs (façades) be constructed and which green roof properties are important for bees?*
5) *What are important parameters for bee habitat creation on green roof (façade) on an individual level, on a micro-scale?*
6) *How should the green roofs (facades) be allocated over the city, in order to create a bee habitat on a macro-scale?*

Figure 5 Thesis structure gives an overview of the questions linked to the method used in the research and it stresses which chapter discusses which topic.

2 Method

The thesis research consists of three different sub-methods: literature research, interviews and the development of case studies.

2.1 Literature research

Literature research is conducted to find out what research has already been done concerning green roofs in relation to the bee population in the Netherlands. Moreover, an analysis of bees in the Netherlands and an analysis of common green roof systems is carried out. The outcome of the literature research forms a basis for the rest of the research. There is also a small section covered on vertical green spaces, since this is also an important upcoming trend in urban green. The main focus is however on green roofs.

2.2 Interviews

Interviews with experts are used to achieve information not found in the literature. The interviews are held with beekeepers and researchers.

2.3 Development of parameters and case studies

Based on the literature research and the interviews parameters are developed for green roofs on different levels of scale; (1) on a micro-scale: individual green roofs and (2) green roofs on the macro-scale: the structure of green roofs spread over the city. These parameters will be summarized into two checklists, which provide a quick overview of the most important information for guidelines of green roof construction.

The first checklist provides an overview of parameters on the scale of an individual roof. Parameters are for example the kind and the spread of vegetation, the orientation of the roof, etc. This checklist is mainly valuable for house owners and companies who are considering building a green roof. They can design the green roof according to the guidelines given by the checklist. This checklist can also be used for testing existing green roofs on their current suitability for bees to establish on this roof and to determine how it can be improved by doing adjustments.

The second checklist provides parameters for multiple green roofs on a city scale. These parameters are for example the presence of current green roofs, the distance between roofs and the presence of vegetation, both on ground level and on rooftops. This checklist is especially valuable for municipalities aiming to stimulate the application of green roofs in the city. The different purposes for how the checklists can be used can be divided into four categories; see also Table 1.

To test and illustrate the functionality and use of the checklists two case studies are developed. The first case study is a case study on an existing green roof, so the methods steps of category I are applied. The case study is done on a 800 m^2 big roof garden in Amsterdam on the main building of the VU University.

The second case study is carried out on a city scale, where no or not many green roofs are present yet. This case study is thus carried out in category IV. To see how the parameters on the micro-level and the macro-level are connected the area surrounding the VU green roof is analysed, the district 'Zuideramstel' in Amsterdam. In this case study is examined how an ideal roof landscape for bees would look like on a city scale.

Case studies / **Aim of research**	**Building scale** **Individual roof**	**City scale:** **Collection of roofs**
Test performance existing roofs (façades)	Category I: Test performance existing individual green roof	Category II: Test performance existing collection of roofs
Guidelines for applying green roofs (façades)	Category III: Guidelines for applying individual roof	Category IV: Guidelines for applying collections of roofs

Table 1 Different function of the created checklists and guidelines for different scales

2.4 Thesis structure

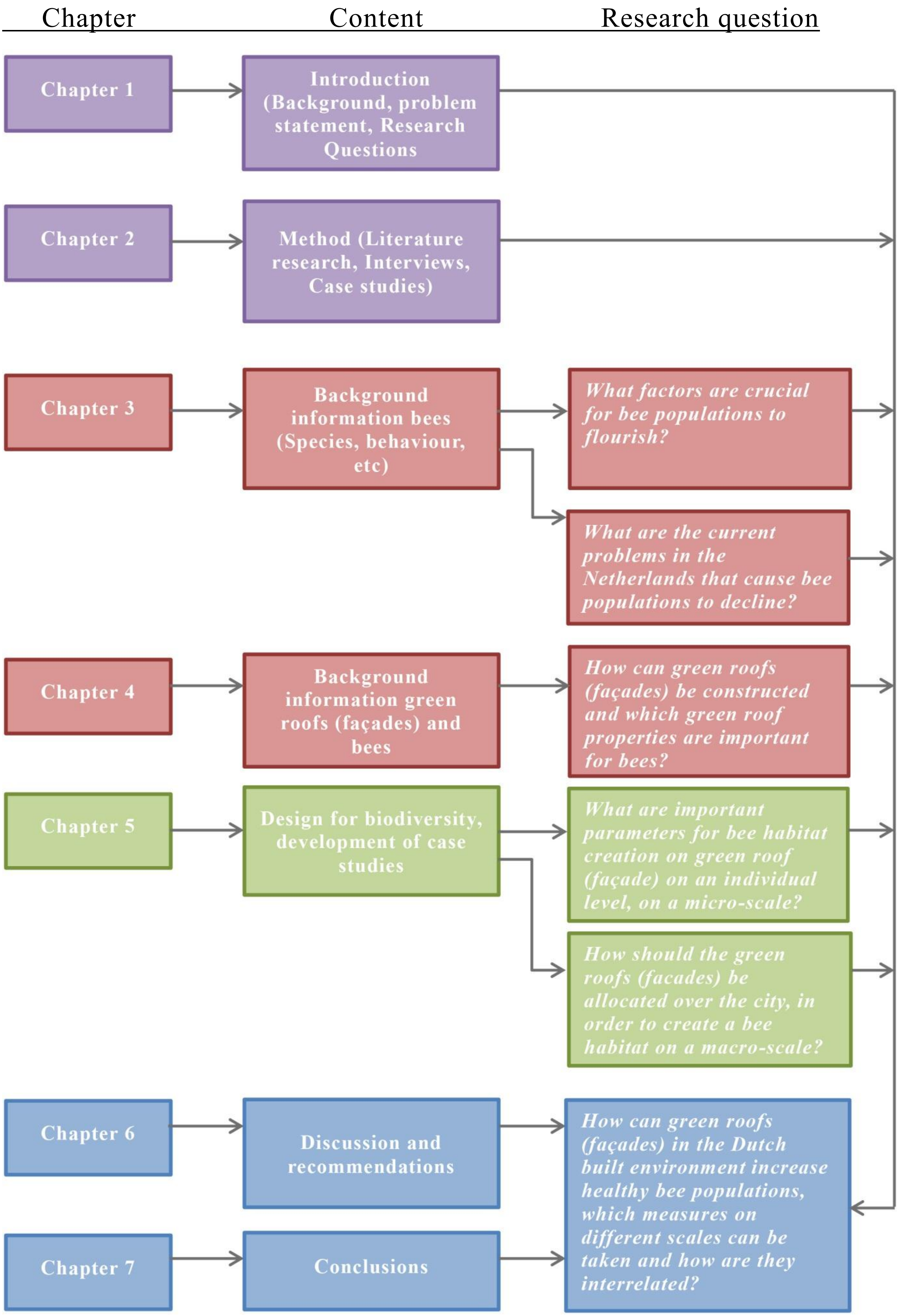


Figure 5 Thesis structure

3 The bee

This chapter examines the bee and its natural environment. At first the different species present in the Netherlands are explored, then the chapter states the behaviour and function of a bee in an ecosystem. Furthermore the food sources are explored and at last the threats why bee populations are declining are stressed.

3.1 Species

Worldwide there exist around 20.000 bee species (*Apoidea*) and circa 350 of them inhabit the Netherlands (van der Sluijs, 2011; Peeters & Reemer, 2003). The different species can be grouped on bases of their social organization and their behaviour. The three resulting categories are solitary bees, social bees and cuckoo bees (Peeters, Raemakers & Smit, 1999). Most bees living in the Netherlands are solitary bees. The female of this species makes her own nest, obtains supply for the breed cell and lays one egg per cell (Peeters, Raemakers & Smit, 1999).

Category	**Characteristic**	**Example**	**Picture**
Solitary bees	Female makes her own nest, obtains supply for the breed cell and lays one egg per cell	Red mason bee *(Osmia leaiana)*	 Source: wildebijen.nl, 2013
Social bees	Hierarchy among individuals in population	Honey bee *(Apis mellifera)*	 Source: Fieggentrio, 2012
Cuckoo bees	Invade nests of other bees	Red cuckoo bumblebee (*Bombus rupestris)*	 Source: wildebijen.nl, 2013

Table 2 Different categories of bees

The second category of bees is the social bee, this bee shows more social interaction than a solitary bee. In 1999 the Netherlands counted 40 of these species. The most basic form of social behaviour is when multiple females live in the same nest. Still every female makes her own breed cell. In a more advanced social behaviour one of the female bees is more dominant then the others. She steers the other females and she lays most of the eggs. The most complex social construction can be found among bumblebees and honey bees. Here only one female, the queen, is fertile and the rest of the females, the workers, take care of food provision and building and maintaining the nest (Peeters, Raemakers & Smit, 1999). The honey bee is almost extinct in the wild in the Netherlands, but in the year 2009 there were about 7000 beekeepers who held circa 63.000 honeybee colonies (van der Sluijs, 2011, referring to NCB, 2011).

The last category of bees is the cuckoo bee. This bee also lives solitary, but she invades nests of other bees. The cuckoo bee kills the young larva of the host and then lays her own eggs in there. Most cuckoo bees only invade one or a few species of one genus. Cuckoo bees and cuckoo bumblebees do not collect their own pollen and nectar, this is done by the host species (Peeters, Raemakers & Smit, 1999; Westrich 1996). In the Netherlands there are 94* different cuckoo bee species of which 7* are cuckoo bumblebees (Peeters, Raemakers & Smit, 1999). All bees except for honey bees are also called wild bees. Bumblebees are often mentioned as a separate group, but they are also a group of wild bees (Koster, 2000).

This research focuses mainly on solitary and on social bees. Since cuckoo bees invade nests of these bees and do not collect nectar and pollen themselves, it is assumed that when favourable conditions are created for these first two groups also favourable conditions for the cuckoo bee are created.

3.2 Behavior and functioning in an ecosystem

Many plant species would not exist if they were not pollinated. Pollination is the transfer of pollen from an anther to the stigma of a flower (Praktijkonderzoek plant & Omgeving Wageningen UR, 2004). This is done by abiotic factors like wind and water or by biotic factors, by insects like butterflies, hoverflies, moths but also hummingbirds and some bat species. Within the group of insects the bee is the most important pollinator (van der Sluijs, 2011). Bees are important functional groups of an ecosystem, because they indicate floral diversity (Steffan-dewenter and Leschke, 2002 referring to LaSalle and Gauld, 1993 and Tscharntke et al., 1998). Besides pollination bees transfer genes of different plants and in this way secure genetic variation which forms the basis for healthy plant populations (Koster, 2000).

Globally the bee pollinates approximately 80% of our most important crops (Gill, 2012; Blaqcuière, 2009). The Netherlands mainly cultivates vegetables and fruits and has a big seeds breeding industry. These sectors heavily depend on the pollination function of bees. Honey bees are the most important pollinators of these crops. The monetary value of the pollination done by the honey bees is around 1 billion euros per year. For other pollinators like bumblebees and solitary bees (mostly the mason bee) this is around 187 million per year. Also wild plant species depend heavily on pollination by insects. 80% of the Dutch wild plant species is pollinated by insects, of which 15% is done by honey bees (Blacquière, 2009).

Bees collect pollen and nectar to feed themselves. Proteins, fats and vitamins present in pollen are needed for growth and carbohydrates derived from nectar are their energy source. Honey bees carry the nectar in their honey stomach and then store it in the honeycombs, where they process it to honey by dehydrating it and by adding enzymes. The honey is consumed when there is little food available or when it is too cold to collect food (van Blitterswijk et al., 2009).

Also pollen are an important food source for bees. The continuity of pollen supply largely determines the vitality of the bee colony. On a yearly basis a honey bee colony consumes 25 – 50 kilograms of pollen (Blacquière, 2009). Gathering bees collect pollen which they bring, bonded on their hind legs, back to the beehive. In the beehive the pollen and nectar are mixed with saliva and it gets stored in the honeycombs. Here lactic fermentation of the substance takes place and the so called ‘bee bread’ is formed. This bee bread is the basis of the formation of jelly which is food for worker bees and drones. Young bees makes this jelly with juices from feed juice glands on their head. The larva of the queen bee gets more of this milk and it has a different composition. This special jelly is called ‘Royal Jelly’. To be able to grow the larva needs much proteins from pollen (Koster, 1999). In case of a lack of protein the feed juice glands cannot develop and grown bees live shorter. Larvae are less taken care of and get less food, which can lead to death (van Blitterswijk et al., 2009).

The bee is the only insect that for its food provision entirely relies on nectar and pollen, this makes it such a good pollinator. In general the closer the bee nest is situated to plants which supply pollen and nectar, the more honey the colony produces (Blacquière, 2009). Wild bees use pollen and nectar to feed their larvae (Peeters, Raemakers & Smit, 1999). The cuckoo bee depends for its food provision on the food collected by its host (Koster, 2000; Westrich 1996).

Besides nectar and pollen honey bees also collect another substance from plants, which is used to create so called ‘propolis’. Honey bees mix plants extracts with wax and then apply it in the honey rates to block holes, to repair cracks, to strengthen combs and to make the entrance of the hive resistant to extreme weather conditions. Moreover, propolis has a natural disinfectant function against bacteria and moulds (Bankova et al., 2005). Propolis is collected from raisin from trees and its composition majorly depends on the surrounding plants (Jacobs, 2002).

3.3 Natural habitat

Most bees prefer to nest in warm and dry places. The majority of bee species in the Netherlands, 246* species, builds their nests in the soil. These species create their own nests, preferably on open soil. On rich soil, bees nest on bare spots between vegetation like ground ivy or nettles and on poorer grounds this can be for example in-between grasses.

They like sandy, flat, or somewhat sloping grounds, while a few species also nest on steep edges (Koster, 1999). Some ground nesting species dig up to 100 cm deep to create nests (Koster, A., Consultancy Vegetation Management, 2013).
Other bee species nest as well in the ground as above the ground, 36* species. The remaining 56* species nest in places above the ground. For making a nest the insects make use of things as old dead wood (Steffan-Dewenter, Leschke, 2002), grass pollen, walls, hollow reeds, blackberry, elder, thistles and umbel lifers. Also human-made objects serve as nesting places, the so called ‘bee hotels’. About 5* percent of the bees species in the Netherlands nests in these facilities (Peeters, Raemakers & Smit, 1999).
During their lifetime most bees stay close to the place they were born. The exact scope of the bees is determined by the kind of species, food specialization, the quality of the living environment and weather conditions. Many species do not forage (flying out to collect food) more than a few dozens of meters away from their nests, this ranges about between 0.5 meters to 300 meters (Westrich, 1996; Koster, A., Consultancy Vegetation Management, 2013), but the exact forage distance of many bees is still unknown. This also depends on many environmental factors like wind force and the shape of the landscape. Researches did find out that forage distance increases with increased body size, but there is a non-linear relations between these parameters. Larger bees (bumblebees and honey bees) have disproportional larger forage distances than smaller bees (Greenleaf et al., 2007). Honey bees and bumblebees have in general larger body sizes than wild bees and cover a larger distance; up to 3 kilometers. In cold periods however these species also fly shorter distances (Blacquière, 2009).
Solitary bees forage only when the weather is warm, preferably sunny, and when there is little wind. They fly out on the warmest part of the day, so in early spring this is between 11.00 hour a.m. and 16.00 hour p.m. and in summer this is usually between 10.00 hour a.m. and 18.00 hour p.m. Only on very warm summer days bees also fly in the early evening hours. Since honey bees are physically very similar to wild bees it is likely that the fly out behavior is similar to wild bees (v. Dugteren, 2013). Bumblebees forage more frequently, they forage during the whole day under different kind of weather conditions, when the temperature is above 8-9 degrees. They start to fly out in the early spring, the beginning of March, till the end of October. (Koster, 2000). Also honey bees forage during the beginning of March till the end of October. The first wild bees to fly out in March are sand bees. The last to fly out in October are mainly mining bees (Koster, A., Adviegroep Vegetatiebeheer, 2013,wildebijen.nl, 2013).
Honey bees and bumblebees fly out at temperatures between 10 and 35 degrees Celsius, temperatures between 18 and 25 degrees are optimum. The temperature of the breed of honey bees has to be constant at 35 degrees. When the temperature tends to come above

this, the bees will cool the breed with their wings. The relative air humidity around bee hives for honey bees should be less than 90%, above this percentage there is chance on the formation of fungus in the hives. Concerning CO_2 content of the air the maximum amount of CO_2 is 0.25%. Naturally the air consists of about 0.035% bees, so this is way lower than the tolerance limit (Praktijkonderzoek plant & Omgeving Wageningen UR, 2004).

*These numbers represent the situation in 1999, so the actual numbers might be slightly different. More up to date numbers were not available.

3.4 Food sources

Solitary bees have special requirements for their biotope; some solitary bees depend in regard to food provision on one plant species (*monophagous*) only. Honey bees and bumblebees are less depended on a certain kind of biotope, because they fly to more plant species (*polyphagous*) (Koster, 2000). Research done in Egypt, England, Scotland, Italy and Switzerland shows that honey bees collect their pollen from a limited number of plants available; usually from common species like agricultural crops. According to publications the five most attractive species for honey bees are corn (*Zea Mays)*, white clover or Dutch clover (*Trifolium Repens)*, dandelium (*Taraxacum Officinale)*, plantago (*Plantago sp)* and rapeseed (*Brassica napus),* see also Figure 6. All these plants grow in the Netherlands, so these result will probably hold for the Netherlands as well.

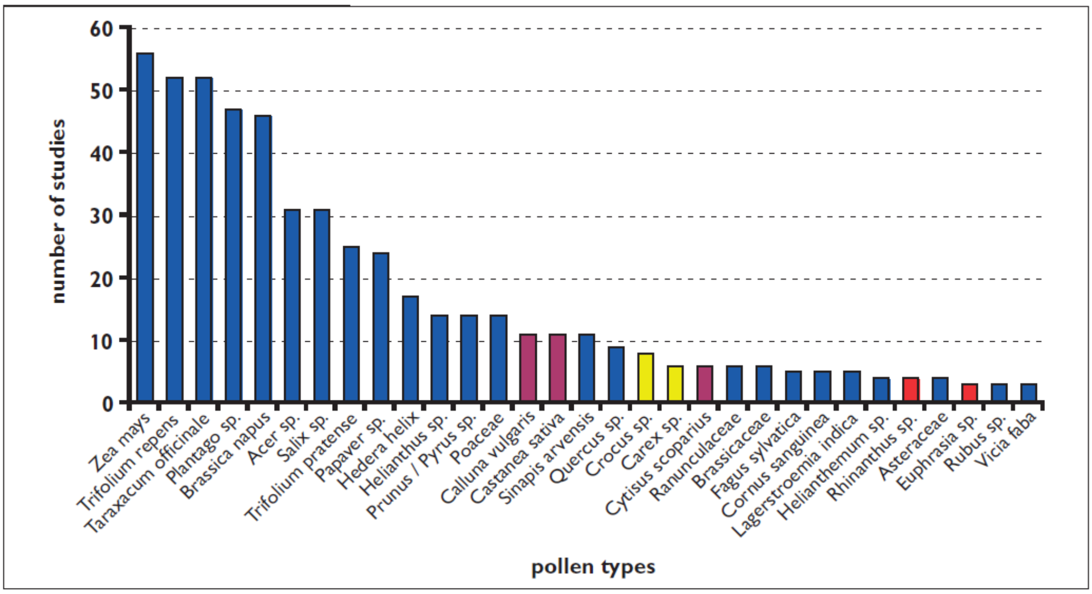


Figure 6 The bars represent the number of studies in which the certain plant species is named as one of the 5 most common pollen sources for honey bees in Switzerland. 114 datasets were in total analyzed. The blue bars represent pollen sources found on several locations, the other colored bars were found only on particular locations. Source: Keller et. al., 2005

Keller et al. found that honey bee colonies differ in their pollen collection at a given location and also the preference of the colony could change from year to year (Keller et al. referring to Van der Moezel et al., 2005). It is clear that besides the availability of a plant species there are more factors determining the foraging behavior of honey bees, but what exactly these factors are is unknown yet (Keller et al., 2005). Seeley et al. found that nectar sources were determined by a process of natural selection. Foragers collecting nectar from more profitable sources continue visiting their sources longer than the ones collecting from less profitable food sources. The foragers from these profitable sources also recruit more new foragers and so more profitable food sources are selected (Seeley et al., 1991).

3.5 Threats for the bee

Both the honey bee and the wild bee population in the Netherlands are declining since more than a century. Of the 350 species present in the Netherlandss 188 are listed on the 'Red List', which means these species are threatened with extinction. For the honey bee this trend is going on since about the last ten years (van der Sluijs, 2011). The honey bee is almost extinct in the wild in the Netherlands, but the colonies kept by beekeepers are not (yet) in danger of extinction. The vitality of the bees however is decreasing. To illustrate the size of the problem; in the winter of 2009-2010 the bee winter mortality was circa 29% (Opera, 2013). This is a lot higher than the 'normal' winter mortality, which is about 8% (van der Sluijs, 2011).

So far there is still a lack of knowledge on which factors are key factors to cause colony losses and which are important risk factors (Opera, 2013). However, there are many reasons considered as being important reasons for the decline of populations, which are land use changes, the intensification of agriculture, the use of pesticides, the deterioration of nature, the increase of human population and pests and diseases (Blacquière, 2009; Opera, 2013). Moreover, also climate change has an influence on complex interactions between bee colonies (Opera, 2013).

3.5.1 Land use changes

Last decennia the quantity and quality of the natural habitat of bees has declined a lot (Westrich, 1996; Blaquière, 2009; van der Sluijs, 2011; Peeters & Reemer, 2003). The presence of (semi-)open nature with an abundance of flowers decreased and therefore suitable habitats disappeared, got fragmented or became polluted. The areas made place for homogeneous intensive agriculture which lead to disappearance of valuable pollen and nectar plants. Also the supply of pollen and nectar is nowadays too unilateral and not equally distributed over the year. Through land-use changes also suitable nesting places disappear (Blaquière, 2009; van der Sluijs, 2011; Peeters & Reemer, 2003). Solitary bees do not need a large habitat, but food provision and nesting possibilities should be in close proximity of each other. So when different habitats are too distant from each other, this distance is not crossed and there is no genetic diffusion and exchange. A species then becomes more vulnerable for extinction (Koster, 2000).

3.5.2 Climate change

Concerning climate change the most harmful effects will be indirect effects; changes in the floral diversity. Different temperatures lead to different flora, so to an altered supply of pollen and nectar (Le Conte & Navajas, 2008; Blacquière, 2009). Extreme droughts will result in less flowers and therefore less food supply (Blacquière, 2009).

It is not exactly known how climate change will influence growth and population dynamics of colonies itself (Le Conte & Navajas, 2008) or how it will influence pathogens (Blacquière, 2009), but a large amount of scientific data indicates that environmental changes affect development of honey bees. Bees will however not directly be affected by a higher average temperature because of climate change, they can adapt to this (Blacquière, 2009). Honey bees can adapt to a broad range of different habitats and to different temperatures. Especially the European honey bee, the *Apis Mellifera* has the capacity to adapt to climates with a hot average temperature (Le Conte & Navajas, 2008). Therefore in particular honey bees should be able to overcome climate change. However, the combination of climate change and other factors threatening the species may lead to high extinction rates in the future (Le Conte & Navajas, 2008).

3.5.3 Decline of honey bee populations

The decline of honey bee populations has additional reasons to the reasons mentioned before. The varroa-mite is the biggest threat for honey bees at the moment. The mite is present in the Netherlands since 1982 and is now spread over all the colonies. The mite bleeds blood from larvae, cocoons and adult bees and weakens the health and vitality of them. The effects of the infection by the mite are becoming more serious. As a result the health of the bees deteriorates, which makes them less resistant for other viruses, bacteria and parasites (Blaquière, 2009).

3.5.3.1 Complexity of beekeeping

The increased risk on diseases and the drop in food supply has made beekeeping a much more complex activity than it used to be. Knowledge and skills are disappearing because they are not transferred from experienced bee keepers to new bee keepers. Furthermore, despite the large indirect economic interest of pollination, beekeeping itself is currently not a very profitable business anymore (Blaquière, 2009).

3.5.3.2 Perception of getting stung by bees

Because of the diversity of plants in gardens and parks in cities, urban areas provide excellent habitats for honey bees. The many kinds of different vegetation provide a continuous and divers supply of pollen and nectar. However a problem for beekeeping in cities is space and the risk of people getting stung by the bees. Newly built houses with small gardens do not have enough space for the placement of beehives. Incidents of people getting stung by bees can lead to hassle between neighbours, where the affected person may claim costs for intangible damage (Blaquière, 2009).

3.5.3.3 Pesticides

Then a much discussed problem for the decline of honey bee populations is the use of pesticides. Pesticides can harm insects in three different ways: they can kill adult insects, they can kill or deform breed and they can cause sub-lethal effects. Sub-lethal effects are problems like influencing the learning behaviour, influencing sense of locality and shortening of lifetime (Blaquière, 2009). The intake of pesticides via nectar and pollen causes the most damaging effects on bees (Opera, 2013). Because of these harmful effects many pesticides are forbidden over the last couple of years (Blaquière, 2009). In July of this year the European Commission put a temporary prohibition on the use of certain applications of some neonicotinoids; the neonicotinoids clothianidine, thiamethoxam and imicloprid, because of the possible effects on bees (van Vliet et al., 2013.). According to Blaquière are these neonicotinoids 1000 times more toxic than organophosphorus pestices which were on the market before (Blaquière, 2009) Because of this toxicity they are considered to be one of the mean reason for the collapse of bee colonies (EFSA, 2013). A reasons why these substances are more poisonous is because these pesticides are systemic (Blaquière, 2009). This means the pesticides are absorbed by plants and then move through the plant to untreated parts of the plant. Therefore also untreated stems and leaves become toxic for insects (Ministry of agriculture UK, 2013). Also, these new pesticides are considered to have sub-lethal effects on the bees. Although sub-lethal concentrations of pesticides have little effect on individuals (Desneux et al., 2007), research done by Gill et al. on bumblebees shows that chronic exposure of field-level concentrations neonicotinoids and pyrethhriod heavily affects the functioning of bumblebees. It impairs the foraging behaviour and causes a higher mortality rate among workers. This leads to a major decrease of brood development and therefore the health of the colony deteriorates. Regarding the foraging behaviour, especially the pollen collecting efficiency was significantly reduced, which lead to less forager recruitment, to diminished worker productivity and even to worker losses (Gill et al, 2012). Furthermore Gill et al. found that a mixture of pesticides is more likely to cause adverse effect on populations than a single pesticide (Gill et al., 2012). Although Gill et al. did research after bumblebee populations, other researches indicate this effect also holds for honey bees (Blacquière, 2009., EFSA, 2013, van der Sluijs, 2011).

Since wild bees are physically similar to honey bees it is very likely they will also be negatively affected by pesticides. However wild bees do not pollinate many crops and are therefore less in contact with pesticides. The effect on them is thus also expected to be lower. Research though is lacking so far (Blacquière, 2010).

4 Urban green and bees

Urban green, green roofs and green façades can provide suitable habitat for bees. This chapter examines how green roofs can be constructed and which types of vegetation are suitable to apply on them. Then it stresses which types of roofs in particular will be suitable for new habitat creation for bees. Also green façades are shortly discussed. Furthermore is analyzed which bees are mainly present in urban areas. The last section of the chapter concludes with which parameters are important for bees on the level of an individual roof and on an city scale.

4.1 Definition and benefits of green roofs

'The term 'green roof' describes both intensive, ornamental roof gardens and extensive, roofs with more naturalistic plantings or self-established vegetation, p 66. (Kadas, 2006).' The term 'green' thus refers to the presence of vegetation on rooftops. These plants can range from small moss and sedum species to big bushes and plants. The difference between intensive and extensive green roofs is stressed in the following sections.

Green roofs have proven to have many benefits for reducing environmental problems in urban areas. Vegetated roofs amongst others reduce storm water (Getter et al., 2007; Obendorfer et al., 2007), improve air quality (Yang et al., 2008), take up CO_2 (Li et al., 2010) and reduce the cooling load because of their insulating capacity. Moreover they increase the lifetime of the roof membrane (Kosareo and Ries, 2006) they mitigate the urban heat island effect, which is the phenomenon that cities warm up faster than their environments because of the large paved areas (Susca et. al, 2011). Furthermore the most important benefit for this research is the benefit of increasing biodiversity (Obendorfer et al., 2007).

4.2 Intensive and extensive green roofs

A green roof consists in essence of 5 different layers, see Figure 7. The first layer on top of the regular roof construction is the water proof layer (1). This layer protects the roof from water leakages. Then there is a protection and storage layer (2), which prevents plant roots from growing through the roof package. This layer also keeps the whole green roof construction in place. The drainage and capillarity layer (3) buffers rainwater and drains surplus water. The root permeable filter layer (4) filters small particles out of the rainwater, to prevent them from ending up in the water drainage system where they might lead to blockages in the system. The final layer of the green roof is the growing media or substrate layer (5), in which plants grow. The thickness of this layer depends on the kind of plants on the roof (Roofsystemconsultants.com, 2013). Vegetated roofs can be categorized by the type of drainage system and their nominal thickness. These two properties determine the structural load, the maximum possible slope, the type of vegetation and the water retention capacity (Green roof Handbook, 2008).

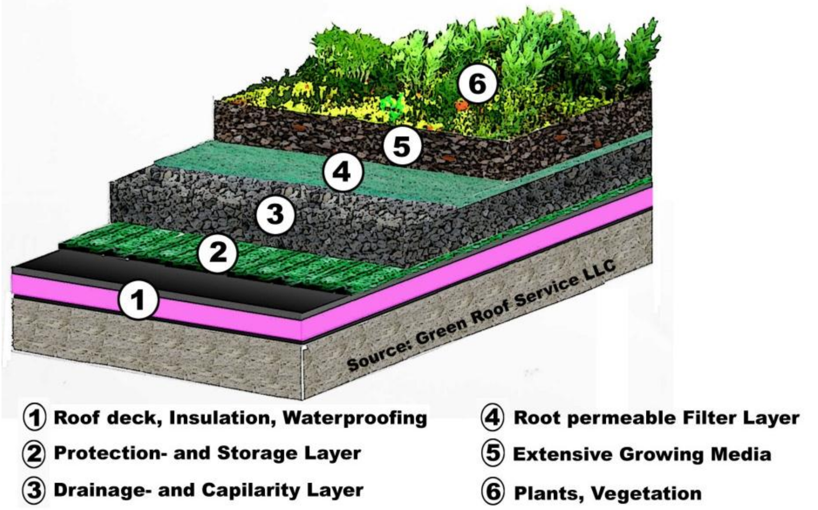


Figure 7 Typical green roof system, Source: Roofsystemsconsultants.com, 2013

An extensive green roof does not require much maintenance, here extensive maintenance is applied. On this roof grows low vegetation like moss, sedum, succulents and herbs. The roof is often limited accessible for people (only for maintenance purposes), has usually a lower carrying capacity than intensive roofs; which is between 40 and 110kg/m^2. The substrate layer thickness of an extensive green roof is typically up to 20 cm. The exact growing depth of plants differs per species, but in general moss and sedum plants need the thinnest substrate thickness and grasses and herbs need the thickest. The growing medium should provide the vegetation sufficient water, nutrients and oxygen. In the Netherlands anyone is allowed to apply a green roofs, there is no permit needed (Groendak.info, 2013).

The following table, Table 3, provides an overview of the properties of an extensive green roof:

Property	Extensive green roof
Surface layer thickness	< 20 cm 2 – 6 cm: sedum, succulents, moss 8 – 12 cm: sedum, succulents, herbs 12 – 21 cm: succulents, grasses, herbs
Slope of the roof	1° to 45° or 60° (2% to 5%)
Load	40 to 110 kg / m²
Walkable	Only for maintenance
Permit needed	No
Maintenance	Low maintenance

Table 3 Properties of extensive green roofs, Source: Groendak.info, 2013

Intensive green roofs are parks or gardens on rooftops. They require deep soil and regular maintenance (Kadas, 2006). This type of green roof, often accessible for people, requires a high carrying capacity of the structure of the building. Intensive green roofs have a substrate layer from 20 cm or thicker. On a green roof with a substrate layer of more than 50 cm can even grow trees (see also Table 4). The growing medium should provide the vegetation sufficient water, nutrients and oxygen. The load of intensive green roofs is usually more than 200 kg/m^2 and there is a permit needed to build such a roof (Groendak.info, 2012).

The following table states the most important properties of an intensive green roof:

Property	Intensive green roof
Surface layer thickness	>20 cm 25-50 cm: grass, herbs, bushes >50 cm: herbs, bushes and trees
Slope of the roof	1° to 4° (2% - 7%) Grass roof to 45° (2% - 5%)
Load	>200 kg/m^2 adjusted roof construction needed
Walkable	Yes
Permit needed	Yes
Maintenance	Similar to a normal garden

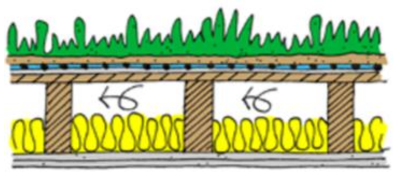
Table 4 Properties of intensive green roofs, Source: Groendak.info, 2013

The boundary between intensive and extensive green roofs is vague and depends on perception. But a common rule of thumb is: non-accessible roofs with low vegetation are extensive roofs and accessible roof gardens with high vegetation are intensive green roofs.

4.3 Construction possibilities

Many different ways exist to construct a green roof. The type of construction is mainly determined by the functional requirements and the most determinative property of the roof itself is the slope of the roof. The slope determines the presence of drainage layers, bars and measures to retain water (Teeuw & Ravesloot, 2011). This section gives a quick overview of construction possibilities of green roofs.

Similar to normal grey roofs, green constructions can be divided into three different types of roofs: cold roofs, warm roofs, inverted roofs and duo-roofs (Teeuw & Ravesloot, 2011). Table 5 gives an description and a system overview of the most important properties.

Type	**Description**	**System overview**
Cold roof	1)Vegetation 2)Substrate 3)Root protecting layer 4)Insulation 5)Vapor protecting layer 6)Roof construction Properties: - Waterproof function is by a cavity separated from bearing and sometimes from insulation structure. - Often condensation on the underside of the roof, when	

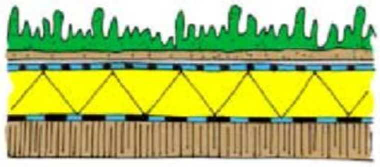
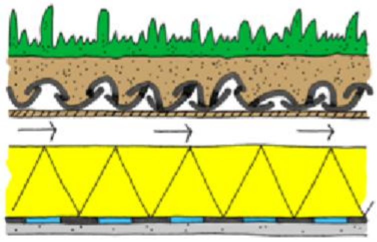
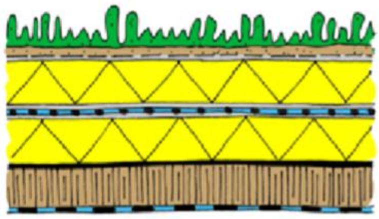
	the outside air temperature cools down majorly compared to temperature of the air in the cavity.	Figure 1
Warm roof	Layers (top-down): 1)Vegetation 2)Substrate 3)Root protecting layer 4)Insulation, since this layer is on the outside of the construction, the construction stays warm. 5)Vapor protection layer, optionally root protecting layer 6)Roof construction Properties: - Generally this roof construction does not have moisture problems, because of the vapor protecting layer under the insulation layer. Insulation layer is placed on top of the bearing construction - This type of roof often used on roofs with plastic membranes	
Inverted roof	1)Vegetation of grass sods 2)Substrate of humus 3)Birch bark 4)Air cavity 5)Roof construction 6)Ventilated cavity 7)Insulation, at the outside of the roof 8)Vapor protecting layer 9)Interior finish Properties: - Vapor protection layer and the water proof layer are placed on the bearing construction. The insulation material in this type of roof thus should be water resistant. In modern systems this principle usually works, but in older systems the insulation material is usually insufficient water proof and then it loses its insulating capacity.	
Duo-roof	1)Vegetation 2)Substrate 3)New roof insulation 4)New root protecting layer 5)Existing insulation 6)Optional existing roof cover 7)Existing roof construction 8)Optional vapor protecting layer Properties: - Combination of a warm roof and an inverted roof - Usually on top of an inverted roof is a new insulation layer placed - Moisture and temperature properties of the roof are difficult to determine because of the composed character of this roof - Little change on damage caused by condensation, because condensation point is usually a bit above the waterproof layer	

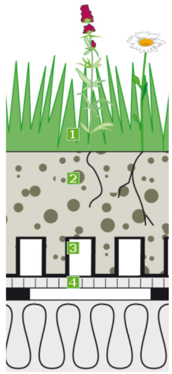
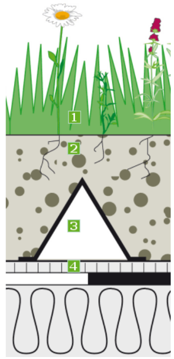
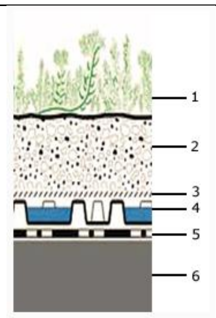
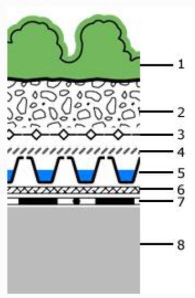
Table 5 Different roof types in combination with green roof systems, Source: Teeuw & Ravesloot, 2011.

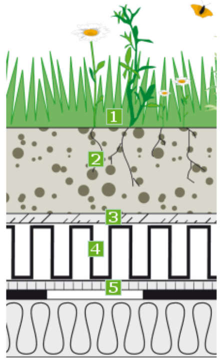
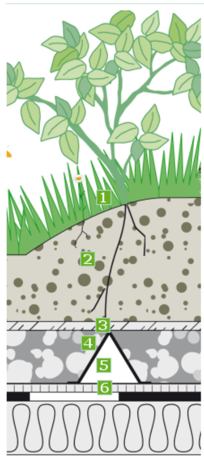
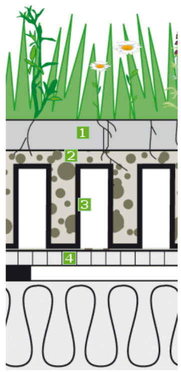
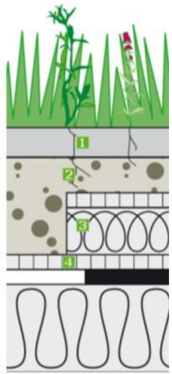
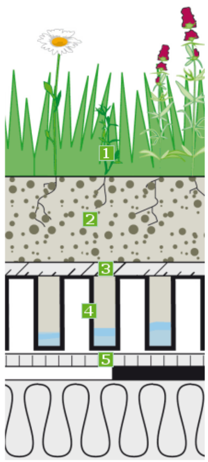
For the green roof construction itself also consist many different possibilities. The different roof types all have specific characteristics, suitable for different either intensive or extensive roofs and for different types of vegetation.

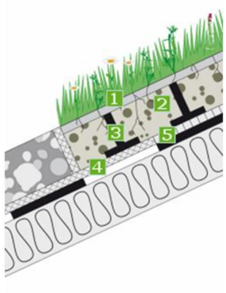
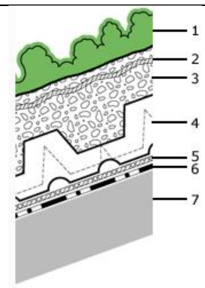
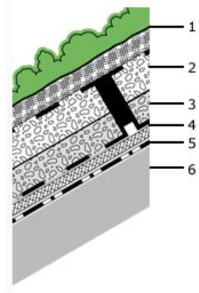
4.3.1 Extensive green roof constructions

The most common green roof constructions are extensive green roofs covered with sedum plants. An extensive green roof can usually be applied without reinforcement of the roof structure. Table 6 provides an overview of different types of extensive roofs available. N.B. This table aims to provide a complete overview of the most common green roof types available on the current Dutch market. However, green roof system suppliers might offer slightly different systems then listed here.

<table>
<tr><th>Type</th><th>Type</th><th>Description</th><th colspan="2">System</th></tr>
<tr><td rowspan="3">1)Basic extensive roof</td><td>1.1)Economic roof ((a/b)Optigroen)</td><td>Low maintenance, little diversity in plant cover

1. Sedum plants in combination with flower seeds
2. 8 cm extensive substrate, high water capacity and good drainage capacity
3.a Drainage plate (2.5 cm), Quick drainage of surplus water, prevention of water stowage on roofs without a slope. Light construction with high drainage capacity.
3.b Traingle drainage system, quick water drainage. More space for roots of plants
4. Protection and absorption layer. Protects roof cover and absorbs water. For inverted roofs a special roof cover layer is needed.</td><td>
a)</td><td>
b)</td></tr>
<tr><td>1.2)Industry Roof (Zinco)</td><td>Integration of different layers, so lower costs, suitable for big roof surfaces (> 1000m²), Sedum plants cover
1. Sedum plants, plug plants
2. 6 cm extensive substrate
3. Fall protection
4. Drainage layer
5. Protection layer
6. Roof construction</td><td colspan="2"></td></tr>
<tr><td>1.3)Sedum Plus (Zinco)</td><td>1.Sedum plants in combination with flower seeds
2. 8 cm extensive substrate
3. Fall protection
4. Filter layer
5. Drainage plate
6. Water buffering protection layer
7. Root protecting layer
8. Roof construction</td><td colspan="2"></td></tr>
</table>

2)Basic extensive roof with more plant diversity	2.1)Nature roof ((a/b)Optigroen)	1. Vegetation with perennials and/or seeds of flowers, herbs, grasses 2. (5-20cm) extensive substrate, high water retention capacity and good pore volume, hills up to 20 cm can be created 3. Filter layer, prevents sipping through of small particles, high water permeability 4.a Drainage plate (4cm). Quick drainage of surplus water, prevention of water stowage on roofs without a slope. Light construction with high drainage capacity. Vapor open layer. 4.b Perl drainage layer. Quick water drainage, more space for plant roots, suitable for leveling of unevenness on the roof, high water storage capacity for plants. 5 (a) Traingle drainage system, quick water drainage. 5/6 Protection and absorption layer. Protects roofcover and absorbs water. For inverted roofs a special roof cover layer is needed.	 a)	 b)
3)Light weigt roof	3.1)Light weight roof ((a/b)Optigroen)	1. Vegetation layer. Pre-cultivated sedum moss mat for rapid vegetation growth, with a digestible under layer 2. 3 cm light substrate. 3.a Drainage plate (2.5 cm) Quick drainage of surplus water, prevention of water stowage on roofs without a slope. Light construction with high drainage capacity. 3.b Drainage mat, quick drainage of water, $4m^2$ per roof vent needed. 4. Protection and absorption layer. Protects roof cover and absorbs water. For inverted roofs a special roof cover layer is needed.	 a)	 b)
4)Water retention roof	4.1)Water retention roof – meander system	1.Sedum plants in combination with flower seeds, Herbs and grasses. 2. 6 cm extensive substrate, high water retention capacity and good pore volume. 3. Filter layer, prevents sipping through of small particles, high water permeability, high tensile strength. 4. Meander plate (6cm), significantly delayed discharge, light construction with high drainage capacity. 5. Protection and absorption layer. Protects roof cover and absorbs water. For inverted roofs a special roof cover layer is needed. *This is just one example of a water retention roof System, there are more construction systems.		

5)Sloping roof	5.1)Sloping roof – without sliding security (Optigroen)	1.Vegetation mat Pre-cultivated sedum moss mat for rapid vegetation growth, with a digestible under layer. 2. 6-10cm extensive substrate, substrate adjusted to sloping roof, high water storage capacity and good pore volume. 3. Protection and absorption layer. For water absorption and drainage of surplus water. 4. Protection and absorption layer. Protects the roof from damage and stores water.	
	5.2)Sloping roof – with sliding security (Optigroen)	1.Vegetation mat. Precultivated sedum moss mat for rapid vegetation growth, with a digestible under layer. 2. 6-10cm extensive substrate, substrate adjusted to sloping roof, high water storage capacity and good pore volume. 3. Anti-slip system. Prevents slipping of vegetation and stabilizes the substrate layer. 4. Protection and absorption layer. For water absorption and drainage of surplus water. 5. Protection and absorption layer. Protects the roof from damage and stores water. For roofs with a slope of more than 15 degrees this layer should be replaced for another layer.	
	5.3)Green roofs on roof slopes till 25° (Zinco)	For roof slopes between 10° and 25°, different drainage plate than flat green roofs, to keep substrate in place, protective mat with higher water retaining capacity, optional with anti-erosion layer 1. Sedum plants, plug plants 2. Jute, anti-erosion mat 3. 8-11 cm extensive substrate 4. Special drainage plate to keep substrate in place 5. Water retaining protection layer 6. Root protection layer 7. Roof construction	
	5.4)Green roofs on roof slopes till 45° (Zinco)	For roof slopes between 25° and 45°, contains special grid elements to create a stable roof package, optional in combination with measures to keep the package in place 1.Sedum mat 2. 10 cm extensive substrate 3. Frame 4. Root protecting layer 5. Roof construction	

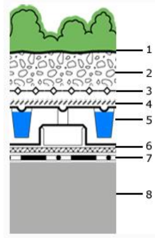
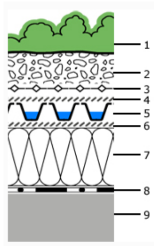
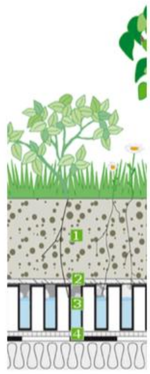
6)Flat roof	6.1)Flat roof (0°-slope) (Zinco)	special drainage element which avoids ponding on the roof, higher than normal green roof, but because of the light weight element same weight 1.Sedum plants, plug plants 2. 6 cm extensive substrate 3. Optional integrated fall protection 4. Filter layer 5. Drainage layer, extra water storage capacity 6. Water retaining protection layer 7. Root protecting layer 8. Roof construction	
7)Green roof on an inverted roof	7.1)Green roof on an inverted roof (Zinco)	Water vapor transport should not be hampered, water retaining layer is replaced by vapor-open separation layer 1.Sedum plants, plug plants 2. 6 cm extensive substrate 3. Optional integrated fall protection 4. Filter layer 5. Drainage layer 6. Vapor open layer 7. Insulation 8. Root protecting layer 9. Roof construction	

Table 6 Overview of different extensive green roof systems, Source: Zinco/Optigroen, 2013

4.3.2 Intensive green roof constructions

Intensive green roofs can range from vegetable gardens till park roofs even. Sometimes the construction below the roof has to be reinforced to be able to build the green roof. Table 7 provides an overview of the different roof types available on the current Dutch market. N.B. This table aims to provide a complete overview, however green roof system suppliers might offer slightly different systems then provided here.

Type	Name	Description	System	
1)Accessible roof	1.1)Accessible roof (Optigroen)	1.Intensive substrate. 23 cm intensive substrate/20 cm grass substrate, substrate high water storage capacity, good permeability and good pore volume 2.Filter layer. 3.aDrainage plate (for roofs with a slope of 0-5°) (6 cm). Quick drainage of surplus water, prevention of water stowage on roofs without a slope. Light construction with high drainage capacity. 3.b Drainage plate (12 cm). Perl drainage layer. Quick water drainage, more space for roots of plants, suitable for leveling of unevenness on the roof, high water storage capacity for plants. (for roofs for roofs with a slope of 0-2°) 4a. Filter layer, prevents sipping through of small particles, high water permeability 4 b. Traingle drainage system (for roofs for roofs with a slope of 0-5°), quick water drainage. 5a. Root protecting layer 5a/6b.Protection and absorption layer. Protects the roof from damage and stores water.	 a)	 b)

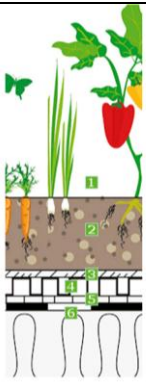
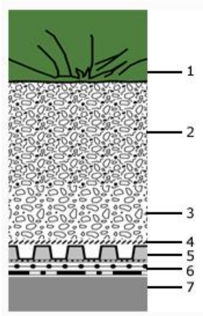
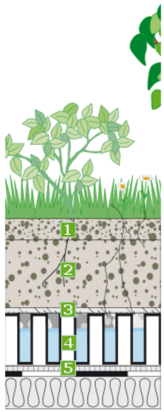
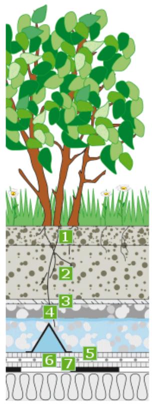
2)Vegetable garden roof	2.1)Vegetable garden roof (Optigroen)	1.Fruit and vegetables 2.20 cm urban farming substrate layer 3. Filter layer. 4. Drainage plate (4 cm) 5. Protection and absorption layer. Protects the roof from damage and stores water. 6. Root protecting roof cover	
3)Park roof	3.1)Park roof (Zinco)	Possibilities of artificial water level control for irrigation and water storage, the system is resistant for extra load to be able to apply e.g. substrate, sand and pavement, the combination of Zincolit Plus layer, Intensive substrate and the special drainage and ABS plastic drainage layer, makes many plant combinations possible 1.Vegetation 2. max 35-40 cm extensive substrate 3. Zinclit Plus layer 4. Filter layer 5. Drainage plate 6. Seperation and sliding foil 7. Roof construction with root and protecting layer	
	3.2)Park roof ((a/b)Optigroen)	1.25 cm intensive substrate/15 cm grass substrate, high water capacity, good permeability and good pore volume 2.29-69 cm sub-substrate. Mineral substrate adjusted to high intensive structure, high water capacity, good permeability and good pore volume. 3.Filter layer 4.a 6 cm drainage plate. Quick drainage of surplus water, prevention of water stowage on roofs without a slope, light construction with high drainage capacity, filled with Perl 4.b Perl drainage layer 5.a Construction protection layer. Protects roof for roots and stores water. 5.bRoot protecting layer 7. Construction protection and water storage layer.	 a)  b)

Table 7 overview of different intensive green roof systems, Source: Zinco/Optigroen, 2013

Literature studies state that extensive green roofs are considered being not very suitable for many animal species to establish (Brenneisen 2006, referring to Buttschardt, 2001). However research done in Basel, Switzerland has shown that this was mainly because of the thin substrate layer. A thin substrate layer is beneficial from a cost perspective, but for biodiversity it is harder to establish on an extensive roof than on an intensive roof (Brenneisen 2006, referring to Brenneisen, 2003).

A variety of substrate thicknesses leads to different microclimates, and provides a wider potential for different species to establish. However, in general can be stated that creating a green roof to foster biodiversity is a difficult task. Construction method, selection and storage of local soil to create suitable substrate is crucial (Brenneisen, 2006). Koster (2013) also emphasizes the importance of the substrate layer for the establishment of bees and in particular wild bees on green roofs. The composition of the substrate, the amount of nutrients in the soils and the humidity of the soil determine which plants can grow there and thus which bees will forage on the roof. For wild bees the soil is also directly important as nesting space (Koster, 2013).

From the different roof systems provided in the tables above can be concluded that the roofs adjusted to a green layer with possibilities for more diverse vegetation cover will create more suitable habitat for bees than other systems. In that respect extensive roof system number 2 is for example better than the extensive roof systems shown under number 1. The substrate layer of intensive roof 2.1 is especially designed for urban agriculture on rooftops. If the roofs are well constructed bees will find here enough vegetable plants to pollinate.

As already stated before different micro-climates are also an important factor for more different species to establish. Sloping areas on the roof are elements which create different microclimates on roofs, so extensive roof type 2.1.b is in this respect an interesting option.

Besides the substrate layer also the type of drainage system is likely to affect the suitability for bees to forage and nest on roofs, because the drainage system affects the humidity of the roof. The roof systems with a triangular drainage plate for example the extensive roof systems 1.1.b and 2.1.b offer more rooting space for plants, so somewhat bigger plants can grow here. However, this drainage system has a bit less drainage capacity than the drainage plates with rectangles (e.g. 1.1.a). Therefore probably plants with a higher water uptake could be planted on this roof, so a surplus of water on the roof is avoided. Important is to adjust the substrate and drainage properties of the layer on the desired plant combinations, so an ideal micro-climate for bees is created.

4.4 Green façades and bees

Besides green roofs are also green façades an upcoming concept of urban green. Just like green roofs green façades exist in different construction possibilities, which will be shortly discussed here.

From 1980 onwards the environmental effects of green on façades are examined. Just like green roofs reduces vertical green the urban heat island effect, it improves air quality and reduces storm water run-off. Vertical green is also beneficial for the development of biodiversity, for example for birds, spiders and beetles (Köhler, 2008).

May different forms of vertical green exist, they differ in whether they are directly attached to the building or that they have a supporting construction. The different systems can also be distinguished on the way water and nutrients are fed to the plants, directly from the soil or via planters placed on the ground or fixed on the façade.

The first concept of vertical green is wall vegetation. Wall vegetation are plants that spontaneous appear at a façade surface, particularly in joints or cracks. Since this is a natural process there is no special growing pattern and the plants are randomly spread over the surface (Mir, 2011). An example of a vegetated green wall is shown in Figure 8.

The second type of vertical green is the so called green façade, see Figure 9. A green façade is a vertical garden in which plants are directly attached to the exterior or interior of a building. The plants extract water and nutrients from the ground (Greenovergrey.com, 2009).

The last type vertical green is the living wall system. This system has a modular system of planter boxes or other structures anchored to the wall. The plants are thus rooted in the planter boxes instead of in the soil at ground level (Köhler, 2008) This system is self-sufficient and plants get water and nutrients from within the vertical support system (Greenovergrey.com, 2009). Figure 10 shows an example of a living wall system.

Green façades can offer both nesting space (Ottelé, 2011) and food supply for bees.

The plant species of vegetated walls, green façades and living wall systems differ a lot. An exact analysis of suitable plant species for green walls is not done in this research. From own observations however can be concluded that green façades covered with ivy is currently one of the most abundant green walls in cities. Ivy is an important food source for bees, also because this is one of the few species which flowers late in the forage season for bees.

Vertical green is not the main focus of this research and therefore when is referred to 'green façades' this could also mean a vegetated wall or a living wall system. The term 'green façade' is thus used to describe any type of façade with vegetation attached to it.

Figure 8 Vegetated wall Source: handleidingbiodiversiteitbrabant.nl, 2013

Figure 9 Green façade Source: upscaledown-home.net

Figure 10 Living wall system, Source: bluebrickconstruction.com, 2013

4.5 Bees in urban areas

Not all bee species present in the Netherlands also appear in urban area. In this research urban area is defined as: a city or town and their surroundings consisting of suburbs. The urban area has a high density of human structures (National Geographic, 2013). Besides honey bees, at least 195 different wild bee species are present in urban areas. This is around 60% of the total amount of bees found within the Netherlands (Peeters et al., 1999, Koster, 2000; also referring to Lefeber 1983-1998 and Smit, 1997). Bees establishing cities are mostly from the genera honey bees *(Apis mellifera)*, Sand bees (*Andrena)*, Mason or Potter bees (*Anthidium)*, *Anthophora,* Bumblebees *(Bombus)*, *Chelostoma (no English name available),* Plasterer bees *(Colletes) Dasypoda(n.a.),* Mining bees (*Halictus)*, Sweat bee/Mining bees *(Lasioglossum)*, Leaf cutter/Dauber bees, *Megachile, Melitta*, Wasp bee, Mason bees (*Osmia)* and cuckoo bee (*Nomada, Specodes, Stelis)*. For a complete overview see appendix 0 (Koster, 2013). In the rest of the research these bees will also be referred to as 'urban bees'.

Koster conducted research after the effect of ecological green management on the wild bee populations in urban areas. Research was done in 26 municipalities where 106 different wild bee species were found, this number was excluding bumblebee species. The bees were found in public green, railway yards and gardens. He concluded that this presence of bees is mainly due to ecological green management, because before ecological green management was introduced wild bees could be barely found in urban areas (Koster, 2000). Although this research gives an indication on how many bees species can be found in urban areas, it is still difficult to predict how many species will occur on a certain location. Therefore standardization of research is needed, which is not done so far. The number of bees depends on diversity, soil, surface area and development period of the area, management and regional biodiversity (Koster, 2000).

General conclusions about the urban bees can be drawn. At first, most of the urban bees are ground nesting bees (31 out of 47 species). Only 13 of the 47 species nest above ground and the other 3 out of the 47 species nest both in and above the soil. For most of the species is not known what their forage distance is, but it is known there is a relation between body size and the distance they fly out. Large bees cover more distance than smaller bees. For some of the Sand bees *(Andrena)* the forage distance and body size is known. The Sand bees have an average body size of between 10 – 15 mm and fly out distances between 260 – 300 meters. The body size of the *Andrena* species is also the average size of most urban bees (25 of the 47 species). The rest of the bee species is on average smaller (22 out of 47 species). Most of these bee species are in between 5 – 10 mm (19 out of 47) and only a few (3 species) are smaller than 5 mm. The body size and forage distance of one somewhat smaller species *Chelostoma* is also known; its average body size is 8 – 10 mm and the average forage distance 200 meters. Since this species is smaller than the *Andrena,* but still covers a distance of 200 meters is assumed that most of the bees at least fly out a distance of 100 meters.

4.6 Bees on green roofs

4.6.1 Parameters on a micro-scale; Individual roof

Besides the construction method of the green roof itself many other properties are important for suitable habitat creation by green roofs. This section stresses these factors.

4.6.1.1 Physical properties roof

Size of the roof:

The minimum size of a roof suitable for bees to establish depends on several factors. The availability and the amount of plants which provide food for bees is one of these factors. Also, the surroundings of the roof are very important. If there is much bee attractive vegetation on a ground level, bees are forced to forage on higher altitudes, on green roofs. The bigger the roof is and the more pollen and nectar supplying plants it has, the more bees can forage on the roof (Koster, 2013). It depends on the bee species, the type of vegetation and the vegetation density whether a roof can provide enough pollen for a certain colony to be self-sufficient. For example when a roof is completely covered with eggplants and peppers one colony of honey bees can pollinate a surface area of 5000 m^2. When the crops are pickles and zucchini this is one colony per 1500 m^2. Crops like strawberries, berries, raspberries and blackberries need the most intensive pollination per m^2, here one colony needed can pollinate 1000 m^2 (Praktijkonderzoek plant & Omgeving Wageningen UR, 2004). Bumblebees have smaller colonies, about 100 individuals per colony. If we assume the vegetation are again crops like strawberries, berries, raspberries and blackberries, there can be 400 nests on one acre. This means the minimum size of a roof to be self-sufficient for one colony of bumblebees is a lot smaller; the minimum size is in this only 25m^2 (1 ha divided by 400). Solitary bees have even smaller colonies, on average 10 individuals per colony (v.Dugteren, 2013). If we again use the same example for one colony of solitary bees only 10 m^2 green roof is needed. In theory a small shelter in a backyard would thus be suitable for one colony of solitary bees to be self-sufficient in food provision, provided that the roof contains vegetation that require the same pollination intensity as strawberries, berries, raspberries and blackberries.

Height of the roof:

Research has shown that green roofs on a relatively high altitudes even attract bees. Studies done by Brenneisen showed that green roofs on 3 floors high building were still visited by bees. Roofs at a higher altitude, on the 9^{th} floor, had only a few (6) visits (Brenneisen, 2005). Assuming that one floor is 3 meters high, bees will thus still frequently fly up to 9 meters high, but 27 meters only in some cases. Observations done by beekeepers in the Netherlands show that the average height up to which honey bees fly out is 12 to 20 meters (v. Dugteren, 2013; Koster, 2013). However, Koster stresses that if beehives are placed on green roofs they can survive on a few tenths of meters above ground level. Also bumblebees are able to survive on these heights. For wild bees much less information is known, but the most important constraining factor for the height up to which bees fly is the wind force (Koster, 2013). When rooftops are designed as a self-sufficient food and nesting space providing bee habitat are bees likely to forage on higher altitudes, because they do not have to fly back to the ground level for food collection. This self-sufficient habitat could very well be achieved by creating terraces on a building or on groups of buildings. Figure 11 provides an example of an example of a terraced building: The Acros Fukuoka Building in Japan.

Figure 11 The Acros Fukuoka Building in Japan, Source: Travellersbazaar.com, 2013

Slope of the roof:

Many ground nesting wild bees nest in open, bare flat or somewhat sloping grounds. Some species also nest in very steep, sometimes unstable, slopes (Westrich, 1996). The slope of the roof is not so relevant, the availability of open spots in the vegetation is more important (Koster, 1999).

Orientation of the roof:

Bees prefer to nest and forage on sunny places (Koster, 1999; 2000) and for nesting spaces they favour South facing spaces (Westrich, 1996). Bee attractive plants also need sunlight to grow.

4.6.1.2 Climatic properties

Wind speed:

With strong winds it is too energy intensive for bees to fly out (Koster, 2000). Observations (non-scientific) done by Koster showed that bees still fly out at wind speeds of 4-5 km/h. Since rooftops are often windier than ground level here also turbulence takes place (Wisse, 2004; Koster, 2013) Therefore wind protecting measures could help bees protecting from the wind (Koster, 2013). This could be for example high vegetation, buildings blocks or walls. On higher altitudes there is more wind, so also the wind nuisance on higher rooftops will be more. Additionally, high buildings alter wind currents which can result in heavy wind also on ground level. Therefore urban planners have to adapt their urban plann on high buildings to avoid deterioration of the urban wind climate (Wisse, 2004). As already analysed in a section before do bees less frequent visit roofs on an higher altitude than roofs on a lower altitude. This is partly because of the strong wind on high altitudes (Koster, 2013).

To be able to make a precise mapping of wind currents on a roof it is best to do measurements. If that is for some reason not possible hen it can be assumed the most common wind direction on the location is South-West, since this the most prevailing wind direction in the Netherlands (MeteoVista, 2010).

Humidity/rain:

Beehives of honey bees have specific requirements for the air humidity in an beehive; it should be at maximum 90% relative air humidity ((Praktijkonderzoek plant & Omgeving Wageningen UR, 2004). The brood nest of honey bees needs a very low relative humidity, between 40-45% relative humidity (v.Dugteren, 2013).

The relative humidity of environmental air does not affect the foraging behaviour of bees (Koster, 2013). Rain is however is a constraining factor. Bees do not fly out when it is raining (Le Conte & Vavajas, 2008, Koster, 2000).

Sun:

Bees have a preference for nesting on warm and dry places (Koster, 1999). They fly out preferably when it is sunny (Koster, 2000). Roofs which receive a lot of sunlight will therefore be more suitable for a bee habitat then roofs which are (to a certain extent) shadowed.

Temperature:

Honey bees and bumblebees fly out between 10 and 35 degrees Celsius, optimum is between 18 and 25 degrees ((Praktijkonderzoek plant & Omgeving Wageningen UR, 2004). Bumblebees fly out more frequently, they fly during the whole day under different kind of weather conditions, by temperatures above 8-9 degrees. Most wild bees fly out at sunny days with temperature of 15-18 degrees Celsius, but with high temperatures they also fly out when it is clouded (Koster, 2013). They start to fly out in the early spring in the beginning of March, till the end of October (Koster, 2000).

Cities have in general higher temperatures than their environments. The highest temperatures are measured in city centers, in the suburbs the difference with rural areas is in general less. The temperatures are determined by the size, structure and shape of the city, the time of the day and the weather conditions. Very dense cities with high buildings retain more warmth than more open cities with low buildings and on a windy day temperatures will be more leveled throughout the whole city than when there is little wind. Human impacts like traffic, district heating and air pollution especially influence the temperature of cities in wintertime. A city can be up to 4 degrees higher for cities with 10.000 inhabitants and up to 7 degrees for cities with 200.000 inhabitants. These differences were measured on windless night with a clear sky (KNMI, 2012).

4.6.1.3 Vegetation

Type of vegetation:

The living conditions for plants on roofs are determined by many factors. These factors are among others the availability of substrate to root and the fertility of the soil. The presence of nutrients in the soil is essential for plants to grow, but in case of too fertile soil, strong plant species displace intended species. Examples of very fertile substrates are expanded volcano granules and clay. Finally air, sunlight and water are essential for plants to grow. The regulate the amount of water reaching the plant roots, a regulated moisture system in the soil is required (Teeuw & Ravesloot, 2011).

Many different plants can grow on green roofs, but they should be resistant to extreme weather conditions; strong winds, extreme droughts and severe frost (Teeuw & Ravesloot, 2011; Oberndorfer et al., 2007 referring to Dunnett & Kingsbury, 2004). In general exotic plant species meet these requirements best, but also some native sedums and mosses can survive these circumstances. Especially rock plants and plants originally growing in dune areas are suitable to grow on roofs. Plants with big leaves are in general less suitable because by strong winds leaves get damaged and they evaporate too much water. Plants with small, hairy or grey leaves perform better (Teeuw & Ravesloot, 2011).

Native plants are adapted to local climates and are therefore one of the best options for to consider for applying on green roofs (Oberndorfer et al., 2007). Teeuw and Ravesloot drafted a list of suitable plant species to grow on green roofs. This list is shown in appendix 0. What should however be stated is that this list is not definite. Oberndorfer et al stresses that nearly every plant species could be planted on green roofs, as long as the species suits the climatic region, it grows in appropriate substrate with the minimum required substrate depth and it has sufficient irrigation. The building height and form of the building will lead to a certain wind stress on the roof, which also determines constrains for the choice of plants. Sedum plants are nowadays the most applied plant species on green roofs, but there are many more options to be explored (Oberndorfer et al., 2007).

To attract bees on green roofs, the vegetation layer should have plants which provide pollen and nectar. In 2005 Brenneisen researched the difference in attractiveness for bees between sedum roofs and herbaceous roofs. The research showed that sedum roofs attract only 50 percent of the bee species compared to herbaceous roofs with more variation in vegetation. The amount of blossom visits on sedum roofs was 80 percent less than on herbaceous roofs (Brenneisen, 2005). Also Kadas stressed in his research that sedums provide pollen and nectar for bees, but since the flowering period of sedums is short these plants should be complemented with a broad range of native flowers so food provision is secured during the whole season (Kadas, 2006).

The research done by Brenneisen and Kadas was conducted in respectively Switserland and the United Kingdom. For the Dutch situation there is no such research available, but there is both information on bee attractive plants and about vegetation suitable to apply on green roofs. By combining this information a list of suitable pollen and nectar supplying plants for green roofs is created. This list is shown in appendix 0.

Besides pollen and nectar, honey bees also need substances of plants to create propolis. In the Netherlands this is mainly collected from poplar trees *(Populus sp.)* (Jacobs,1992), but since this is a very big tree it is not very likely this tree will grow on green roofs, so this could be complementing vegetation on ground level.

Distribution of vegetation/bare soil:

In addition to suitable pollen and nectar supply plants, wild ground nesting bees also need bare ground to create nests (Westrich, 1996). There are no exact numbers available on what the ratio between planted area and bare area should be, but a few m^2 per $100m^2$ is already sufficient (Koster, 2013). For honey bees this area is even smaller, since a colony in of one beehive can pollinate 1000 m^2 of plants. Here only 1 bare m^2 per 1000 m^2 of plants is needed for placing a beehive. For bumblebees the amount of required bare soil is something in between these two numbers.

4.6.1.4 Management type

Maintenance:

For the maintenance of the roof it is important that the vegetation offers a continuous supply of pollen and nectar during the forage season of bees, so from the end of March to the beginning of October. This implies that plants which are flowering should not be cut or mowed. The mowing or cutting should preferably be done before or after flowering of the plants (Koster, 2000). The same maintenance advice holds for green façades, vegetation should not be cut when it is flowering.

The use of pesticides is harmful for honey bees and research indicated this is also likely to cause adverse effects on wild bees and should therefore be avoided. Koster concluded in his research that ecological green management is a key factor for bees to establish in urban areas. With ecological green management is tried to foster all kinds of biodiversity, so both flora and fauna. A diversity of animals in an ecosystem contributes to a biological equilibrium in cities. The existence of gradients in green are very important for the establishment of biodiversity. An example of a gradient is the side of a pond or lake. When the side has a gentle slope the humidity of the soil also gradually changes. This makes different micro-habitats are created and higher biodiversity establishes.

For the variation of plants the floral diversity and the structure of the vegetation is important. Floral diversity is mainly important for insects and some seed-eating birds. Diversity in in structure is more important for fauna in general. The more variation in vegetation in terms of openness, coverage and layering, the more diverse the fauna will become. Vegetation is important for fauna as a nesting space, but also as a food source. Mowing, cutting therefore should be tried to be done in phases. Since there are many plants which attract bees and can be placed on green roofs/attached to façades, it is not possible to give specific upkeep measures for each plant species individually. For bee species which only fly on one or a few plant species it is important to pay extra attention on the spread of this species. Many weed species also appear to be valuable pollen and nectar sources for bees. Since weed tends to spread without the direct intervention of people, it does not need maintenance (Koster, 2000). Many fast growing meadow flowers, like bluebottles and marigold provide also pollen for honey bees and bumblebees. These flowers could be sown for a quick source of food for bees.

4.6.1.5 Soil/substrate

Local soils support local biodiversity and they are therefore considered to be best suitable for constructing green roofs (Brenneisen 2005, Dunnet, 2006). Since the transport distance is kept at a minimum the embodied energy is also low (Dunnet, 2006). The soil is often derived from established meadow lands or from woodlands. Soil from agricultural land is often not suitable, since it is too loamy. The soil is mixed with mineral rich soil layers, with the so called B-horizon soil layer. This soil mix tends to silt up which makes it unapt for plants to grow (Brenneisen, 2005).

For recreating urban habitat 15 cm subsoil from nearby green areas should be carefully removed and stored, so existing vegetation, seeds and soil organisms are conserved. For varying the microclimate substrates sand and gravel from nearby areas can be used too (Brenneisen, 2005).

Not much research is done on bees nesting in substrate layers on green roofs. In experiments Brenneisen found ground nesting bees present on green roofs. The research however does not clearly state whether these bees only use the roof as feeding ground or also as nesting place (Brenneisen, 2005).

The green roof should be designed with varying substrate depths and drainage regimes, so different microhabitats on and below the surface are created and preconditions for a diverse flora and fauna is created (Brenneisen, 2006; Koster, 2000). Soil gradients in humidity, nutrient richness and acidity should be created (Koster, 2000). Ground nesting bees dig nesting holes themselves up to 100 cm deep (Koster, A., Consultancy Vegetation Management*(Adviesgroep Vegetatiebeheer (1982-1990)),* 2013). Since the condition of the soil microclimate is a very determining factor for bees to nest, it is difficult to predict whether bees will really nest on green roofs. Further research and experiments are needed (Koster, 2013).

4.6.1.6 Nesting possibilities

In general are cities more favorable environments for bees to forage than agricultural area, since here is a more suitable micro-climate and there are many gardens and parks available which offer food sources for bees (Blaqcuière, 2009; v. Dugteren, 2013). In particular old neighborhoods are suitable for bees, since here buildings often contain cracks and holes where bees can nest. Also usually here is a larger supply of pollen and nectar, since the vegetation has had time to grow. New neighborhoods are often neat and clean, therefore some additional measures might have to be taken; for example the introduction of bee hotels to give bees possibilities to nest, or sowing of flowers which quickly provide food (Koster, 2013).

4.6.1.7 Additional objects on the roof

Although research does not secure bees nest on green roofs, Kadas found that bees visit green roofs with suitable nesting spaces significantly more than green roofs without these suitable nesting spaces. These nesting-space elements are elements like old dead wood (Steffan-Dewenter, Leschke, 2002; Westrich, 1996; Kadas, 2006), grass pollen, walls, hollow reeds, blackberry, elder, thistels, umbel lifers (Peeters, Raemakers & Smit, 1999), fissures in rocks (Westrich, 1996) or beehotels (Peeters, Raemakers & Smit, 1999). Also (sand)banks (Kadas, 2006) and cliffs, unstable slopes, field paths; bare or sparsely vegetated soils provide good nesting possibilities (Westrich, 1996). Domesticated honey bees need a beehive to nest (Koster, 2013). The complex structure of vegetation of green façades also offer suitable habitat for bees (Ottelé, 2011).

Furthermore honey bees also need water for the production of honey. Especially on a roof a small pond or puddle is convenient this saves them energy to fly tot water bodies on ground level. On very hot days this water is also used for cooling the colony (Le Conte & Vavajas, 2008).

4.6.1.8 Air Pollution

NO_x:

Literature stated the effect of air pollution on honey bees (and wild bees) is still quite unknown, but it might have a significant effect on their foraging behaviour. Honey bees use odours from flowers to locate flowers for collecting pollen and nectar. Disruption of the these odours by for example greenhouse gas emissions could therefore affect their ability to detect this odour. Theoretical models predict that greenhouse gas emissions (for example ozone, nitrate radicals and nitrate radicals) are expected to decrease the distance over which pollinators can smell plant odours. Empirical research has already shown that these polluting substances disrupt plant-to-plant odour communication (Girling et al., 2013). Girling et al. researched how diesel exhaust fumes influence the floral odours in air. They made a synthetical floral odour blend and analysed how the NO and NO_2 could change the composition of the odours in the air. They discovered that some components of the synthetically flower odour mix were undetectable when it was mixed with diesel exhaust fumes. This indicates that impedes honey bees to detect the flower odour and thus makes it harder to navigate to their food sources (Girling et al, 2013).

From this information can be concluded that bee attractive plants should ideally be located on areas where air pollution is low. It is also wise to take into account where pollutants will be blown by the wind. Since the wind in the Netherlands often blows from a South-West direction it would be better to create green areas for bees at the South – West side of a polluting source, for example a highway, than on the North-East side. Vegetation can also be applied to clean air, this vegetation has to have big leaf surfaces (Yang, 2008).

The degree of NO_2 pollution in the Netherlands differs a lot per city. The most congested areas in the Netherlands; Den Haag, Delft, Zoetermeer, measure the highest yearly average NO_2 concentrations. See Figure 12. In the heavy polluted cities it is especially important to apply vegetation for cleaning the air. In these cities it is of extra importance to create bee nesting spaces distant from busy traffic roads.

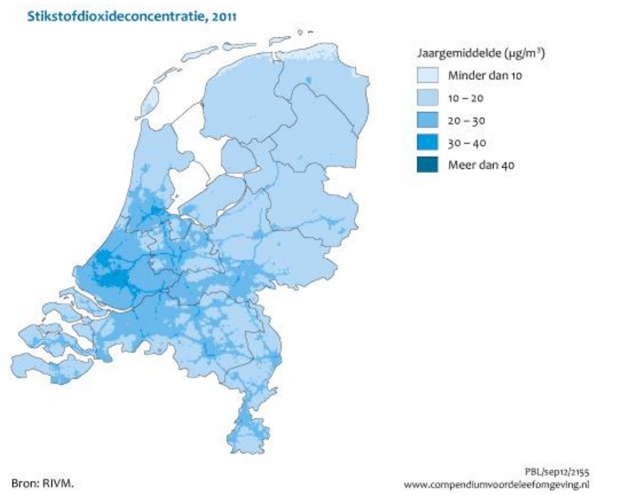


Figure 12 NO_2 concentrations in the Netherlands, Source: Compendium voor de leefomgeving, 2013

Dust/Particulate Matter:

Bees avoid foraging on flowers which are covered by dust/Particulate Matter from highways (v. Dugteren, 2013). The NO_x level in a city is a good indicator for the amount of particulate matter in a city. Bee habitats are here also best created on spaces where the pollution level is low.

CO_2

The average CO_2 content of atmospheric air is only about 0.03% (Brimblecombe, 1996) and small changes in this percentage will not adversely affect bees. Only non-atmospheric high percentages of CO_2 levels do effect bees, but this will not usually not occur in cities, only in controlled laboratory experiments. For more information see appendix 0.

4.6.2 Parameters on a macro-scale; green roofs allocated over the city

Besides parameters on the scale of an individual roof (micro-scale) are also some parameters on the scale of a city important (macro-scale) for bees to diffuse in an area. This section stresses these factors.

4.6.2.1 Proximity of roofs

The distance bees cover to forage is different for all types of bees. Wild bees fly out the shortest distance from the nest. This ranges from 0.5 meters up to about 300 meters (Westrich, 1996; Koster, A., Consultancy Vegetation Management, 2013). For honey bees and bumblebees this distance is much larger; they forage up to 3 km (Blacquière, 2009). Assuming that vegetation on green roofs should provide the entire food provision for populations, the distance between the roofs should thus for wild bees be at highest 300 distant from each other. For honey bees and bumblebees it could be up to 3000 meters. Of course in reality there usually is vegetation present at the ground level as well. Green roofs then have to complement the existing vegetation for food provision. The distant between the green roofs can then be shorter. Also green façades can complement roofs.
As already explained in section 3.2 relates the exact forage distance of a species to its body size. Of a few urban bees their forage distance and body size is known. For example the sand bees *Andrena barbilabris, Andrena cineraria, Andrena flavipes and Andrena vaga* have body sizes of in between 10 -15 centimeters. Their forage distance is 300, 300, 260 and 260 respectively. One of the smaller bees is *Chelostoma rapunculi*. This bee has a body size of in between 8 – 10 centimeters. This bee flies out less far than the sand bees, only 200 meters. Most of the urban bees have a body size of 5 – 10 (19 out of 47 species) centimeters or of 10 - 15 centimeters (25 out of 47 species). Only 3 bee species present in the urban area are smaller than 5 centimeters, see also appendix 0. For the design of green roofs is therefore assumed that most urban bees fly out at least 100 meters.

4.6.2.2 Integration green roofs with existing green

Green roofs can be designed as a self-sufficient habitat for bees or they can complement vegetation/nesting possibilities on ground level. For integrating the green roofs with existing green it is especially important to look at the flower season of the current vegetation and the kind of bees which are attracted by these plants. The current food provision might not provide pollen and nectar supply throughout the entire forage season. Also, the current vegetation may supply pollen and nectar only for (some) particular types of bees. With more variation in vegetation, there is more change of attracting a higher diversity of bee species during a longer period of the forage season.
Concerning nesting possibilities should be analysed whether the city urban area has suitable nesting spaces for bees. This could be sandy roads, plant stalks, straw mats, thatched roofs, cracks in buildings, bee hotels, wooden logs, etc (Koster, A., Consultancy Vegetation Management, 2013).

5 Design for biodiversity, design for bees

This chapter describes how the parameters explored in the previous chapter can be implemented on the scale of an individual roof and how the roofs should be spread over a city. The chapter first answers how design for biodiversity is perceived by different stakeholders. Then it is stated how the design for biodiversity, and in particular design for bees, is carried out in this research.

5.1 Design for biodiversity

For nature conservation in Europe the concept of ecological networks is increasing in importance both in policies and in practises (Ozinga and Schaminée, 2005). Wells, director of 'Biodiversity by Design' and Yeang call for design for biodiversity;'*The next level of urban 'greening' must go beyond the mere introduction of soft landscape into and around built form. It must exceed the eco-mimetic balancing of the abiotic (non-living) with biotic (living) constituents of built form and urban development, instead striving to produce buildings and urban areas as living habitats that are designed as functional ecosystems. p. 130 (Wells & Yeang, 2010).'* The reason for this advanced way of designing is because more complex ecosystems with a high biodiversity tend to be more resilient to disturbances. Also, balanced ecosystems need less expensive maintenance than monocultures (Wells and Yeang, 2010).

De Jong distinguished roughly two different approaches for design for biodiversity; conditionally (bottom-up) and operationally (top-down) design. The conditional approach is based on abiotic starting points on which vegetation possibilities are explored and then some of them are selected for the design. In this approach there is no clear vision on which species would or should establish in this area. The operational approach starts with desired target species and creating ideal habitats for them. These habitats should also attract other species. This top-down approach is often used by policymakers (de Jong, 2006).

Depending on the scope of the project, the targets can be set at many different levels. Biodiversity targets should be 'SMART' which means: Specific, Measurable, Realistic and Time-scaled (de Jong, 2006) and they can be chosen on different arguments. For conservation of species in Europe, the European Union establishes the 'Pan Ecological European Network.' Here target species for conservation are defined on basis of three different criteria. The first one is legal protection. The European Union is obliged to impose measures for conservation of these species according to agreements with international partners. The second criteria is species listed on IUCN Red lists, these species are threatened for extinction. Furthermore European endemic species, species which can only be found in Europe, can be protected. Each target species should meet at least one of these criteria. Besides these criteria, the species should also be assessed on the keystone function in an ecosystem and to which extent the species is a 'flagship' for other threatened species and ecosystems (Ozinga and Schaminée, 2005).

Protection of bees fits the requirements of the European guidelines, since bees can be considered as a keystone species (Wells and Yeang, 2010). The bee is essential for crop pollination and therefore essential for global food provision. Bees function as an indicator for floral diversity and ensure genetic variation of plants. A top-down approach as described above is used for the development of the case studies in section 5.4 and section 5.5. The intention of the case study is to develop an ideal habitat for bees. Bees are the keystone species and a top-down approach is used to provide implementation guidelines.

5.2 Levels of scale design for biodiversity in urban areas

Green networks are very important for biodiversity conservation. Different levels of green networks can be distinguished. The first level is the Ecological Head Structure (EHS). The EHS is a green network within the Netherlands. Its purpose is to increase natural areas and to connect existing natural areas. The main aim of EHS is to provide habitat for flora and fauna. Plants and animals can distribute over large distances by connecting their natural areas. Large natural areas are beneficial because they have a higher biodiversity and their ecosystems are more resilient for disturbances than small natural areas. The EHS is formed by:

- existing natural area, reserves and natural developing areas and their robust connections
- agricultural areas with possibilities for agricultural nature management
- large water bodies

The three components in the Ecological Head Structure are green core areas, natural developing areas and connecting areas. Green core areas are zones with a surface area of at least 250 acres, these are natural areas, estates, forests, large water bodies and valuable agricultural landscapes. Nature developing areas are fields with high potential for creating international or national valuable natural areas. Connecting areas are areas which connect the green core areas and the nature developing areas (GroeneRuimte.nl, 2013). Figure 13 shows the Ecological Head Structure in the Netherlands.

The second level of scale for green structures is a green network between cities. Municipalities assign different names to this level of scale, but this green network is usually called 'Green Structure' or 'Green Head Structure'(Zutphen.nl, 2013; maps.amsterdam.nl, 2013). Figure 14 shows the Green Head Structure in Amsterdam as an example.

Level three consists of the 'Ecological Structure' within cities. The Ecological Structure connects the elements from the Green Head Structure and it connects the city green with green outside the city (maps.amsterdam.nl, 2013; denhaag.nl, 2013). Figure 15 shows the Ecological structure of Amsterdam as an example.

The last level considered is formed by other trees, shrubs, green walls and façades which are not part of the above mentioned categories.

Figure 13 Level I: EHS, Source: Ministry of Economic Affairs, Agriculture and Innovation, 2011

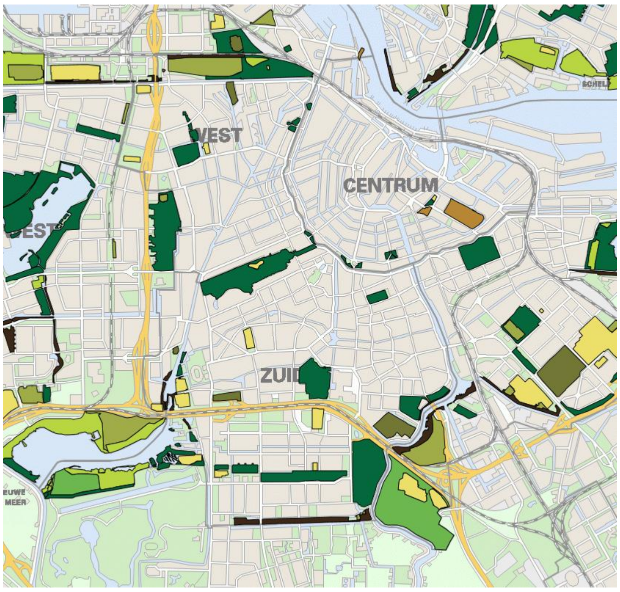


Figure 14 Level II: Green Head Structure in Amsterdam, Source: maps.amsterdam.nl, 2013

Figure 15 Level III: Ecological Structure, Source: maps.amsterdam.nl, 2013

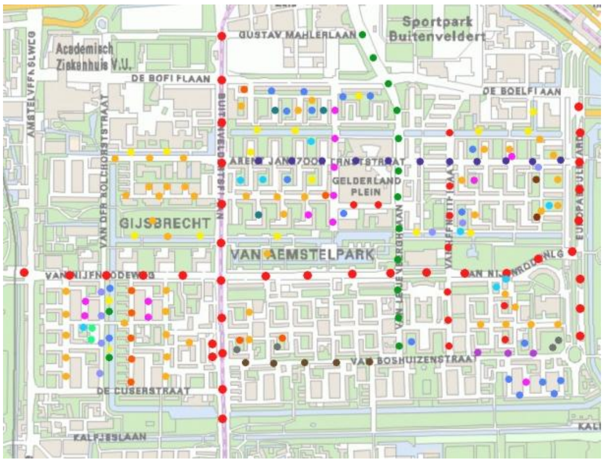


Figure 16 Level IV: Structure of other vegetation, Source: own figure, 2013

Since wild bees only fly out at distances between 0.5 and 300 meters especially the last level, level IV is an important green network structure for bees. If the vegetation on this level of scale provides a continuous food supply and sufficient nest possibilities, bees can diffuse over the city. If there is a lack of pollen and nectar or a lack of nesting possibilities on this level of scale, bees cannot spread over the city.

Design for biodiversity on an architectural level also has different levels of scales. Here three different scales can be distinguished; the urban/city scale, the scale of an individual building itself (a combination of green roofs and façades) and the scale of a building component, a green roof of façade. Figure 17 to Figure 20 show these different levels of scale.

Figure 17 Urban/city scale, Source: Rotterdam.nl, 2013

Figure 18 House, Source: iconarchive.com, 2013

Figure 19 Building component, Source: iconarchive.com, 2013

In this research case studies are carried out on the urban/city scale and on the scale of a building component. For the case study on urban/city scale is chosen because this scale is important for the ability for bees to diffuse over the urban area. The case study on the scale of a building component is chosen because on this scale has to be determined which properties are important to create bee habitat. The scale of the house (green roofs and facades) will be quite similar to the scale of the building component, so therefore investigating this scale will probably not lead to major new insights.

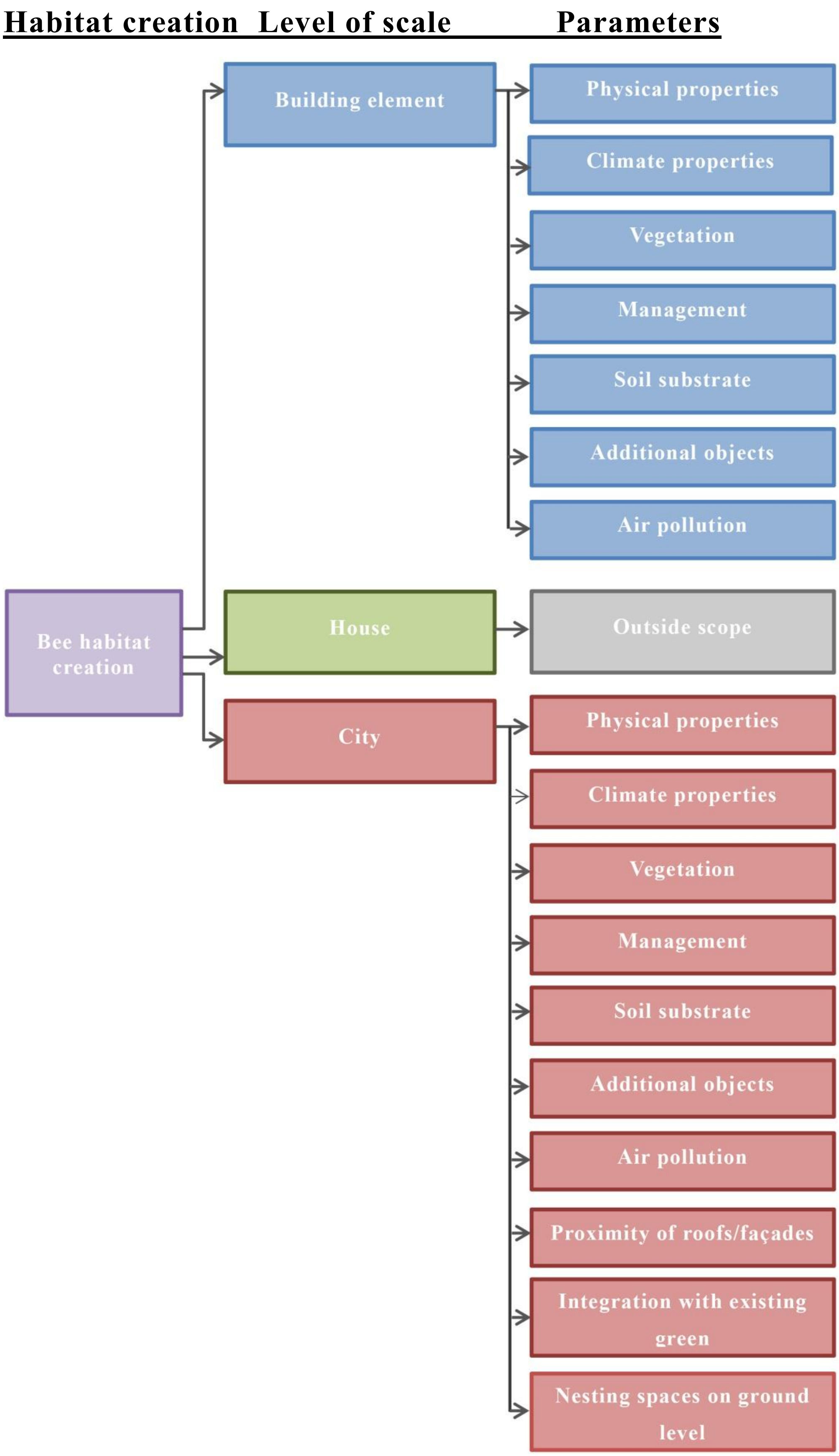


Figure 20 Bee habitat creation

5.3 Dutch trends in 'Green architecture'

The first green roof in the Netherlands was applied in 1987 on a residential building. Residents, architect and the building constructor formed a tight collaboration for the execution of the project. By then the term sustainability as we know it now was not yet widely known, but the focus was on creating 'ecologies' and to make buildings which were human- and environmentally friendly. Professors at the TU Delft highly questioned the success of the green roofs (Fraanje, 2012). Nevertheless, nowadays there are many examples of successful green projects; buildings with green roof and or green façades (Fraanje, 2012). Many private houses have a sedum- or grass cover, the grass lawn on the TU Delft attracts numerous tourists each year and companies cover parking lots with a green layer.

Green roofs and green façades fit perfectly in the concepts 'Cradle to Cradle' and 'bio-based built' and to build energy neutral. The main thought behind Cradle to Cradle is that waste is a source of food, so used materials form the basis of a new product. All waste products should be reused or should be environmental neutral, so the cycle is closed (Cradle-to-Cradle.nl, 2013). An energy neutral building has an yearly energy use equal to zero or even produces energy (Ministry of Housing, Spatial Planning and Environment, 2010).

In times of the first applied green roof the roof fitted within the concept of 'constructing ecological'(*'bouwbiologisch bouwen'*), which focusses on creating a healthy indoor climate. In the 1980ies much was known about how to create this healthy climate. Nowadays sustainable design concepts focus on reducing energy demand and using renewable energy sources. Although concepts aim to be 'ecological', many buildings end up having an unhealthy indoor climate which causes the 'sick building syndrome'. The sick building syndrome refers to people suffering from health problems because of an unhealthy indoor climate. Pijnenborgh, the architect of the first applied green roof, stresses the importance of integral project design, which implies more should be done than focusing on reducing energy consumption. A green roof can be part of integral project design, because it has many other advantages besides reducing energy. These advantages range from a better indoor climate to reducing the urban heat island effect and enhancing biodiversity, see also section 4.1.

One of the first carried out green roof projects are the formal head quarter of NMB (currently ING) in Amsterdam-Southeast (1979-1987) and the building of 'Gasunie' in Groningen, both designed by architects Alberts & Van Huut. A very pioneering project designed by Bethem Crouwel Architects was the sedum roof applied on the Schiphol plaza in 1992-1995. Since this project counted a surface area of 8.500m^2 area and Schiphol being a busy transport hub, many people were exposed to the concept of green roofs. BEAR architects designed 'The Little Earth' ('De Kleine Aarde') in Boxtel in 1995. This is an example of a project where the green roof was part of the integral concept. In this project also rain water was used to flush toilets. Another location of a green roof which got much exposure but via a different route was the grass, moss and sedum roof in the Media park in Amsterdam, made by MVRDV architects. This roof was shown in several tv broadcasts (Bouwtrends, 2011).

Currently even more green roof projects are established. In 2003 in Best the biggest roof garden landscape of the Netherlands was created. The surface area of 4 acres completely covers the train tracks connecting the city with other neighboring cities. In Barendrecht was in 2006-2007 a green roof containing a pond applied on the roof of the train tracks. By then educational institutions also began to build green roofs, for example the Academy of Physical Education in Amsterdam in 2006 and the ROC Graafschap College by Atelier Pro in Doetinchem in 2010. In Hoogvliet a project designed for musicians proved that green roofs have a good soundproofing effect (Bouwtrends, 2011).

This trend goes along with the trend that municipalities become more and more aware of the beneficial effects of green roofs and therefore stimulate the build of green roofs by providing subsidies (Amsterdam.nl, 2013; gemeentegroningen.nl, 2013; Rotterdam.nl, 2013). Table 8 shows an overview of different municipalities and the different subsidies they provide. Especially the municipality of Rotterdam is currently very much interested in applying green roofs because of the water retaining capacity of green roofs. The city suffers from a water storage problem and this problem is expected to increase due to climate change. The research of the municipality begins with a striking quote from Le Corbusier: '*Is it not against all logic when the upper surface of a whole town remains unused and reserved exclusively for a dialogue between the tiles and the stars'- Le Corbusier* (Le Corbusier, quoted by Municipality Rotterdam, 2007).

Municipality	Subsidies
Alphen aan den Rijn	20 €/m^2
Amsterdam, district Nieuw-West, West, Zuid	Max. 50 €/m^2
Cappele aan den IJssel	25 €/m^2
Den Haag	25 €/m^2
Eindhoven	25 €/m^2
Groningen	Max. 30 €/m^2
Harderwijk	25 €/m^2
Leeuwarden	Max. 30 €/m^2
Nieuwegein	25 €/m^2
Nijmegen	25 €/m^2
Rotterdam	25 €/m^2
Utrecht	30 €/m^2

Table 8 Overview subsidies for green roof different municipalities, Source: Zinco.nl, 2013

The costs for an extensive green roof are on average 50 €/m^2 (sedumshop.com, 2013 groendak.info, 2013, groenedaken.net, 2013). From the above table can be concluded that about half of the price per m^2 can be covered by subsidies. Since green roofs extend the lifetime of the roof membrane, the maintenance costs of the roof is further lowered. Also the green roof leads to some energy savings within the building. The payback time of the investments for a green roof is between 8-20 years (Groendak.info, 2013).

From the above section above it can be concluded that the build of green roofs is an upcoming trend in the Netherlands. The benefits of green roofs are more and more recognized: roofs are applied for rain water retention, for sound insulation and even fit within an integral sustainable concept as ‘The Little Earth’. The provision of subsidies by municipalities makes the investments for green roofs even more attractive.

The following chapters of this research will carry out case studies on both an individual roof and roofs spread out over the city to see how green roof design for bees could be carried out. The first case study analyses the qualities of an existing roof for bees, the second case study explores how a green structure should be developed in a city when fostering the bee populations is one of the important aims of the project.

5.4 Individual roof; Micro-scale

From the chapters before conclusions can be drawn for implementation parameters important for bees to flourish on a green roof. These parameters are summarized in the following table:

Parameter	**Sub-parameter**	**Required**
Physical properties roof	Height of the roof	• 12-20m
	Size of the roof	• HB*: >1000m^2 • B*: 25m^2 • WB*: 10m^2
	Slope of the roof	• Flat, somewhat sloping
	Orientation of the roof	• South
Vegetation	Types	• Local indigenous plants (see appendix 0) • Pollen supply guaranteed throughout the forage season (see appendix 0)
	Distribution/density	• Few m^2 bare, sandy open area
Management	Pesticides, Pesticide A,B,C	• Preferable none

	Management type	Organic control: • Different stages of development of plants should be coherent and in an optimum ratio • Mowing, cutting done in phases. • Letting weed species grow
Soil/substrate	Type	• Use of local soil and substrates • Top 15 cm layer derived from meadow lands and woodlands, but also sand and gravel • Varying substrate depths, up to 70 cm to support all types of ground nesting bees • Varying drainage regimes, differences created in humidity, nutrient richness and acidity
Climatic properties	Wind	• Sheltered place, little wind, especially the opening of the nest should be sheltered. • Wind speed less than 4-5km/h • Little turbulence • Protection (e.g. by high buildings) from the wind on the south-west side.
	Humidity/Rain	• Dry places • Humidity air of bee hive less than 90%.
	Sun	• Sun when bees fly out mostly, so between 11.00 a.m. and 16.00 p.m.
	Temperature	• *HB+BB*:* 10-35 °C, optimum 18-25 °C • *HB+BB*:* 10-35 °C, optimum 18-25 °C • WB: 15-18 °C
Nesting possibilities	Environment in general	• Natural area
	Buildings	• Buildings with nesting possibilities
Additional objects on the roof	Beehive, blocks with wholes, sand layer, etc.	• Old dead wood, grass pollen, walls, hollow reeds, blackberry, elder, thistles and umbel lifers, bee hotel, sandy slopes,

		cracks in rocks
Pollution	Air pollution NO_x/PM	• Little NO_x pollution • Little dust/particulate matter

Table 9 Overview of micro-scale parameters

*HB: Honey Bees, WB: Wild Bees, BB: Bumblebees

5.5 Green roofs in cities; Macro-scale

From the chapters before conclusions can be drawn upon design parameters/factors important for bees to flourish in Dutch cities. For analysing the circumstances on a city scale the micro-parameters are also important, but then they are scaled up to a larger level. The parameters on city-scale are additional parameters on top of the micro-parameters.

Parameter	**Sub-parameter**	**Required**
Micro parameters	*Micro parameters*	*Micro parameters*
Proximity of roofs		HB* + BB*: ≤ 3 km WB*: ≤ 0.5 - 300 metres → 100 meters for urban bees
Integration with existing green		• Roofs (facades) self-sufficient in food/nesting possibilities
		• Vegetation complementary to present vegetation
Nesting spaces on ground level		• Sandy soils, cracks in buildings, old dead wood, logs, hollow reed, beehotels, etc.

Table 10 Overview of macro-scale parameters

*HB: Honey Bees, WB: Wild Bees, BB: Bumblebees

5.6 Individual roof; Case study roof garden VU University of Amsterdam

For the case study on the scale of a building component a case study of a green roof in Amsterdam is chosen. This roof is analyzed to see if the current situation is a suitable habitat for bees. Then it is determined if any improvements can be made to make the roof more attractive to bees. To illustrate how the list of parameters can be used, the list is tested on a case study in Amsterdam, on a roof garden at the VU University of Amsterdam.

The VU University Campus is located in the middle of the district 'Zuideramstel', in between the financial district the 'South-axis', in the north and living areas in the south. One kilometer westerly there is a green area 'Amsterdam Wood' ('Amsterdamse Bos') which contains the well-known rowing track ‘The Wood Lane’(‘De Bosbaan’). At the eastern side of the campus there is an important traffic road and next to this road there are living areas, see also Figure 21. The red star on the map represents the VU green roof.

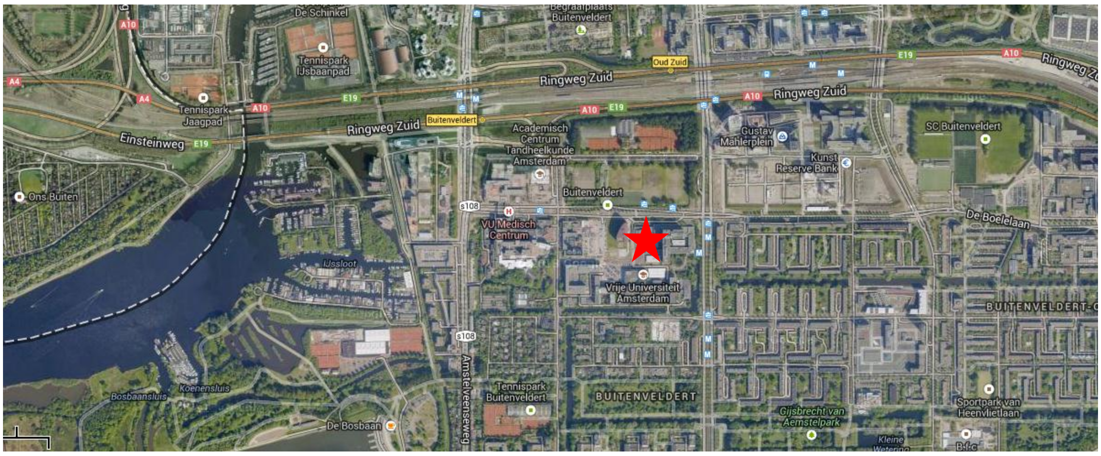


Figure 21 The VU university in Zuideramstel Source: Google maps, 2013

The university campus itself has little green space. The main campus square has few trees and is barely green. A big share of the square is used as parking lot. The newest building on the south of the campus, the so-called ‘red potato’ is placed on a lawn, which is the most green space to be found. Since May 2013 the green space on the campus is increased by the built of a green roof on the lowest part of the main building. This is so far one of the few green roofs in the area. However in the vision of the VU campus green roofs are integral component of the future developments. *‘The future campus is a car-free, urban environment with green roofs, squares, underground car-and bicycle parking lots and open buildings* (VU University Amsterdam, 2013).*’* Transparency is a key word in the vision so meeting other people is stimulated. Sustainability is a concept carried out on all aspects of the future campus; in flexible buildings, in carrying out the concept of ‘Trias energetica’, in the quality of urbanism and architecture and the (technical) infrastructure (VU, 2013). The ‘Trias Energetica’ is a three-step approach to become more sustainable in terms of energy use. These steps are minimalizing energy use, using renewable energy sources and using fossil energy sources as efficient as possible (Trias Energetica.com, 2013).

Figure 22 VU University of Amsterdam Campus, source: Google maps, 2013

Figure 23 VU University of Amsterdam Campus, source: Google maps, 2013

Figure 24 VU Campus square

Figure 25 VU Green roof

Sustainability in terms of biodiversity does not get special attention in the plans for future developments. Creating an environment suitable for bees is thus also not considered. When the concept for the green roof was developed it was thought of placing bee hives on the roof, but this was not executed because of the fear of getting stung by bees. Though there is a small test garden available to execute research after bees and their habitat. The picture on the bottom right of Figure 25 shows this test garden.

The management team has indicated to be interested to get to know how the roof garden performs in terms of a suitable bee habitat and what can be done to improve the roof. The following sections explore this. The analysis is done based on the different parameters as stated in section 4.6.1.

5.6.1 Physical properties roof

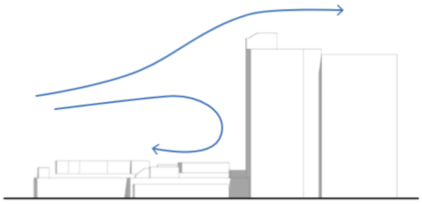
The roof garden is on top of the 4th floor and the surface of the garden is 823,69 m^{2} (Karres en Brands, 2012). The surface of the garden is flat. The roof is not completely vegetated so it is difficult to provide self-sufficient food supply for honey bees. For a colony of bumblebees or wild bees there is more possibility to provide a self-sufficient food supply. However, the current vegetation not provide pollen and nectar in the beginning of the forage season, in March and April.

The orientation of the roof is beneficial, the roof is connected to a higher building at the east side, but not at the south side, so the sun is not blocked during most of the solar hours, see also section 5.6.2.

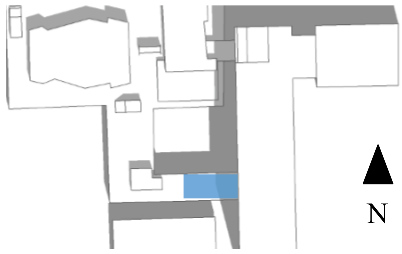
5.6.2 Climatic properties

In the Netherlands wind often comes from a South-west direction. This green roof is located on a roof without other high buildings at the South-west part of the roof which can block the wind, see Figure 26. Since the roof is on the 4th floor, strong winds can be expected, especially on the North part of the roof. The blue square on the drawing on the bottom right is the part of the roof where the highest wind speeds can be expected, see Figure 26. From own experience it can be stated that the roof is often a windy place. However, for more precise information measurements should be done. Habitat creation on the roof should thus focus more on the North part of the roof, because here is less wind nuisance.

High façade on the east



Assumption fall wind



Assumption most wind load roof

Figure 26 Wind study, Source: Karres en Brand Architects, 2012

Since there are no high buildings blocking the prevailing wind coming from South-West direction, also rain is not blocked. Additional measures to protect bees from strong winds and rain on their nesting spaces could improve the situation to establish on roofs. This could be for wild bees for example high vegetation, or a 'Beeglo'(Beelease, 2013), see Figure 27.

Figure 27 'Beeglo'protecting honey bee hives Source: Beelease, 2013

Figure 28 shows a sunlight study of the roof. It shows that the roof is only covered with shadow during the morning. From around 11.00h 'o clock onwards the roof is without shadow. Bees fly out between 11.00h and 16.00h and this roof is then un-shadowed. This is thus favourable for bees. The graph on the bottom right shows the parts of the roof receiving most sunlight (white) and parts of the roof receiving least sunlight (dark yellow).

Figure 28 Sunlight study Source: Karres en Brands Architects, 2012

5.6.3 Vegetation VU

Figure 29 shows an overview of the vegetation present on the campus of the university.

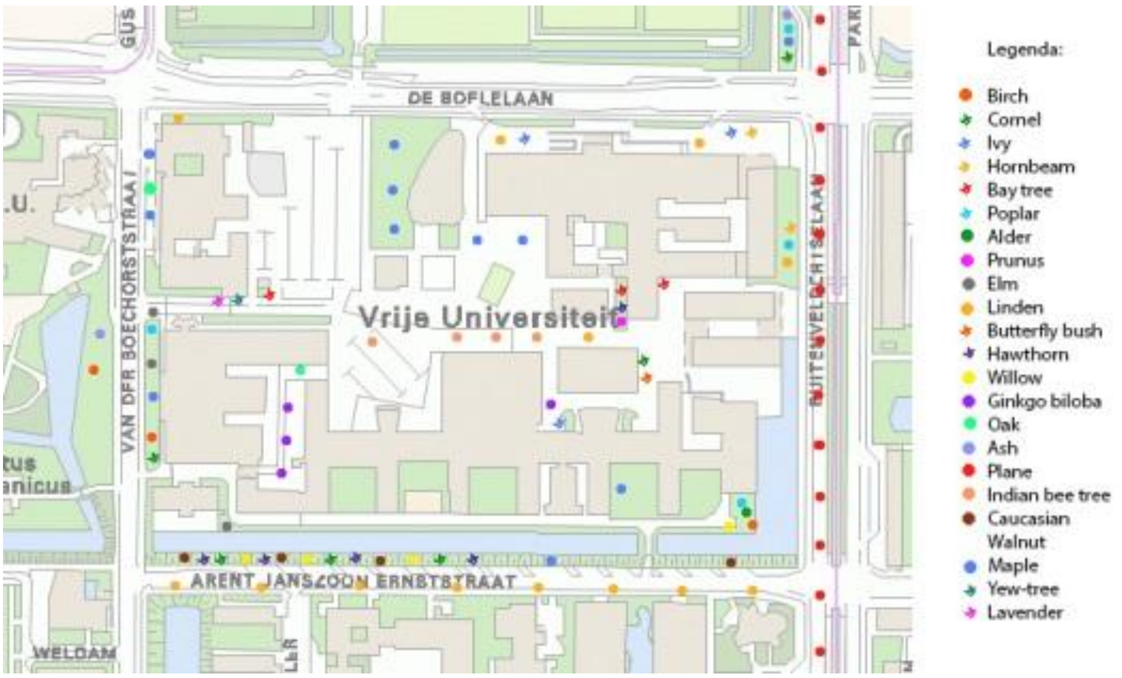


Figure 29 Vegetation environment VU*

Most of these plants are attractive for bees:

Figure 30 Bee attractive plants in the environment of the VU*

*N.B. The figures do not represent the exact number of trees, this is a simplification of the real situation.

Case VU			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Fly seeson bees		HB + BB + WB												
		Bumblebees												
		Honey bees												
Current vegetation	**Native**	**Types of bees attracted**												
Bay tree *(Prunus Laurocerasus)*	No	Bumblebees, honey bees, wild bees (sand bees (Andrena))												
Birch *(Betula)*	Yes	Honey bees												
Black poplar *(Populus nigra)*	Yes	honey bees												
Butterfly bush	No	Butterflies, bumblebees, honey bees												
Cornel *(Cornus)*	Yes	Honey bees												
Hawthorn *(Crataegus)*	No	honey bees												
Indian bee tree *(Catalpa bignonioides)*	No	Bumblebees, honey bees												
Linden *(Tilia)*	Yes	Bumblebees, honey bees, wild bees, butterflies												
Lavender *(Lavendula angustifolia)*	No	Butterflies, bumblebees, honey bees, wild solitary bees, (Leaf cutter and dauber bees (Megachile willughbiella, M. centucularis, M. versicolor, mason bees(Osmia).)												
Ivy *(Hedera helix)*	Yes	Wild bees (only Ivy bee *(Colletes hederae)*),honey bees, bumblebees and butterflies												
Maple *(Acer pseudoplatanus)*	Yes	Solitary wild bees(sand bees *(Andrena)* , amongst others *A. barbilabris* , yellow-ledged mining bee *(A.flavipes)* , A. fulva *(A. fulva)* , Early mining bee *(A. haemorrhoa)* , *A. tibialis* , mining bees *(Osmia rufa)* , bumblebees												
Yew-tree *(Taxus baccata)*	Yes	Honey bees												
Oak (Summer) *(Quercus robur)*	Yes	Honey bees												
Willow (crack-) *(Salix fragilis)*	Yes	Bumblebees, honey bees												
Willow (weeping-) *(Salix x seprucalis)*	Yes	Bumblebees, honey bees												

Table 11 Flowering period bee attractive plants environment VU

Advised complementary plants														
Cross-leaved Heath (Erica tetralix)	Yes	Bumblebees, honey bees, wild bees												
Linden tree *(Talia)*	Yes	Bumblebees, honey bees, wild bees												

Table 12 Advised complementary plants environment VU

As can be seen from the previous figures the vegetation on the VU campus is self-sufficient for honey bees, because there are plants flowering during their whole forage season. In March however the only flowering plant is a Yew-tree hedge. At the end of the forage season Ivy is the main source for pollen and nectar supply. For bumblebees the only month lacking pollen and nectar supply is March. For wild bees the environment is not self-sufficient. However, most urban bees fly out during May-August (see also appendix 0), this is also the flowering season of many plant species. Therefore for most wild bees it is more important there is a variety of plants flowering in May-August. Much vegetation flowers in this period. This could be for example a Linden tree (*Talia*) flowering in June-July and Cross-leaved Heath (*Erica tetralix*) flowering from June to September.

5.6.3.1 Vegetation VU green roof

In the former section is concluded that the environment of the VU green roof provides pollen and nectar during the whole forage season for honey bees and that most plants flower during the period in which most wild bees fly out. In this section the same analysis is carried out for the plants on the green roof itself.

For the design of the green roof a few starting points are considered. The vegatation, especially bigger plants, are selected on basis of their weight. Plants with a relatively low weight are chosen. These are for example birches, which are slender trees with a low specific gravity. Moreover, the management team of the VU wanted to integrate some of the shrubs from the botanical garden on the roof (Koningen, 2013). The rest of the vegetation is chosen by the appointed landscape Architects. For the complete list of vegetation on the roof, see appendix 0. From all the vegetation on the roof only a small share is bee attractive vegetation, see Table 13.

Case VU green roof			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Fly seeson bees		HB + BB + WB												
		Bumblebees												
		Honey bees												
Current vegetation	**Native**	**Types of bees attracted**												
Whirling butterflies *(Gaura lindheimeri)*	No	Honey bees, bumblebees, wild bees (Leaf cutter and dauber bee *(Megachile versicolor)*												
Oxe-eye daisy *(Leucanthemum vulgare)*	Yes	Butterflies, solitary bees (*Colletes daviesanus*), *(Heriades truncorum)* , sand bees *(Andrena flavipes)* , sweat bees, mining bees (*Halictus rubicundus; Lasioglossum calceolatum , H. tumulorum, L.eucozonium, L.malchurum, L. morio, L.parvulum, L. pauxillum, L.vollosulum, L. zonulum*) and honey bees												
White Stonecrop *(Sedum album)*	Yes	Wild bees (yellow-masked bees (*Hylaeus brevicornis, H communis, H. gibbus, H hyalinatus*) sweat bees, mining bees (*Lasioglossum morio, L. sexstrigatum*) sand bees *(Andrena)* , bumblebees, honey bees, butterflies												
Breckland thyme/wild thyme/creeping thyme *(Thymus serpyllum)*	Yes	Butterflies, solitary wild bees, bumblebees, honey bees												
Oregano, wild marjoram *(Origanum vulgare)*	Yes	Butterflies, solitary wild bees (mason bee *(Osmia)* , sand bees *(Andrena)* , sharp tailed bee *(Coelioxys)* , wasp bee *(Nomada)* , blood bee *(Specodes)* , bumblebees, honey bees												

Table 13 Current bee attractive vegetation VU green roof

Advised complementary plants			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Winter heath 'Winterbeauty' *(Erica carnea)*	No	Honey bees, bumblebees, butterflies												

Table 14 Advised complementary vegetation VU green roof

Out of the current vegetation, only 5 out of the 16 plant species are bee attractive plants. Also, the flowering periods of these plants do not cover the entire forage season of bees. Bees fly out from March to October, but the current plants do only supply pollen and nectar from May to October. Therefore additional plants could be introduced to also supply pollen in March and April. Best is to choose native plants, but the list of bee attractive plants to plant on green roofs does not provide a native plant flowering in March (see appendix 0). There is only one of the plants which flowers then; the Winter heath or Winter beauty *(Erica Carnea)*, so this would be the best option. As already stated before, this list is not definite, but further research is needed to determine which other plants are both suitable on roofs and are attractive for bees.

5.6.4 Management

Weed is frequently removed by weeding, shrubs are pruned every now and then. There are no pesticides and or herbicides being used (Koningen, 2013). It would be more favourable for bees to let weed grow, so it can flower and it can provide extra pollen and nectar in addition to the other vegetation. The fact that there are no pesticides being used however is very positive.

5.6.5 Soil/substrate

Extensive substrate is used for the part of the roof covered with sedum. An intensive substrate layer in combination with an intensive mineral substrate layer is used for the parts of the roof where higher vegetation is planted (Koningen, 2013). The intensive and extensive substrates are also applied in different soil depths, and thus different microclimates are created. The brand and therefore the exact properties of the substrate layer and the construction system is not exactly known. This is needed for more precise analysis.

The roof does not contain any sandy soil, only a gravel substrate layer. Therefore it is questionable whether ground nesting bees will nest on this roof. By introducing some sandy areas the chances bees will nest on the roof increase. In further research this roof could be used for carrying out experiments to see if bees are willing to nest in the substrate layer of the roof.

5.6.6 Additional object on the roof

In the green roof design is no attention paid to habitat creation for bees. This resulted in a design with little nesting possibilities for bees. One possible nesting space could be the joints in between the wooden decking (see Figure 31 and Figure 32). The situation can be easily improved by for example placing dead tree branches on the roof or by placing a bee hotel. Also a small pond could improve the roof as a bee habitat.

Figure 31 Southern part of the roof and the high building connected to it.

Figure 32 Northern part of the roof and the 'red potato' building next to it.

Figure 33 Example of a beehotel, Source: Inhabitat.com, 2013

Figure 34 Bee nesting in beehotel, Source: pawesome.net, 2013

5.6.7 Air Pollution

The university is located in between several important traffic roads. At the North-side the university is about 300 meters distant from the highway A10. At the west-side the main traffic junction for the district Zuideramstel is connected to the road 'Amstelveenseweg'. This road is often very busy since it is the main access route for the VU medical centre and for the rest of the Zuideramstel. Also the road on the east-side, the 'Buitenvelderstelaan' is an important connection between de Zuideramstel and the other part of Amsterdam-South on the other side of the A10. Then the 'Boelelaan' connects the 'Amstelveenseweg' with the 'Buitenvelderstelaan', which is also a very busy road. See also Since there is much road traffic surrounding the campus the amount of air pollution can also be expected to be more than more Southwards in the area, where there is less traffic. It is however beneficial that the roof garden is located on the square-side of the building, so the high building on the east-side could prevent some of the particulate matter to deposit on the roof. Exact measurements however are needed to determine the exact air pollution level. On the scale of one roof, it is not really possible to improve air quality. On a bigger scale planting green can improve air quality. This is further elaborated in section 5.7.3.

Figure 35 Roads surrounding the VU Campus

5.6.8 Conclusion

Table 15 shows a summary of the analysis done on the VU green roof. When a value has a green box, the situation regarding to that parameter is considered as beneficial, since the value fits within the required ideal value. If the box is red the current situation does not meet the ideal required value. An orange box means some properties are beneficial, some are not, or there is more research required to give an accurate judgement.

Parameter	Sub-parameter	Required	Value	Remarks
Physical properties roof	Height of the roof	• 12-20m	4th floor	
	Seize of the roof	• HB: >1000m^2 • B: 25m^2 • WB: 10m^2	823,69 m^2	Roof can be self-sufficient for wild bees + bumblebees. For honey bees more surface is needed
	Slope of the roof	• Flat, somewhat sloping	Flat	
	Orientation of the roof	• South	South (surrounded by higher buildings at north and east side)	
Climatic properties	Wind speed	• Sheltered place, little wind, especially the opening of the nest should be sheltered. • Wind speed less than 4-5km/h • Little turbulence • Protection (e.g. by	No high buildings blocking the wind, most wind nuisance on the South part of the roof	Habitat creation for bees is best at the North part of the roof since here is less wind nuisance

		high buildings) from the wind on the south-west side.		
	Humidity/Rain	• Dry places • HB: Humidity air of bee hive less than 90%.	No high buildings blocking the wind, so also not blocking the rain	
	Sun	• Sun when bees fly out mostly, so between 11.00 a.m. and 16.00 p.m.	Between 11.00 a.m. and 16.00 p.m.	
	Temperature	• *HB+BB:* 10-35 °C, optimum 18-25 °C • *HB+BB:* 10-35 °C, optimum 18-25 °C • WB: 15-18 °C	Low wind-chill	Exact measurements are needed
Vegetation	Types	• Local indigenous plants (see appendix 0) • Pollen supply guaranteed throughout the forage season (see appendix 0)	5/16 bee attractive plants, all of them indigenous Pollen and nectar is lacking in March Non-bee attractive plants have a higher soil cover than non-bee-attractive plants	Only a few plants
	Distribution/density	• Few m^2 bare, sandy open area	No sandy, open soil available	No
Management	Pesticides, Pesticide A,B,C	• Preferable none	Management	Pesticides, Pesticide A,B,C
	Management type	Organic control: • Different stages of development of plants should be coherent and in an optimum ratio • Mowing, cutting done in phases. • Letting weed species grow		Management type
	Management type	Organic control: • Different stages of development of plants should be coherent and in an optimum ratio • Mowing, cutting done in phases. • Letting weed species grow	Weeding and pruning	
Soil/substrate	Type	• Use of local soil and substrates • Top 15 cm layer derived from meadow lands and woodlands, but also sand and gravel • Varying substrate depths, up to 70 cm to support all types of ground nesting	Combination of intensive and extensive substrate in different layer thicknesses. More details however needed for better analysis	Difficult to predict, more specification needed (exact properties of the substrate)

		bees, • Varying drainage regimes, differences created in humidity, nutrient richness and acidity		
Climatic properties	Wind speed	• Sheltered place, little wind, especially the opening of the nest should be sheltered. • Wind speed less than 4-5km/h • Little turbulence • Protection (e.g. by high buildings) from the wind on the south-west side.	No high buildings blocking the wind, most wind nuisance on the South part of the roof	Habitat creation for bees is best at the North part of the roof since here is less wind nuisance
	Humidity/Rain	• Dry places • HB: Humidity air of bee hive less than 90%.	No high buildings blocking the wind, so also not blocking the rain	
	Sun	• Sun when bees fly out mostly, so between 11.00 a.m. and 16.00 p.m.	Between 11.00 a.m. and 16.00 p.m.	
	Temperature	• *HB+BB:* 10-35 °C, optimum 18-25 °C • *HB+BB:* 10-35 °C, optimum 18-25 °C • WB: 15-18 °C	Low wind-chill	Exact measurements are needed
Geographic location	Environment in general	• Natural area	Little green	
	Buildings	• Buildings with nesting possibilities	'Clean' buildings	
Additional objects on the roof	Beehive, blocks with wholes, sand layer, pond, etc.	• Old dead wood, grass pollen, walls, hollow reeds, blackberry, elder, thistles and umbel lifers, bee hotel, sandy slopes, cracks in rocks	Not there	
Pollution	Air pollution NOx/ Dust/PM	• Little NO_2 pollution • Little dust/particulate	In between 3 busy traffic roads	Exact measurements are needed

Table 15 Score parameters VU green roof

The next table provides an overview of all the parameters. It states which ones are strong points and which ones are weak points. Moreover improvements are stated in the last column. The parameters which are valued as 'in between' or those that need more research are also listed among the weak points. This is because there is also room for improvements.

Strong points	**Explanation**	
Physical properties roof	All 4 parameters offer potential to create an ideal bee habitat	
Weak points		**Improvements**
Climatic properties	Quite open space, so windy, low wind-	Create protected nest spaces, e.g.

	chill	vegetation or 'Beeglo' for honey bees
Vegetation	Only a few bee attracting plants, with the lowest soil cover	Introducing vegetation which flowers also in the early spring. Change the ratio of bee attractive plants and non-bee attracting plants
Management	No use of pesticides, but weed is frequently removed	Weed should not be removed when it is flowering
Soil/substrate	More research needed	Doing research after the exact roof system. Experiments could be done to see if bees want to nest in roof substrate at all.
Geographic location	Little green and nesting spaces	Creating nesting spaces
Additional objects on the roof	Little additional objects	Place beehotel, small pond, dead wood, ect.
Pollution	Roof in between three busy traffic roads	Difficult to improve, it could be tried by planting plant species which are specifically good in cleaning the air

Table 16 Summary VU green roof strong and weak points

Overall it can be concluded that there is a lot of room for improvement concerning the analyzed parameters. The most important properties, and the ones most difficult to change, the physical properties of the roof are beneficial. Therefore the potential of developing the roof into a favorable environment for bees is high. Most improvements to be done are small interventions.

Also when a bit larger scale is considered (e.g. the scale of the whole campus) then the potential is also significant. In the campus development plans, green roofs are named as one of the key words. So the checklist provided in this research can be used to create bee-attractive roofs from the initial state of the design. The current vegetation on the ground level is supplying nectar and pollen throughout the year, but since the quantity of the plants is not so big, could the green roofs very well complement to this vegetation.

5.7 Green roofs in cities: city district Zuideramstel

In this paragraph is analyzed how green roofs(and façades) can be used to create an ecological network for bees on a city level. The scope of this case study will be a city district in Amsterdam; the Zuideramstel. Since this district is connected by the Green Head Structure and the Ecological Structure of Amsterdam this area covers level of scale IV as described in section 5.2; the level connecting the Ecological Structure to the rest of the vegetation.

The Zuideramstel is one of the post-war areas of Amsterdam. These post-war areas can be recognized by the green environments designed according to the principles light, air and space and are also called 'garden cities' (Dutch: 'tuinsteden'). In comparison to pre-war neighborhoods are post-war neighborhoods much less condensed and vegetation is here spread throughout the area. The concept of the garden city is that houses in the city are with a green corridor connected to the green areas outside the city (District council of Amsterdam-South, 2012).

The garden cities have a strong hierarchical character concerning spatial structure, infrastructure and vegetation. The green areas consist of city green (parks), areal green (green lanes and park lanes), district green (courts), living green (gardens). The public space is designed as use and meeting space for all residents (District council of Amsterdam-South, 2012).

Last year the district council of Amsterdam-South became aware of the need to foster bee populations and proposed measures to the executive board to stimulate healthy bee populations in the area. Four concrete measures where suggested: creating a 'bee path' (bijenlint) in the district council, attention should be drawn to a diversity of bee attracting plants in public green and in the green policy should attention be paid for sufficient and sufficient diversity of bee attracting plants. This plan is currently however still in an initial phase. The case study carried out in this research therefore could be a preparation research for policymaking of the district council (GroenLinks, 2013).

In the case study mainly public green is analyzed, since this is the major share of green in the area which forms a green structure through the district. Private green however can also consist of valuable bee attractive plants, but this should be explored in future research.

Therefore this case study mainly focuses on trees and less on shrubs, since trees create a network through the city, like explained in section Levels of scale design for biodiversity in urban areas 5.2. It should be stressed though that many shrubs are also important bee attracting plants. Here a first step in analyzing the shrubs is done, this is however a very rough indication. The analysis of the trees is more complete, but is also not totally complete yet, since the main aim was to get an overview of the green structure in the area.

5.7.1 Physical properties of the roofs:

Figure 36 Typical buildings in 'Zuideramstel

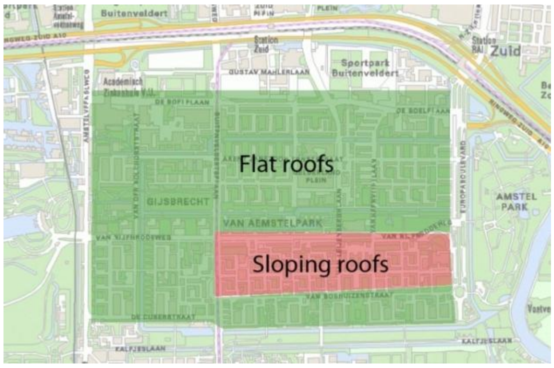


Figure 37 Division flat and sloping roofs

Most of the buildings in the area are apartment buildings of 3 or 4 stories high. The biggest share of these roofs has a flat roof, see Figure 36 and Figure 37. The roofs are thus suitable for the application of extensive green roofs. For intensive green roofs it is more likely to expect that reinforcement measures of the building construction are needed. Assuming that one story of a building is 3 meters, the buildings are thus 9 to 12 meters high. Bees fly up to heights of 12-20 meters, so they will be able to reach the roof. Since most buildings are of the same height and have a flat roof the orientation of the roof is not very important to consider. What mainly determines the amount of sun a roof gets is the trees surrounding the buildings. The courtyards of the buildings are pretty green and some of them contain high trees. Details about the amount of sun can be found in section 5.7.2.

The sizes of the roofs differ in the area. One of the biggest roofs is about 1720 m^2, see Figure 38and one of the smallest about 540m^2 see Figure 39. But the buildings in the area are very close located to each other, so the green roofs do not have to function self-sufficient for pollen and nectar supply.

Figure 38 Typical building roof surface ± 1720 m^2

Figure 39 Typical building roof surface ± 540 m^2

5.7.2 Climatic properties

5.7.2.1 *Wind*

As already stated in the former section are most buildings about 12 meter high. Since bees were found on heights up to 12-20 meters they are also likely to forage on this height when there will be green roofs with food supply. Some of these roofs are likely to be more sheltered from wind than other roofs. This will be mainly due to high trees surrounding the district and in the district itself. An estimation of where the most wind-sheltered places will occur is shown in Figure 40. This figure is drawn based on the prevailing wind direction in the Netherlands, South-west, and the fact that trees in the parks block some of this wind. The roofs in the blue area will be more suitable for bees to forage and to nest. These roofs are also more for placing beehives.

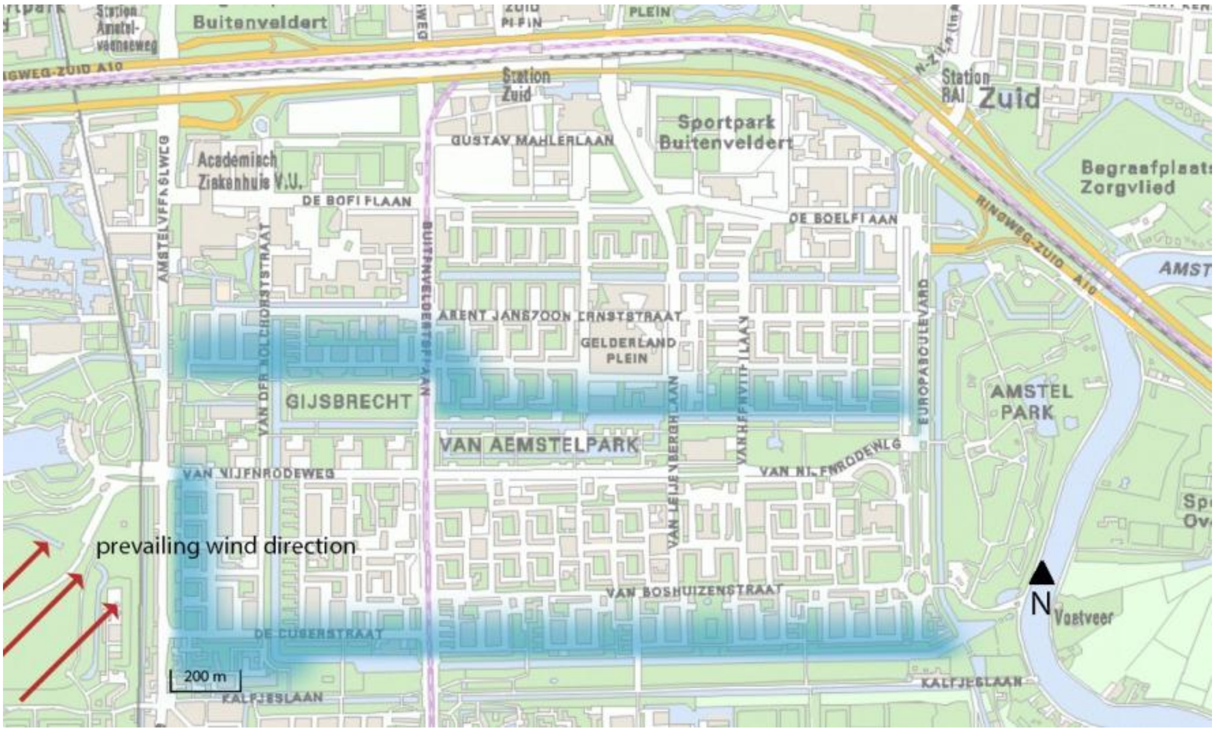


Figure 40 Wind sheltered roofs

5.7.2.2 Humidity/precipitation/Temperature

The amount of average precipitation in the Netherlands slightly differs per city. The figure below, Figure 41, shows that especially the western part of the Netherlands suffers from a lot of precipitation. The yearly amount of rain is thus on average more in Amsterdam than in for example Helmond. The question is if this difference on a yearly basis affect bees in their forage behavior; probably not. The need of applying green roofs however, might be more urgent in the western part of the Netherlands than in the Eastern part. Not only because of precipitation, but also because of climate change which will most heavily affect the western part of the Netherlands due to sea level rise. In the 20th century the rainfall on the Northern hemisphere also increased with 5-10% (KNMI, 2013). Water storage will thus be a challenge in the future and green roofs can offer a solution for this.

For the average temperature an similar explanation holds. Figure 42 shows that the average temperature is highest in the southwestern part of the Netherlands. But this difference does probably not affect the foraging behaviour of bees, since it is only a small difference and bees are not sensitive to a small difference in temperature. In the Zuideramstel other parameters, for example vegetation and nesting possibilities, will be more constricting than the average temperature.

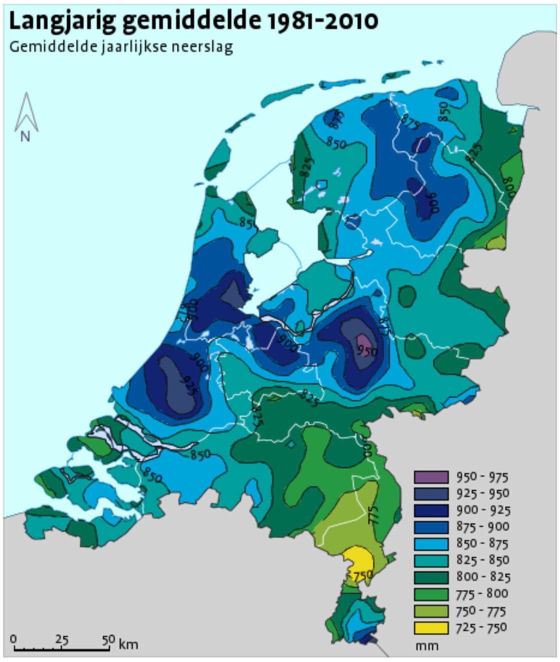


Figure 41 average precipitation in the Netherlands Source: KNMI, 2012

Figure 42 avarage temperature in the Netherlands Source: KNMI, 2012

5.7.2.3 Sun

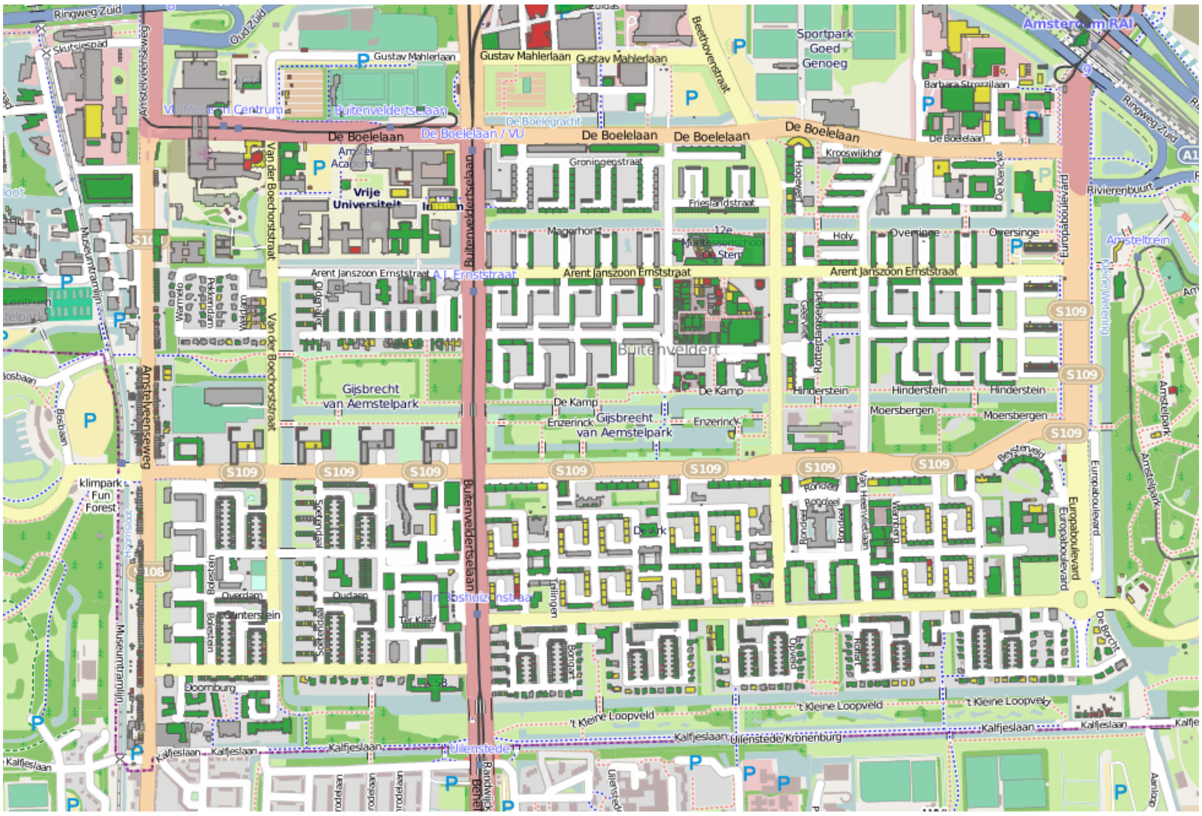


Figure 43 Suitable roofs for applying solar panels (green), Source: Zonatlas.nl, 2013

Figure 43 shows the suitability of roofs in the Zuideramstel to apply solar panels. Most of the buildings are very suitable (green), or suitable (yellow) so these roofs receive a certain amount of sunlight. These roofs are therefore probably also suitable for bees to establish regarding to the amount of sun the roofs receive. N.B. In the picture some roof surfaces are grey, which means there is no information available on this roof. It can be expected that most of these roofs are also un-shadowed. Furthermore in Figure 37 was already concluded that most roofs are flat which makes that the amount of incoming sunlight is the same on every part of the roof.

5.7.3 Vegetation

To secure valuable green and water elements in the city, district council Amsterdam-South created in 2006 a policy framework on how the green and water in the city should be integrated, managed and sustained. The four main aims of the district council are:

1. Preserve and strengthen the current green and water qualities
2. Add lacking ecological connections
3. Improve and restore the degraded plan
4. High quality, sustainable and historical conscious maintenance (Vision Green and Blue, district council Amsterdam-South, 2006).

Figure 44 shows an overview of the current green key structure in the area:

Figure 44 Head tree structure in Zuideramstel Source: district council Amsterdam-South, 2013

5.7.3.1 Green Head structure

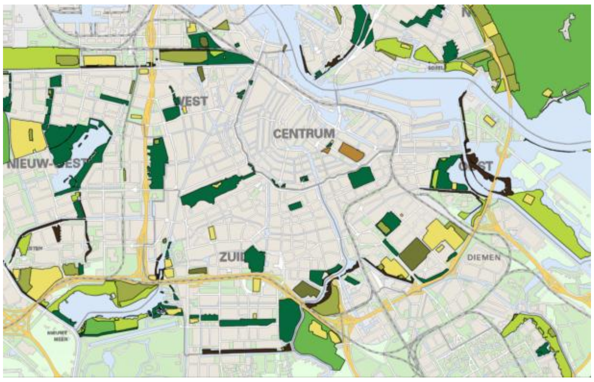


Figure 45 Green Head Structure according to spatial planning, Amsterdam, Source: maps.amsterdam.nl, 2013

Figure 46 Green Head Structure according to spatial planning, Amsterdam-South, Source: maps.amsterdam.nl, 2013

Compared to the rest of Amsterdam, Amsterdam-South is a relatively green area. See Figure 45 and Figure 46. The Zuideramstel is located in between two big green parks; the Amsterdam Wood and the Amstel Park at the right. The Green Head structure contains the minimum amount of green to preserve, because this fulfills an important function for food production, improving air quality, water management, heat reduction, biodiversity, recreation and quality of life. Protecting the Green Head structure must also secure that cultural historical values are preserved and a diversity of green is conserved (maps.amsterdam.nl, 2013).

The Green Head structure in the Zuideramstel is mainly horizontally oriented. It consists of a green corridor, which is formed by the 'Gijsbrecht van Aemstelpark' in between the Amsterdam Wood and the Amstel Park. The ecological structure connects the green areas on a smaller scale. The ecological structure consists of 'green' and 'blue' areas of different sizes. It makes green connections within the city and connects the city with environmental landscape outside the city. The ecological structure is indispensable for biodiversity. In the Zuideramstel the ecological structure mostly overlaps the green head structure. Furthermore the ecological structure also connects the horizontal structure with vertical corridors, see Figure 47.

Figure 47 Ecological structure according to spatial planning Source: maps.amsterdam.nl, 2013

Figure 48 Fauna passages for squirrel

At some points the ecological structure gets intermitted by roads. At these points fauna passages are introduced. Figure 48 shows a picture of one of these fauna passages; a squirrel bridge. All the fauna passages are mainly focused on amphibians and small mammals.

5.7.3.2 Green roofs and Green walls

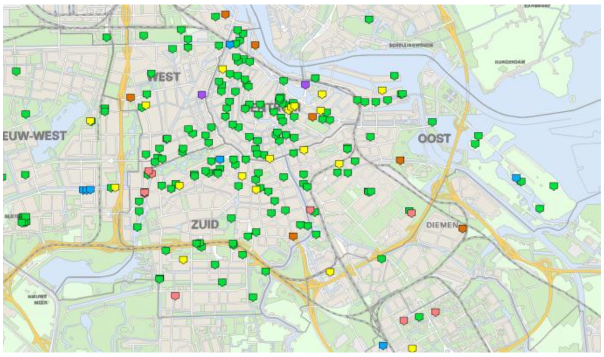


Figure 49 Green roofs in Amsterdam, Source: maps.amsterdam.nl, 2013

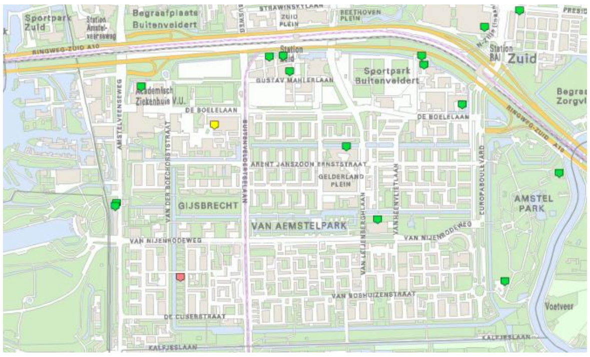


Figure 50 Green roofs in Zuideramstel, Source: maps.amsterdam.nl, 2013

Compared to the rest of Amsterdam has the Zuideramstel relatively few green roofs. Just like the rest of Amsterdam are most of the roofs in the Zuideramstel sedum roofs (green dots). The Zuideramstel has one intensive roof garden on the VU University (yellow dot) and one sedum roof combined with solar panels (pink dot)(maps.amsterdam.nl, 2013). The information on the maps is however not completely up to date. The district Amsterdam-South has currently in total about 21.670 m^2 green roofs, spread over 94 different roofs (de Boer, 2013).

The buildings in the Zuideramstel are little 'green' in itself. Many people do not keep much plants at their balconies. An exception is some of the apartment buildings in the 'Van Lijenberghlaan'. Here 'green walls' are created by integrating planters in the façades, which makes it look like a kind of green façade, see also Figure 52.

Because the Zuideramstel is a garden city the courtyards are relatively green. Also some green façades in the shape of ivy-covered walls can be found. Most of the buildings in the area however do not have a green façade. The amount of green walls is not mapped like is done with the green roofs, so for an exact estimation more research should be done.

Figure 51 Green roofs

Figure 52 Green facades Green roofs

5.7.3.3 Trees

The following figure, Figure 53, shows an inventory of the tree species in the Zuideramstel.

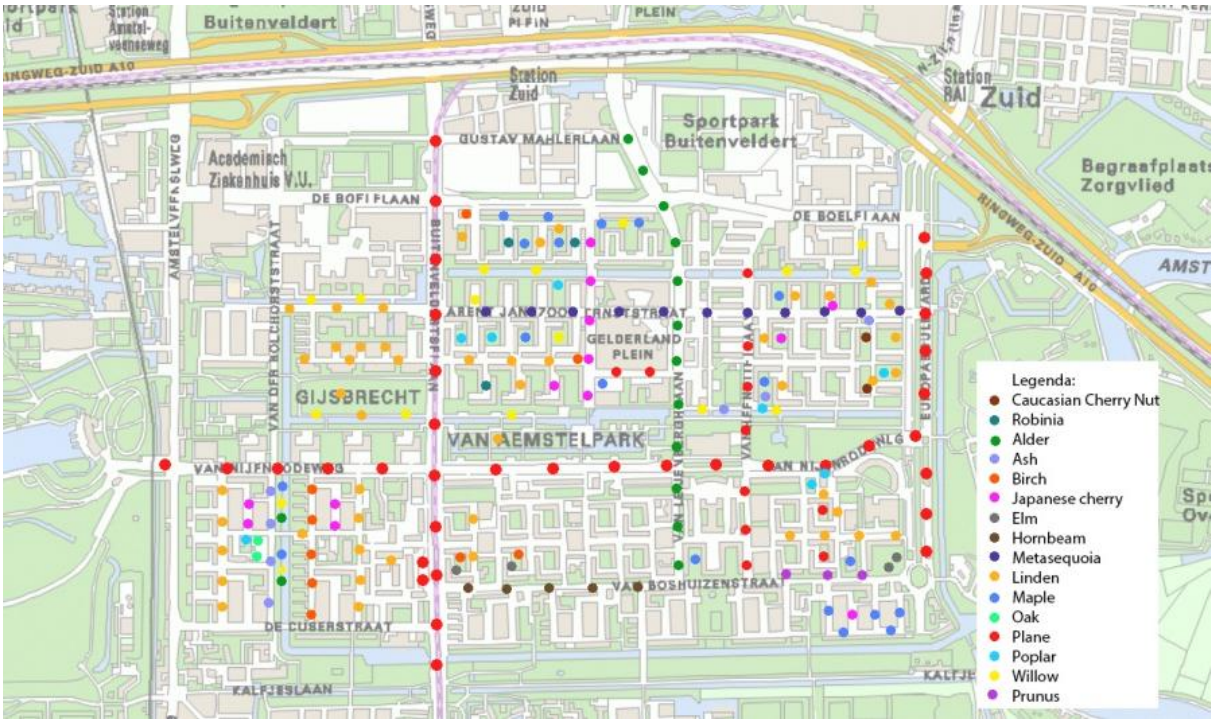


Figure 53 Tree species in Zuideramstel*

Figure 54 shows an overview of the bee attractive trees.

Figure 54 Bee attractive tree species in Zuideramstel

An important conclusion can be drawn from Figure 54. Along main roads mostly grow plane trees. Along another important road, the ‘Van Lijenberghlaan’ grow alder trees. Both of these trees are not attractive for bees. The most abundant trees along secondary roads are linden trees. These are attractive for bees. Vegetation along the primary roads thus does not offer food supply for bees, so a connection on this level is lacking. When the plane trees along the primary road would be replaced by bee attracting trees, like for example linden trees, the connection would be better. It would be even better to plant bee attractive trees which flower at different periods, so a continuous food supply is secured.

*N.B. The figures do not represent the exact number of trees, this is a simplification of the real situation.

Case Zuideramstel			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Fly seeson bees														
		Bumblebees												
		Honey bees												
Current vegetation	**Native**	**Types of bees attracted**												
Birch *(Betula)*	Yes	Honey bees												
Black Locust *(Robinia pseudoacacia)*	Yes	Bumblebees, honey bees												
Black Poplar *(Populus nigra)*	Yes	Honey bees												
Cherry (Japanese) *(Prunus subhirtella)*	Yes	Honey bees												
Linden *(Tilia)*	Yes	Bumblebees, honey bees, wild bees, butterflies												
Maple *(Acer pseudoplatanus)*	Yes	Solitary wild bees(sand bees *(Andrena)* , amongst others *A. barbilabris* , yellow-ledged mining bee *(A.flavipes)* , A. fulva *(A. fulva)* , Early mining bee *(A. haemorrhoa)* , *A. tibialis* , mining bees *(Osmia rufa)* , bumblebees												
Oak (Summer) *(Quercus robur)*	Yes	Honey bees												
Willow (crack-)	Yes	Bumblebees, honey bees												
Willow (weeping-)	Yes	Bumblebees, honey bees												
Advised complementary plants														
Silver maple *(Acer saccharinum)*	No	Bumblebees, honey bees												
Red Maple *(Acer rubrum)*	No	Bumblebees, honey bees												
Goat willow (*Salix caprea)*	Yes	Wild bees (sand bees a.o.*Andrena clarkella* , *A. bicolor, A. cineria, A. flavipes* , Tawny mining bee (A. fulva), Early mining bee *(A. haemorrhoa)* , *A. Mitis* , *A. Aplicata* , early sand bee *(A. praecox)* , *(A. ruficrus)* , A. tibialis, Solitary digger bee *(A. vaga)* , *(A. Ventralis)* , *(A. Nigroaenea)* Creeping Willow Bee *(Colletes cunicularus)* , *(Osmia cornuta)* , bumblebees, honey bees												
Bee tree *(Tetradium daniellii)*	No	Bumblebees, honey bees												

Table 17 Flower season bee attractive trees Zuideramstel

To be able to draw more valuable conclusions the flowering period of the trees is observed. It can be concluded that the current trees do not flower during the whole forage season of bees. When just forage trees are considered (so birch, oak, poplar and Japanese cherry are left out) can be concluded that there is a food supply from April to July, see Table 17. To make the trees having a self-sufficient supply of pollen and nectar, trees should be planted which also flower in March and August-October. For the pollen supply in March several options are available. Examples could be the Silver maple *(Acer saccharinum)* or the Red maple *(Acer rubrum)*. These two maple trees provide food supply for bumblebees and honey bees. The best option however would be the Goat willow *(Salix caprea)* since this is a native species and feeds besides honey bees and bumblebees also many wild bee species. To cover the lacking pollen and nectar supply in August-October is more difficult. One bee attracting tree which flowers in August to October is the bee tree *(Tetradium daniellii).*

In this research is only determined whether a certain tree species attract bees or not. In more refined research should also the distinction be made between trees which are very attractive and trees which are a bit less attractive.

5.7.3.4 Shrubs

The major share of the shrubs can be found in the different parks in the area. In the biggest park in the area, the 'Gijsbrecht van Aemstelpark', are the following shrubs most abundant:

holly, cornel, hawthorn and elderberry. Additional plants abundantly present in the rest of the area are: Bay tree, Cornel, Hawthorn and Ivy. Most of the identified plants are attractive for bees, see also Table 18. It should be noted that this list is not a complete list of plants. Further research is needed to make the list complete and to determine the exact spread over the city.

Shrub species	Attractive for bees?	Species	Flowering season
Bay tree *(Prunus laurocerasus)*	Yes	Bumblebees, honey bees, wild bees (sand bees *(Andrena)*)	May-June (Drachtplanten.nl)
Butterfly bush *(Buddleia dividii)*	Yes	Butterflies, bumblebees, honey bees	July-October (Drachtplanten.nl)
Cornel *(Yellow) (Cornus mas)*	Yes	Honey bees, bumblebees, wild bees (Mining bees (Lasioglossum))	May-June
Cornel red*(Cornus (sanguinea)*	Yes	Honey bees, butterflies, bumblebees, solitary wild bees (Mining bees (Lasioglossum), sand bees *(Andrena nitida)*	June (Drachtplanten.nl)
Elderberry *(Sambucus nigra)*	Yes	Honey bee (Drachtplanten.nl)	June-July (Floravannederland.nl)
Hawthorn*(Crataegus)*	Yes	Honey bees	May (Drachtplanten.nl)
Holly *(Ilex aquifolium)*	Yes	Honey bees, Wild bees (sand bees *(Andrena)*,mason bees *(Osmia)*)	May-June (Drachtplanten.nl)
Hornbeam (*Carpinus betulus)*	No	-	-
Ivy *(Hedera helix)*	Yes	Wild bees (only Ivy bee *(Colletes hederae)*), honey bees, bumblebees and butterflies (Drachtplanten.nl)	September-December (Floravannederland.nl)
Lavender *(Lavendula Officinalis)*	Yes	Butterflies, bumblebees, honey bees, wild solitary bees, (Leaf cutter and dauber bees (*Megachile willughbiella, M. centucularis, M. versicolor*, mason bees*(Osmia)*.)	June-July (August) (Drachtplanten.nl)
Mountain-ash *(Sorbus Americana)*	Yes	Bumblebees, honey bees, solitary wild bees (sand bees *(Andrena haemorrhoa)* and	June-July (Drachtplanten.nl)

		butterflies	
Fire-thorn *(Pyracantha)*	Yes	Wild bees (sand bees *(Andrena)* sweat bees, mining bees *(Lasioglossum)*, yellow-masked bees *(Hylaeus))* bumblebees, honey bees, butterflies	May-June (Drachtplanten.nl)
Rose … *(Rosa …)*	No	-	-
Yew-tree *(Taxus baccata)*	Yes	Honey bees	March-May (Floravannederland.nl)
Snowberry *(Symphoricarpos albus)*	Yes	Bumblebees, honey bees	June-September (Floravannederland.nl)

Table 18 Overview of the most abundant shrub species in the area

The table below lists the flowering period of the different shrubs. Although not all plants are already inventoried it is already clear that there are plant species flowering during the whole forage season. For a more advanced inventory should also be assessed where the plants grow and in which quantities. Also, in this research is only determined whether a certain shrub species attracts bees or not. In more refined research also the distinction should be made between shrubs which are very attractive and shrubs which are a bit less attractive.

Case Zuideramstel Shrubs			Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Fly seeson bees		HB+BB+WB												
		Bumblebees												
		Honey bees												
Current vegetation	**Native**	**Types of bees attracted**												
Bay tree *(Prunus Laurocerasus)*	No	Bumblebees, honey bees, wild bees (sand bees *(Andrena)*)												
Butterfly bush *(Buddleja davidii)*	No	Butterflies, bumblebees, honey bees												
Cornel *(Yellow) (Cornus mas)*	Yes	Honey bees, bumblebees, wild bees (Mining bees *(Lasioglossum))*												
Cornel *(Red/(Cornus sanguinea/mas)*	Yes	Honey bees, butterflies, bumblebees, solitary wild bees (Mining bees (Lasioglossum), sand bees *(Andrena nitida)*												
Elderberry		Honey bees												
Hawthorn *(Crataegus)*	Yes	Honey bees												
Holly *(Ilex aquifolium)*	Yes	Honey bees, wild bees (sand bees *(Andrena)* ,mason bees *(Osmia)*)												
Indian bee tree *(Catalpa bignioides)*	No	Honey bees, bumblebees												
Ivy *(Hedera helix)*	Yes	Wild bees (only Ivy bee (Colletes hederae) , honey bees, bumblebees and butterflies (Drachtplanten.nl)												
Lavender *(Lavendula angustifolia)*	No	Butterflies, bumblebees, honey bees, wild solitary bees, (Leaf cutter and dauber bees (Megachile willughbiella, M. centucularis, M. versicolor, mason bees(Osmia).)												
Mountain-ash *(Sorbus aucuparia)*	Yes	Bumblebees, honey bees, solitary wild bees (sand bees (Andrena haemorrhoa) and butterflie												
Fire-thorn *(Pyracantha coccinea)*	No	Wild bees (sand bees *(Andrena)* sweat bees, mining bees *(Lasioglossum)* , yellow-masked bees *(Hylaeus)* , bumblebees, honey bees, butterflies												
Yew-tree *(Taxus baccata)*	Yes	Honey bees												
Snowberry *(Symphytum grandiflorum)*	No	Bumblebees, honey bees												

Table 19 Flowering period present shrubs

5.7.3.5 Urban agriculture

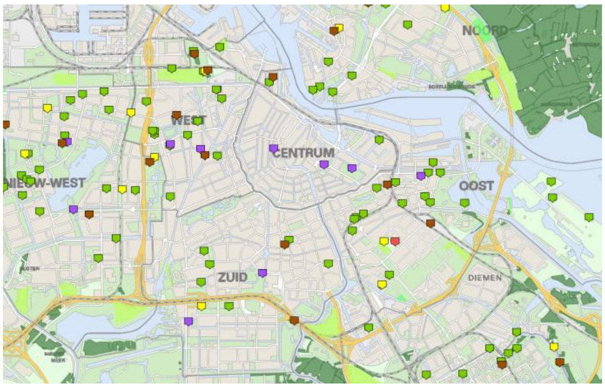


Figure 55 Urban Agriculture in Amsterdam, Source: maps.amsterdam.nl, 2013

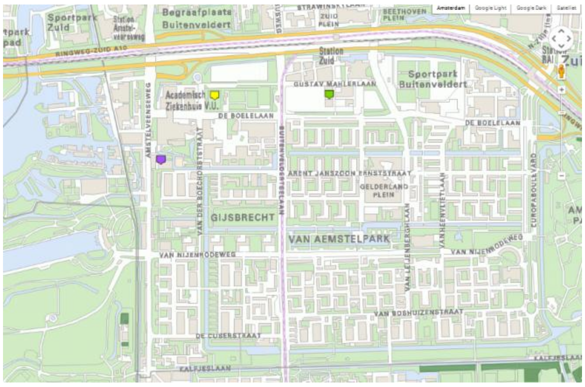


Figure 56 Urban Agriculture in Zuideramstel, Source: maps.amsterdam.nl, 2013

Figure 55 and Figure 56 show the number of agricultural projects in Amsterdam and in the Zuideramstel respectively. The different kind of categories of Urban Agriculture are vegetable gardens (green), school gardens (yellow), herb gardens (purple), children's farms (brown) and greenhouses (pink). From the map can be concluded that the outer areas of Amsterdam have the most urban agriculture spots. The Zuideramstel has one vegetable garden, one school garden and one herb garden. At the south edge of the district is a path with regular agriculture, which is called 'peri-urban agriculture' in this map. This is because it is located in between urban and rural area.

5.7.4 Management

Figure 57 Current Management

Figure 58 Desired management, Source: diverse websites, 2013

The major part of the district consists of post-war apartment buildings. Most of the apartments do not have private green, only public green. The public green areas in general consist of lawns and trees. The lawns are planted with grass, which is kept short. Therefore the trees are currently likely to be the major source of pollen and nectar for bees. For a more beneficial environment for bees should the mowing and cutting be done in phases, so plants have opportunities to flower. It would also be an improvement, if possible, to let weed grow, so for example dandelions and clovers can grow.

5.7.5 Additional objects


Figure 59 Current nesting possibilities


Figure 60 New nesting possibilities Source: diverse websites

The Zuideramstel is one of the post-war garden cities which has resulted in a district with much green. This is in general beneficial for establishment of biodiversity, so also for bees. However, there are not many nesting possibilities. Streets are completely covered with tiles, there are no sandy joints in between them. Also the houses are still in a good state, joints of walls are completely plastered with cement, so here is also no nesting possibility. Follow land is in particular a favorable environment for bees, since here is often sandy area (for future or past construction work) and vegetation is not mowed or cut. In the Zuideramstel there is however not much follow land. In observations there was only one found.
Also in the parks there are little nesting possibilities. On the open spaces in the park the soil is completely covered with grass. The roads in the parks are paved. Furthermore there are only few dead trees left in the parks, see Figure 59.
To improve the situation for example sandy roads could be created to complement the paved roads. Also more old wood can be left in the park. Currently the park has some pieces of art presented. To make the park more attractive for bees, art could be combined with nesting spaces for bees. A bee hotel can be designed in a way which makes it a nice piece of art, see the examples in Figure 60.

5.7.6 Air Pollution

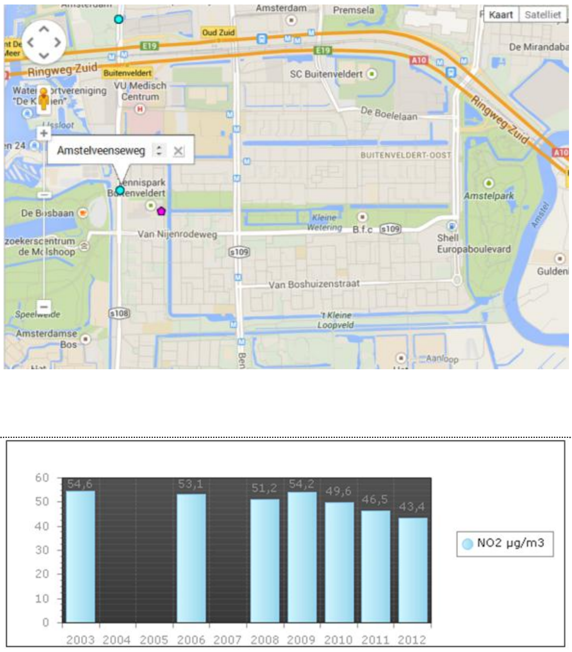


Figure 61 NO_2 pollution Amstelveenseweg Source: Maps.amsterdam.nl/GGD Amsterdam, 2013

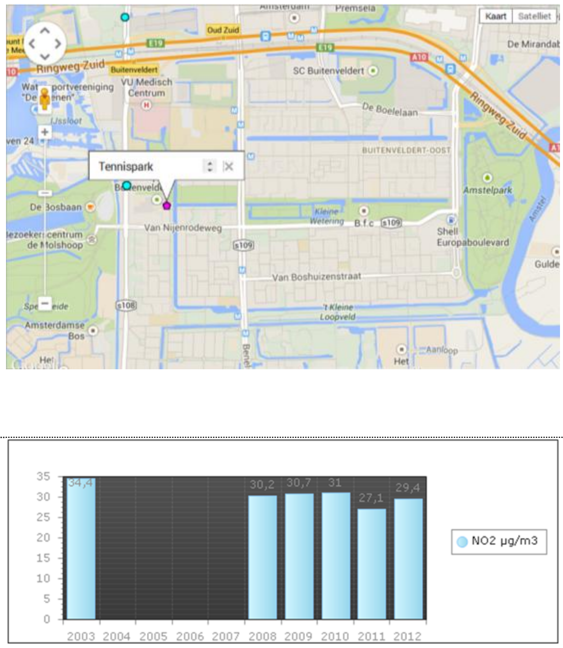


Figure 62 NO_2 pollution tennis court, Source: Maps.amsterdam.nl/GGD Amsterdam, 2013

On many places in Amsterdam is the air quality worse than the standards require. The most important source of pollution is traffic, but also industries contribute a lot. To improve air quality the Amsterdam municipality is mainly looking at measures to change traffic in cities, so by stimulating the use of ‘clean vehicles’, like electrical vehicles and vehicles with relatively few emissions (GGD Amsterdam, 2013). To keep track of the current emissions the municipality has several measuring points spread over the city. These measuring points measure the amount of NO_2 in the air as indicator for the particulate patter concentration in the air. The amount of NO_2 present is often representative for the amount of particulate matter in the air as well. NO_2 is easier to measure than particular matter and the substance in itself also has negative effect on humans, by causing respiratory problems, and on the environment, by causing acidification (Environmental Assessment Agency (*Planbureau voor de leefomgeving*), 2013) .

The Zuideramstel has two NO_2 measure points. One of them is located next to a busy traffic road, one of them more at the background, distant from a road. The results of the measurements done over the last period (2003-2012) are shown in Figure 61 and Figure 62. Striking is the big difference between these two meeting points. In 2011 and 2012 the NO_2 emissions at the Amstelveenseweg were respectively 46,5 and 43,4 µg/m$_{3,}$ but the values on the tennis court nearby were only 27,1 and 29,4 respectively for the same years (GGD Amsterdam, 2013). The threshold for the yearly average NO_2 emissions is set by the

European Union at 40 µg/m3. The Netherlands however has been given delay to meet this standard till the first of January. Currently the threshold value amounts 60 µg/m3. For now the Amstelveense weg thus exeeds the future limits for NO_2 emissions.

To give an estimation of the NO_2 values of the entire district the measured values in the Amstelveense weg and the tennis court are extrapolated on a map, shown in Figure 63. N.B. This map is a very rough estimation, more measurements should be done for more precise results.

Figure 63 Areas of most expected NO_2 emissions

On the areas where most NO_2 emissions can be expected it is best to install green roof with plants especially designed to enhance air quality. Although research done by the National institute for public health and environment (*Rijksinstituut voor Volksgezondheid en Milieu ((RIVM)*) states that vegetation (trees and plants) in streets does not significantly improve air quality since it hinders the wind from blowing through the streets. Vegetation in a big area can however lead to a small reduction of Particulate Matter and NO_2 (National institute for public health and environment, 2013; Yang et al., 2008). Since vegetation on green roofs is not directly next to roads will it less block the wind and will thus have a more beneficial effect for the air quality when it is applied on a large scale.

5.7.7 Proximity of roofs/Integration with existing green

Although the Zuideramstel is not a very dense area, the buildings are not far distant from each other. Therefore the roof surfaces are also about 20-30 meter separated from each other. Since the current structure of trees is not self-sufficient in food supply for bees. Also, the district does not offer many nesting spaces for bees. Therefore could the green roofs and façades could very well function as ‘stepping stones’ for bees in regard to food provision and nesting spaces.

5.7.8 Conclusion

Parameter	**Sub-parameter**	**Required**	**Value**	**Remarks**
Physical properties roof	Height of the roof	• ≤12-20m	Most buildings 4 stories high = +/- 12m	
	Size of the roof	• HB: >1000m^2 • B: 25m^2 • WB: 10m^2	Buildings ranging from 500-1800m^2	This surface area is assumed for having a dense vegetation cover like strawberries,
	Slope of the roof	• Flat, somewhat sloping	Mostly flat. Some sloping roofs, see picture xx	
	Orientation of the roof	• South	Most of the day sunny	
Climatic properties	Wind speed	• Sheltered place, little wind, especially the opening of the nest should be sheltered. • Wind speed less than 4-5km/h • Little turbulence • Protection (e.g. by high buildings) from the wind on the south-west side.	No outstanding high buildings, roofs about 12 meters high	
	Humidity/Rain	• Dry places • Humidity air of bee hive less than 90%.	No particular circumstances	
	Sun	• Sun when bees fly out mostly, so between 11.00 a.m. and 16.00 p.m.	Most roofs suitable for solar panels, so sunny	
	Temperature	• *HB+BB:* 10-35 °C, optimum 18-25 °C • *HB+BB:* 10-35 °C, optimum 18-25 °C • WB: 15-18 °C	No particular circumstances	
Vegetation	Types	• Local indigenous plants (see appendix 0) • Pollen supply guaranteed throughout the forage season (see appendix 0)	Only 4/16 trees, shrubs are better but not continuous through the city	

	Distribution/density	• Few m^2 bare, sandy open area	No, not much available	
Management	Pesticides, Pesticide A,B,C	• Preferable none	Unknown	
	Management type	Organic control: • Different stages of development of plants should be coherent and in an optimum ratio • Mowing, cutting done in phases. • Letting weed species grow	Weed species are frequently removed	
Soil/substrate	Type	• Use of local soil and substrates • Top 15 cm layer derived from meadow lands and woodlands, but also sand and gravel • Varying substrate depths, up to 70 cm to support all types of ground nesting bees, • Varying drainage regimes, differences created in humidity, nutrient richness and acidity	-	
Climatic properties	Wind speed	• Sheltered place, little wind, especially the opening of the nest should be sheltered. • Wind speed less than 4-5km/h • Little turbulence • Protection (e.g. by high buildings) from the wind on the south-west side.	No outstanding high buildings, roofs about 12 meters high	
	Humidity/Rain	• Dry places • Humidity air of bee hive less than 90%.	No particular circumstances	
	Sun	• Sun when bees fly out mostly, so between 11.00 a.m. and 16.00 p.m.	Most roofs suitable for solar panels, so sunny	
	Temperature	• *HB+BB:* 10-35 °C, optimum 18-25 °C • *HB+BB:* 10-35 °C, optimum 18-25 °C • WB: 15-18 °C	No particular circumstances	
Geographic location	Environment in general	• Natural area	Garden city, much green	
	Buildings	• Buildings with nesting possibilities	Not many nesting possibilities	
Additional objects on the roof	Beehive, blocks with wholes, sand layer, etc.	• Old dead wood, grass pollen, walls, hollow reeds, blackberry, elder, thistles and umbel lifers, bee hotel, sandy slopes, cracks in rocks	-	
Air pollution	Air pollution NOx/ Dust/PM	• Little NOx pollution • Little dust/particulate matter	Measurements show that at some parts of the area the (future) limit is	

			exceeded	

Table 20 Score parameters Zuideramstel

Parameter	Sub-parameter	Required	Value
Micro parameters	*Micro parameters*	*Micro parameters*	*Micro parameters*
Proximity of roofs/façades		HB + BB: ≤ 3 km WB: ≤ 0.5 - 300 metres → < 100 meters for urban bees	Roofs are about 20-30 meters distant from each other
Integration with existing green		• Roofs (facades) self-sufficient in food/nesting possibilities	For wild bees this would be most interesting
		• Vegetation complementary to present vegetation	Trees do not provide enough food, so green roofs could complement this
Nesting spaces on ground level		• Sandy soils, cracks in buildings, old dead wood, logs, hollow reed, beehotels, etc.	Not many available

Table 21 Score parameters Zuideramstel

Strong points	Explanation	
Physical properties roof	Roofs of buildings are flat, have a significant surface area and catch a significant amount of sun	
Proximity of roofs	Roofs not far apart (< 20-30m)	
Weak points		**Improvements**
Vegetation	Bee attracting trees do not create network	Adding bee attractive trees which flower in the period when food supply is lacking
Climatic properties	Wind: Most roofs are not sheltered from wind	Roofs next to parks will be most sheltered from wind and thus best for habitat creation
Georaphic location/additional objects	Paved roads, 'clean buildings', no almost no fallow land	Create nesting spaces; combine art with nesting spaces, create sandy roads, leave old wood in parks
Management	Weed frequently removed, grass is kept short	Let (partially) weed grow, mowing and cutting in phases
Air Pollution	Pollution level at some points exceeding the minimum limit	Planting vegetation which improves air quality, only
Integration with existing green	Structure of tyrees is lacking food provision	Green roofs/façades could complement this

Table 22 Summary weak and strong points Amsterdam Zuideramstel

The Amsterdam Zuideramstel is a neighborhood with, compared to other sub-urban areas, a lot of vegetation. This vegetation provides substantial food provision for bees, but does not supply sufficient pollen and nectar during the entire forage season of bees. Nesting possibilities are also lacking. The district does not contain many green roofs and façades yet, but there is a potential for creating more green roofs and façades. Most roofs are flat or somewhat sloping, which is in most cases suitable for the built of a green roof.

From the environmental parameters especially the wind force and the level of air pollution are important to consider for allocation of the green roofs. The amount of wind differs per location. Roofs located on the North-East side of the parks in the area will be more sheltered from the wind than other roofs in the area. Concerning the level of air pollution are roofs and façades next to heavy traffic roads less suitable for habitat creation than roofs further away from polluting roads.

5.7.9 Green roofs/façades implementation advice district Zuideramstel

Based on the analysis above the following starting points are adviced for creating a green roof structure in the Zuideramstel:

- For wild bees it is especially important to create 'stepping stones' in regard to food provision and nesting spaces since they only cover relatively small distances. The minimum average forage distance is estimated at 100 meters. Therefore the existing bee attractive vegetation and the (new) green roofs and façades with bee attractive vegetation should be at highest 100 meters distant from each other. The orange circles in Figure 64 represents this fly out distance of 100 meters.
- Since bees get affected by air pollution it should be tried avoid to grow too many forage plants along busy traffic roads. The plants applied along busy traffic roads should have a big leaf surface so they improve air quality.
- The high trees in the adjacent parks, the Gijsbrecht van Aemstelpark and the park in between the Zuideramstel and Uilenstede, will partially block the prevailing South-West wind from flowing to the district. The roofs directly located northwards from the trees will be thus more sheltered from the wind than other roofs. These roofs are better suitable for the placement of beehives for honey bees than other roofs.
- Regarding other climatic properties, there are no significant differences in the area so green roofs could be applied everywhere.

The following figure, Figure 64 provides an overview of the suggestion for a green roof structure in the Zuideramstel. Since the built of green roofs and façades has investment costs it is here assumed that it is not feasible to cover all roofs and façades green at once. A network is created consisting of stepping stones with the 100 meters forage distance in between them.

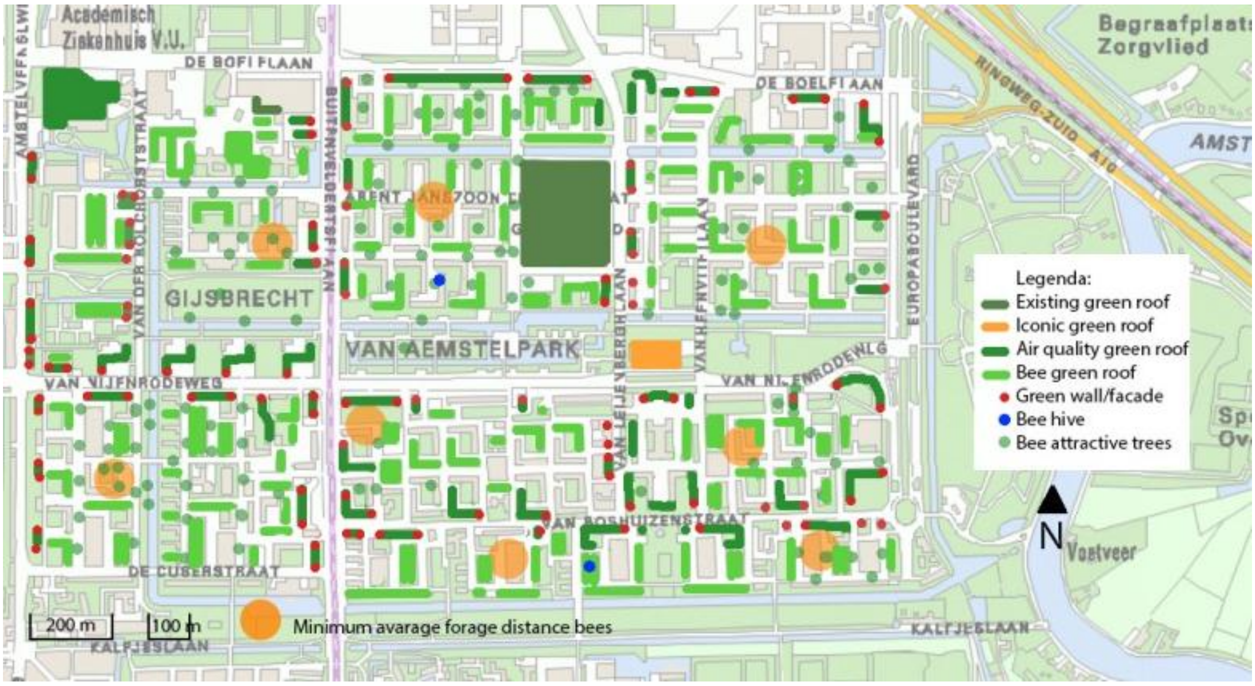


Figure 64 Design example of how a green structure in the area could look like

Existing green roof

These are the roofs already present in the area.

Air quality green roof

This green roof has a double function. At the one hand the roof designed is to provide food supply for bees during the whole forage season. At the other hand plants are planted with a total big leaf surface to filter air and capture particulate matter. This roof is not designed for nesting spaces for bees, since it is expected the air pollution is somewhat higher here.

Bee green roof

This roof is designed to provide both food provision and nesting space for bees. To create the most favorable environment different substrate depths are applied.

Green wall/green façade

The green walls will function complementary to the green roofs. Green walls are at any case applied on the façades next to busy traffic roads. Here the green façades can both improve air quality and provide food provision for bees. By placing the green walls on façades next to heavy roads, bees will get stimulated to cross the road to forage on the green façade to collect pollen and nectar, so they will function as a kind of 'fauna passage' for bees.

Iconic roof

An iconic roof is created on top of a department of the municipality located at the 'Van Heenvlietlaan'. This roof could function as a showcase for how an ideal green roof could look like.

Bee hive

To get more bees in the district introducing new bee hives in the area is a good option. Roofs offer an ideal location to place the hives, since here is no disturbance from human beings for example by traffic. In Figure 64 the hives are placed on roofs which are favorable in terms of all the analyzed parameters. The hives are placed on roofs which are sheltered from the wind since they are next the high trees from the park blocking the wind. Moreover, the hives are placed at a location where the air pollution is relatively low.

Bee attractive trees

These are the bee attractive trees analyzed in section 5.7.3.3. The vegetation on the green roofs are thus complementing the existing bee attractive vegetation on ground level.

Additional to the green roof structure other recommendations can be given related to the management of existing public green:

- Mow grass lanes only partially. In this way weed gets the opportunity to flower, species like dandelions, daisies and white/red clover.
- When trees fall ill, it is especially valuable to replant linden trees, since they provide food to all types of bees. On the ground level the trees could be complemented with soil cover vegetation, which flowers complementary to linden trees. Linden trees flower during June and July. Therefore the soil cover vegetation should ideally flower during the beginning of forage season, during March/April/May and the end of the forage season, during August/September/October. A soil cover shrub which could flowers during the beginning of the forage season could be the yew-tree *(Taxus baccata)* and for food provision during the end of the season Ivy *(Hedera helix)*. The yew-tree however does only provide pollen and nectar for honey bees, so it would be better to add also other vegetation. In general should be aimed for species diversity as much as possible.

6 Discussion and recommendations

This research provides practical implementation guidelines for policymakers and house owners with ownership of a green roof or a roof area suitable for transforming into a green roof. The research also gives recommendations on how public green and private green can offer bee habitat. However the implementation guidelines focus on bee habitat creation on the level of one green roof or façade, and on the city scale; green roofs and façades allocated over the city.

The research describes guidelines on how to create a favourable environment for all types of bees, but in particular for the bees already present in urban areas. In literature however most research focuses on honey bees. There is less information available on wild bees. This research therefore draws on assumption that negative effects for honey bees also negatively affect wild bees. It is expected though that this generalizing approach is not likely to cause major flaws in the guidelines, because physical demands for wild bees are very similar to those of honey bees. Also in regards to forage behaviour urban wild bees are very similar to honey bees, as they both forage on a broad diversity of plants. The biggest difference between them is that honey bees fly out during a longer timespan; from the beginning of March till the end of October. The majority of urban wild bees only flies out between May and August. The diversity among bee species is the reason why there is so much emphasis in this research on creating diverse micro-habitats with many gradients and diverse vegetation on green roofs and façades.

One of the most important recommendations before the provided implementation guidelines can be implemented is to test whether ground nesting bees indeed make use of nesting spaces on green roofs and on green façades. Best is to carry out experiments on different green roof systems with different substrate layers and micro-climates. The results of these experiments can be used to conclude which types of roofs are ideal nesting spaces. From the research can be concluded this is in general likely to be roofs with loose, sandy soil and much diversity in micro-climates and vegetation.

Concerning the analyzed parameters on the micro-scale, the scale of a building component, a few conclusions can be drawn. A general conclusion is that not all parameters are equally easy to define, not all parameters are of equal relevance to bee population growth, or differ a lot per location. The most constraining factors that determine whether a green roof of façade will function as a bee habitat is the availability of nesting space and food provision. For food provision it is important that the green roof/green façade structure supports bee attractive vegetation. Also, a suitable method of green maintenance should be applied on this bee attractive vegetation. Another important, but a less constraining factor is wind force. With very strong wind forces it becomes too energy intensive for bees to fly out. Air pollution is an environmental factors important to take care of, as research indicates forage behaviour of bees is negatively influenced by NOx emissions, and in particular by NOx. However, exact threshold values of these parameters should be further researched. Also on the green roof/façade itself measurements should be done to determine exact values of the different parameters, like for example the wind force. Regarding other parameters, for example the air humidity, the amount of rain and the temperature on a roof, it is difficult to come to specific conclusions on a certain green roof location. These parameters differ a lot, e.g. depending on the time of the year, however not per location within the Netherlands. Therefore these parameters can be considered less important, although it is good to be aware that they do influence the behaviour of bees; bees do not fly out when it is raining, there is a minimum requirement for the air humidity of a beehive and bees fly out between March and October, because the temperature is then on average in between 18 and 25 degrees.

This research provides a graphic visualization of a bee habitat on an urban scale. Another outcome of this research, could be a rough design of a typical bee habitat for a single roof. For an individual roof the possibilities for a design are very broad however. Therefore providing a typical design does not provide extra information on top of the stated implementation guidelines.

Regarding the diffusion of bees over cities the current vegetation and nesting spaces on existing green roofs, on green façades and on the ground level were analyzed. Implemented green roofs and façades have to complement the current available food sources and nesting spaces. However, one could chose to make the green roofs and façades self-sufficient habitats, so the bees do not have to fly to the ground level anymore. In the case study 'Zuideramstel' in this research this however did not result to be a logic choice, because the buildings in the analyzed area were only of low to medium heights (up to 3-4 floors). Bees that forage on ground level could therefore also easily reach rooftop levels. In very dense urban areas like the city center of Amsterdam there is only little green area on ground level, so there is more need for a self-sufficient food and nesting space layer formed by rooftops and green facades. Creating a self-sufficient network of green façades and green roofs would also make sense in areas with many high buildings. Then the 'ceiling of the city' (the sum of all the roofs of the city) can create an additional habitat for colonies on roof levels while other bee populations can forage on ground level (in case there is sufficient green). In particular honey bees and bumblebees can forage on a roof level, since they fly out under more extreme weather conditions and fly out to larger distances. The ground level is more suitable for wild bees.

In this research the structure of trees on ground level is mainly analyzed, to see how the current food provision for bees is. Shrubs in public green are less extensively researched since they in general do not form a continuous green network through the city, which is important for bees to be able to diffuse into different areas.
Moreover, this research focused on public green areas. Further research should focus on a more precise inventory of shrubs in public green areas and on an inventory of available private green spaces in addition to this.
Furthermore, as already stated in the introduction, this research focuses in particular on green roofs. Since most parameters for creating bee habitats on façades are similar (the influence of climatic parameters like wind, sun, rain and environmental parameters like air pollution) most of the results of this research can also be applied to green façades. The biggest difference between green roofs and green façades is the orientation: a green roof is a horizontal surface and a green façade vertical. This orientation determines which construction system is required. Furthermore it can be expected that the micro-climate is different on façades while on façades also a smaller range of plants can grow as there is only a limited space for plants to root. Therefore more precise research regarding green façades would add value to this research.
Finally, from the perspective of the framework of this research, Industrial Ecology, it has to be stressed that a design for a bee habitat should before implementation also be analyzed systematically on its environmental effects over the entire life cycle of the roof of façade. Benefits should be considered within the overall context. Therefore a questioning of the new green roof or green façade provides overall environmental gains should be included. This avoids that benefits only concern bee populations and biodiversity. If for example a green roof design contains bee attractive trees which require an extra irrigation system, it should be analyzed whether the green roof including this irrigation system leads to overall positive effects in terms of water, material and energy (reductions) over the entire life cycle of the roof.

7 Conclusion

Bees are keystone species in ecosystems, they provide a key ecosystem service: pollination. Pollination is essential for our food provision and therefore conservation of bees is very important. Nowadays bee populations are globally in decline, particularly in the Netherlands. Green roofs have proven to offer suitable habitat for bee populations, which increases the chances for populations to flourish. Thus, the main research question for this master thesis was *How can green roofs (façades) in the Dutch built environment increase healthy bee populations, which measures on different scales can be taken and how are they interrelated?*

In order to answer this question a number of sub questions had to be answered. First of all, *what are the factors that are crucial for bee populations to flourish?* Literature review has shown that the crucial factors for bees to flourish are:

- <u>Food provision.</u> Bees depend for their entire food collection on pollen and nectar supplied by flowering plants. Some bee species depend completely on one plant species (*monophagous*), but most species forage on a diversity of plants (*polyphagous)*. The sum of bee attracting plants should provide food provision during the entire forage season of bees, which is from the beginning of March till the end of October.
- <u>Nesting spaces.</u> Bees store their food and raise their larvae in the nesting spaces. Different bee species have different requirements for nesting spaces. This is further elaborated under research question 3 to 5.

The second question was: *what are the current problems in the Netherlands that cause bee populations to decline?* The last decades bee populations are in strong decline. Literature states that especially agricultural areas have become unsuitable for bees to forage and nest. There are several reasons why a (partial) shift of the habitat of bee populations from agricultural areas towards cities should be considered, if not supported strongly. The reasons for this are:

- <u>Unilateral and discontinuous supply of food.</u> The current method of agriculture only supplies an unilateral supply of pollen and nectar, a supply which is also not equally distributed over the fly season of bees.
- <u>Pesticides.</u> In agricultural areas many pesticides are being used, which causes major adverse effects on bee populations. In cities the use of pesticides is much less. Regarding the pesticides introduced in the last few years, especially the neonicitoids,

are very harmful. These systemic pesticides are considered to be 1000 times more poisonous than the organophosphorus pesticides, which were used before.

- Decrease of natural area. The increase of human population causes urban area expansion, which in turn leaves less space for natural area which is of importance for bee habitat. The current newly built living areas replace natural area and have little vegetation and provide little nesting spaces for bees.
- New and altering pests and diseases. Also due to climate change, pests and diseases are altering and new pests and diseases are introduced.
- Beekeeping of honey bees has become a difficult task. Although the importance of beekeeping is high, without bees most of our crops would not be pollinated, it is still not a very profitable business. Because of the decrease of the number of beekeepers important knowledge and skills tend to disappear. The exact effect of pests and diseases on wild bees is not exactly known, but since wild bees are physically similar to honey bees it can be expected they also suffer from adverse effects.

Thirdly had to be determined: *which bees are present in Dutch urban areas?* The Netherlands counts around 350 bee species of which at least 195 inhabit cities. The 195 species have in general a broad range of flowers on which they forage. They forage in cities because cities offer a broad variety of flowering plant species. Most of these species are wild bee species, only one of them is domesticated: the honey bee. 47 of the 195 species are very common in cities. These species have three different nesting places:

- Ground nesting bees. Most of the species (31 out of 47) present in urban areas are ground nesting bees. These bees preferably dig nests in sandy soil. This nesting hole can be up to 100 centimeters deep.
- Above ground nesting bees. The second biggest group of bee species (13 out of 47 species) nests in elements as old dead tree branches, reed, hollow plant stems, cavities in walls etc. Honey bee colonies are held in beehives, they thus also nest above ground.
- Ground and above ground nesting bees. A few urban bee species are nesting both in the ground or above the ground (3 out of 47 species).

The fourth question focused on habitat creation by the built of urban green (green roofs and green facades): *How can green roofs (façades) be constructed and which green roof properties are important for bees?* Green roofs and green façades can provide a solution for many of the above mentioned problems. Research has shown that bees forage on green roofs and that green façades provide suitable habitat for bees. The following (construction) parts of the green roof system determine how suitable the roof is for habitat creation:

- The drainage and capillarity layer. These layers define the microclimate on the roof and determine the quality for bees to settle on the roof.
- Selection (and storage) of local soil. The selection and storage of local soil is crucial for suitable habitat creation. The composition of the substrate, the amount of nutrients and the humidity of the soil determine which plants can grow and therefore which type of bees will forage on the roof. For ground nesting wild bees the substrate itself is also important as nesting space.
- Substrate thickness. Literature states that extensive green roofs with a thin substrate layer are considered to be not very suitable for many animal species to establish, but currently many construction possibilities for extensive green roofs exist. Often, also to create roofs where the substrate layer is partly thickened. Hills up to 20 centimeter can be created. This variety of substrate thicknesses leads to different microclimates, which provides a broader potential for different species to establish.

The fifth question focused on important parameters of an individual roof and measures to be taken on an individual roof: *What are important parameters for bee habitat creation on green roof (façade) on an individual level, on a micro-scale?* Table 23 concerns the entire table as presented in section 5.4. The most important parameters and measures concern:

- The construction system. As already stated under research question four are the drainage and capillarity layer determining layers for the potential of habitat creation for bees.
- The physical properties of the roof. Bees forage up to heights of 20 meters, therefore green roofs should preferably be located on heights lower than this altitude.
- The climatic properties. Wind is one of the main climatic properties that determines whether a green roof creates a good habitat for bees or not. Strong wind forces make it too energy intensive for bees to fly out. Therefore nesting spaces should be sheltered from wind by for example vegetation or by surrounding buildings. For honey bee beehives for example a 'beeglo' could be introduced. This is a tent protecting the beehive from strong winds. Ideally a good habitat is located on a sunny roof, because bees prefer to nest on warm and dry spaces.
- The vegetation and its management. For food provision aim should be to realize for a diversity of flowering plant species, which in total provide food supply during the entire fly season. To be able to survive on a roof these plant species should be resistant to extreme weather conditions as extreme droughts and severe frosts.

Especially mosses and sedum species meet these requirements. However, mosses and sedums do only have a relatively short flowering period. Therefore they have to be complemented with other vegetation to secure a pollen and nectar supply during the whole season.

- Additional objects/Nesting possibilities. Although it is not known yet whether wild bee species will nest on roofs, literature does emphasize that wild bees forage more on roofs in case these contain more objects where they usually nest, for example in old dead tree branches, reed, hollow plant stems and cavities in walls. Therefore placing these elements on the roof will help increase the visit and stay of bees on roofs and it will in the end increase the changes bees will nest here.
- The level of air pollution. Concerning environmental properties research indicates that forage behaviour of bees is negatively affected by emissions as particulate matter and NO_x. Therefore it should be aimed to create nesting spaces for bees distant from heavy traffic roads, which is the main source of these pollutants.

The sixth question focused on a collection of roofs: *How should the green roofs (facades) be allocated over the city, in order to create a bee habitat on a macro-scale?*
At a larger scale-level, the scale of the network of green roofs and façades spread over the city is important to consider in order to determine how bees can diffuse over the city. To achieve positive overall effects on the biodiversity, creating green networks on different levels of scale is essential. By creating green networks flora and fauna can spread over large distances, which ultimately will lead to a higher biodiversity in ecosystems. The added value of this is that ecosystems with a high biodiversity are more resilient for disturbances than ecosystems with a lower diversity. It is important that green networks at different scale-levels provide stepping stones for bees to fly out from their nest and to find sufficient food. For habitat creation on a macro-level of scale two factors are important:

- Green roofs and green facades should complement existing vegetation and the nesting possibilities for bees on the ground level (e.g. in public green areas and/or private gardens). A share of the vegetation on ground level will supply pollen and nectar.
- The distance between green roofs and/or green façades. In this research it is estimated that the maximum distance different bee species fly out is 100 meters or more. So a few species will fly out maximum 100 meters from their nest, but most species fly out further than 100 meters to collect food. This implies the in between distance of stepping stones for food supplying plants and nesting spaces should ideally not be more than 100 meters. A quick investigation of some Dutch cities

shows that on average, the existing Ecological structure in most cities is not dense enough to cover this scope. For the diffusion of bees over the city, therefore an extra level of scale needs to be introduced. Trees and shrubs in an urban district form this additional level of scale of these stepping stones. However, these trees and shrubs in general do not provide enough food and nesting spaces. Green roofs and façades then can provide such additional stepping stones focusing on food and nesting spaces.

These findings prove that the most important factors and measures of/on green roofs (façades) for increasing healthy bee populations in the Netherlands on the scale of a single roof (façade) are:

- Increase natural area and avoid the use of pesticides, so bees become less vulnerable for pests and diseases.
- Maximize the amount of food supply and nesting spaces for bees.
- Maximize diversity of pollen and nectar supplying plants, which provide pollen during the entire fly season of bees.
- Provide nesting spaces in and above ground: sandy soil, dead tree branches, reed, hollow plant stems, cavities in walls, etc.
- Build green roofs (façades) with suitable construction systems, for creation of a beneficial micro-climate. For a green roof especially the selection of the drainage and capillarity layer, the soil and the substrate thickness are important.
- Build green roofs by preference on roofs with heights at highest 20 meters from ground level.
- Build green roofs by preference on roofs (façades) on wind sheltered and sunny locations.
- Build green roofs by preference on roofs (façades) which are distant from heavy traffic roads.

On the city scale, the most important factors and measures of/on green roofs (façades) for increasing healthy bee populations in the Netherlands (façade) are:

- Build green roofs(façades)strategically, in a way that the roofs and façades complement food sources and nesting spaces on ground level.
- Build green roofs(façades) strategically at highest at 100 meters distant from each other.

The measures/factors on the city scale complement the measures/factors on the scale of an individual roof (façades). The table below provides the entire checklist as a result from this research.

Parameter	Sub-parameter	Required
Physical properties roof	Height of the roof	• 12-20m
	Size of the roof	• HB: >1000m^2 • B: 25m^2 • WB: 10m^2
	Slope of the roof	• Flat, somewhat sloping
	Orientation of the roof	• South
Vegetation	Types	• Local indigenous plants (see appendix 0) • Pollen supply guaranteed throughout the forage season (see appendix 0)
	Distribution/ density	• Few m^2 bare, sandy open area
Soil/substrate	Type	• Use of local soil and substrates • Top 15 cm layer derived from meadow lands and woodlands, but also sand and gravel • Varying substrate depths, up to 70 cm to support all types of ground nesting bees • Varying drainage regimes, differences created in humidity, nutrient richness and acidity
Climatic properties	Wind	• Sheltered place, little wind, especially the opening of the nest should be sheltered. • Wind speed less than 4-5km/h • Little turbulence • Protection (e.g. by high buildings) from the wind on the south-west side.
	Humidity/Rain	• Dry places • Humidity air of bee hive less than 90%.

	Sun	• Sun when bees fly out mostly, so between 11.00 a.m. and 16.00 p.m.
	Temperature	• *HB+BB:* 10-35 °C, optimum 18-25 °C • *HB+BB:* 10-35 °C, optimum 18-25 °C • WB: 15-18 °C
Geographic location	Environment in general	• Natural area
	Buildings	• Buildings with nesting possibilities
Additional objects on the roof	Beehive, blocks with wholes, sand layer, etc.	• Old dead wood, grass pollen, walls, hollow reeds, blackberry, elder, thistles and umbel lifers, bee hotel, sandy slopes, cracks in rocks
Management	Pesticides, Pesticide A,B,C	• Preferable none
	Management type	Organic control: • Different stages of development of plants should be coherent and in an optimum ratio • Mowing, cutting done in phases. • Letting weed species grow
Pollution	Air pollution NO_x/PM	• Little NO_x pollution • Little dust/particulate matter

Table 23 Overview of micro-scale parameters (HB: Honey Bees BB: Bumblebees WB: Wild Bees)

Parameter	**Sub-parameter**	**Required**
Micro parameters	*Micro parameters*	*Micro parameters*
Proximity of roofs		HB + BB: ≤ 3 km WB: ≤ 0.5 - 300 metres
Integration with existing green		• Roofs (facades) self-sufficient in food/nesting possibilities
		• Vegetation complementary to present vegetation

Nesting spaces on ground level		• Sandy soils, cracks in buildings, old dead wood, logs, hollow reed, beehotels, etc.

Table 24 Overview of macro-scale parameters HB: Honey Bees BB: Bumblebees WB: Wild Bees

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Appendix

Green roof transfer plants

Vegetation both suitable for green roof as good for bees

Tabel A: Dry, sunny circumstances, substrate thickness 20-40 mm

Native	English name	Botanical name	Blossom	Species	Bron
No	Allium, Ornamental Onio	Allium atroppurpureum	May/June	F. b.	1, 2
No	Allium moly	Allium moly	May/June	F. b.	1, 2
Yes	Chives	Allium schoenoprasum	May/June	F. b.	1, 2
No	Round headed Leek	Allium sphaerocephalon	May/Aug	F. b.	1, 2
Yes	Wallpepper	Sedum acre	June/July	Per.	1, 2
Yes	White Stonecrop	Sedum album	June/July	Per	1, 2
No	Stonecrop	Sedum kamtschaticum var. M	July/Aug	Per	1, 2
No	Stonecrop	Sedum kamtschaticum var. M	July/Aug	Per	1, 2
No	Jenny's stonecrop	Sedum reflexum	July	Per	

Tabel B: Sunny circumstances, little shadow, substrate thickness 50-70 mm

Native					
Yes	Superba' Clustered Bellfl	Campanula glomerata	July/Aug	Plnt.	1, 2
No	Wall bellflower	Campanula portenschlagiana	June/Aug	Plnt.	1, 2
No	Trailing bellflower	Campanula poscharskyana	June/Sept/Oct	Plnt.	1, 2
Yes	Blueweed	Echium vulgare	June/Aug	Plnt.	1, 2
No	Winter Heath	Erica carnea 'Winterbeauty'	Jan/April	Plnt.	1, 2
No	Bloody geranium	Geranium sanguineum	June/Aug	Plnt.	1, 2
Yes	Common Rockrose	Helianthemum nummularium	May/June	Plnt.	1, 2
Yes	Mouse ear Hawkweed	Hieracium pilosella	May/Sept	Plnt.	1, 2
No	Catmint	Nepeta x faassenii	May/Sept	Plnt.	1, 2
	Oregano	Origanum laevigatum		Plnt.	1,2,3
Yes	Oregano, Wild Marjoram	Origanum vulgare	July/Oct	Plnt.	1,2,3
No	Bulbous Buttercup	Ranunculus bulbosus	April/July	Plnt.	1,2,3
No	Autumn Stonecrop	Sedum spectabile	Aug/Oct	Plnt.	1, 2
No	Autumn Stonecrop	Sedum x telephium 'Herbstfre	Oct/Nov	Plnt.	1, 2
Yes	Wall Germander	Teucrium chamaedrys	July/Aug	Plnt.	1, 2
Yes	Wild Thyme	Thymus serpyllum	May/Aug	Plnt.	1, 2

Tabel C: Sunny and shadowed circumstances, substrate thickness 70-120 mm

Yes	Yarrow	Achillea millefolium	June/Aug	Plnt.	1, 2
Yes	Nettle-leaved bellflower	Campanula trachelium	July/Aug	Plnt.	1, 2
No	Lavender	Lavandula angustifolia	July/Aug	Plnt.	1, 2
Yes	Musk-mallow	Malva moschata	June/Sept	Plnt.	1, 2

Tabel D: Shadow places; substrate thickness 50-70 mm

Yes	Common bugle	Ajuga reptans	April/May	Plnt.	1, 2
No	Spreading Rock Cress	Arabis procurrens	April/May	Plnt.	1, 2
Yes	Kenilworth ivy	Cymbalaria muralis	June/Sept	Plnt.	1, 2
Yes	Ground-ivy	Glechoma hederacea	April/May	Plnt.	1, 2
Yes	Spotted deadnettle	Lamium maculatum 'Argenteu	May	Plnt.	1, 2
Yes	Dwarf meadow rue	Thalictrum minus 'Adiantifoli	June/Aug	Plnt.	1, 2
No	Speedwell	Veronice officinalis	June/Aug	Plnt.	1, 2

Tabel E: Shadow places, substrate thickness 70-120 mm

Yes	European columbine	Aquilegia vulgaris	May/June	Plnt.	1, 2
No	Rockcress	Arabis caucasica	April/May	Plnt.	1, 2
No	White heart-leaf aster	Aster divaricatus	Sept/Oct	Plnt.	1, 2
No	Rhone Aster	Aster sedifolius 'Nanus'	Sept/Oct	Plnt.	1, 2
No	Carpathian harebell	Campanula carpatica	June/Aug	Plnt.	1, 2
Yes	Wood spurge	Euphoria amygdaloides	April/May	Plnt.	1, 2
	Hardy geranium	Geranium macrorrhizum	June/Aug	Plnt.	1, 2
Yes	Yellow archangel	Lamium galeobdolon	Aril/June	Plnt.	1, 2
No	Japanese spurge	Pachysandra terminalis	April	Plnt.	1, 2
Yes	Burnet rose	Rosa pimpinellifolia	May/June	Bush	1, 2
No	Iberian Comfrey	Symphytum grandiflorum	May	Plnt.	1, 2

F.b.= Flower bulb, Per.= Perennial, Plnt.= Plant
Source: 1: Drachtplanten.nl, 2: Teeuw & Ravesloot, 3: van Blitterswijk et al., 2009

Bees in cities

Species and properties

Food sources

All bees depend on different plant species and are thus *polyphagous*

Forage season

Mostly from May-August. *Andrena* species early in the season, from March- June. Bumblebee species during the entire forage season from March – September (October).

Body length

The different body lengths and related number of species:

- Red box: 0-5 mm; 3
- Blue box: 5-10 mm; 19
- Green box: 10-15 mm; 25 (+2 cuckoo bumblebees)
- Purple box: 15-25 mm; - (2 cuckoo bumblebees)

Total: 47

Nest sides

The different nest sites and related number of species:

- Brown box: ground nesting bees; 31
- Blue box: above ground nesting bees; 13
- Orange box: in + above ground nesting bees; 3

Total: 47

Species	**Body length**	**Forage distance**	**Forage period**	**Plant species**	**Nest site**
(Lat.) **Andrena** – *(Eng.)* **Sand bee** *(Dutch: Zandbijen)*					

Andrena barbilabris	11.5 mm	300-400m (Koster, 2013), 500m Witt (1992), 300m Wesserling (1996)	End March-End June	Willow, later many different plants(e.g. dandelion, ground elder, etc.)	Soil, sandy, bare or sparsely vegetated
Andrena bicolor	9-11 mm		March-August (Sept)	No particular preference (e.g. dandelion, blackthorn, etc.)	Soil, sandy, bare or sparsely vegetated, dig up to 1m deep
Andrena carantonica	f 13-14 mm; m 12 - 13 mm		End March-June	Hawthorn, Maple, Spanish barge, dandelion, ground elder, etc.	Soil, sandy
Andrena chrysosceles	f 9-10 mm; m 8-9 mm.		April-End June	e.g. ground elder, cow parsley, hemlock, etc.	Soil, sandy
Andrena cineraria	14mm	300m Gebhardt & Röhr (1987)	End March-begin June	Diverse e.g. willow, hemlock, cow parsley, etc.	Soil, sandy
Andrena denticulata	f 10-11 mm ; m 9-10 mm.		End June-End August	Ragwort species	Soil, sandy
Andrena flavipes	12 mm	260m Wesserling (1996)	Half March-End August	Very diverse	Soil, sandy, to clay, bare or sparsely vegetated
Andrena florea	11-13 mm.		Half May-End June	Bryony	Soil, sandy to loamy
Andrena fulva	f.12 -14 mm; m 10-14 mm.		Second half March-Second half May	e.g. Currant, black currant, gooseberry, redcurrant	Soil, sandy, to clay, bare or sparsely vegetated
Andrena haemorrharoa	11mm.		End March-half June	e.g. Dandelion, Willow	Soil, sandy to loamy, bare or sparsely vegetated
Andrena nigroaenea	f. 13-15 mm; m 12-14 mm.		End March-Half June	e.g. Willow, dandelion, bryony, hemlock, cow parsley, wild radish, cabbage and ground elder.	Soil, sandy to loamy, bare or sparsely vegetated, 40 cm deep, could reach depth more than 1m
Andrena nitida	f. 12-15 mm; m12-13 mm.		Half March-Half June	e.g. goat willow, hemlock, cow parsley, common hogweed, dandelion, blackthorn, hawthorn, field maple, celandine, elder	Soil, sandy to loamy,
Andrena proxima	8-10mm.		April-May	Umbellifers, e.g. cow parsley, ground elder and hemlock	Sandy, to sabulous clay
Andrena subopaca	6-7 mm.		April-begin August	e.g. elder, cow parsley, dandelion, wild strawberry, hemlock, cabbage. (Koster 2000)	Sandy, light mineral soil
Andrena tibialis	f. 13-14 mm; m 12-14 mm.		End March-end May (begin June)	e.g. Willow, coltsfoot, elder, dandelion, celandine, Acer tataricum.	Soil, sandy

Andrena vaga	14 mm	260m Wesserling (1996)	mid-March to mid-May (start flowering goat willow - end of flowering creeping willow)	All native willows	rich sandy loam to loam poor on flat bottoms and on steep soils, bare or sparsely vegetated
(Lat.) **Anthidium –** *(Eng.)* **Mason or potter bee** *(Dutch: Wolbijen)*					
Anthidium manicatum	f. 10 -13 mm; m 10-16 mm.		End May – Begin September	lipped flowers and pea family, e.g. cats thorn, alfalfa, mountain stone thyme, foxglove, motherwort, purple dead nettle, horehound, fur crown herb, trefoil, foxglove, dog-ear, clary sage.	dead wood, holes in walls, hollow plant stems, artificial nesting
(Lat.) **Bombus – Bumblebees** *(Dutch: Hommels)*					
Bombus bohemicus	f.18-26 mm ;m 15-18 mm.		females in early April to late June; males. late May-early September.	e.g. dandelion, thistles, knapweed (Westrich, 1989).	Cuckoo bee
Bombus campestris	f. 17-22 mm; m 15-17 mm		End March, begin October	e.g. dandelions and thistels (Westrich, 1989)	Cuckoo bee
Bombus hortorum	q.17-22 mm; f.11-16 mm. m 13-15 mm.		queen, worker bees mid-March to early September, males June - early September.	Divers	Cuckoo bee, in abandoned mouse nests in the ground, bird nests, nest boxes and cavities in buildings (Westrich, 1989).
Bombus lapidarius	q.20-23 mm; f. 12-16mm; m 14-16 mm.		March-October	Divers	Cuckoo bee, mainly under rocks, among roots of trees, bird nesting boxes.
Bombus pasuorum	?	?	?	?	?
Bombus pratorum	q.15-17mm; w. 9-14mm; m.11-13 mm.		March-September	Divers	mainly above the ground, both in vegetation and in other cavities.
Bombus terrestris	q.20-23		March-	Divers	nests in the

	mm, f 11-17 mm , m 14-16 mm.		October		ground, and in particular in cavities in walls
Bombus vestalis	f. 20-23 mm; m 15-17 mm.		March-September	Divers	Cuckoo bee, nest in nest of B. terrestris
(Lat.) **Chelostoma -** *(Eng.)* (n.a.) *(Dutch: Klokjesbijen)*					
Chelostoma campanularum - Harebell Carpenter Bee	4-7 mm.		June-half August	clocks including: harebell, bluebell field, bluebell rugged, magnificent bluebell, etc.	dead wood, fence posts, hollow stems, reed roofs, insect nest, beehotels.
Chelostoma rapunculi	8-10 mm (Koster 2013), 8.5 mm (Gathmann (1998))	200 m	End May – Begin August	All kind of flowers with bells	dead wood with old beetle walks, plant stalks, straw mats, thatched roofs, bee hotels, particularly logs
(Lat.) **Colletes –** *(Eng.)* **Plasterer bees -** *(Dutch:Zijdebijen)*					
Colletes daviesanus	8-11 mm.		begin June - begin September.	essentially tansy; further yarrow, chamomile, daisy fleabane, daisy, ragwort, feverfew, etc.	steep walls steep edges of roadsides, dry ditches, in (old) walls with fairly soft joints in walls
(Lat.) **Dasypoda –** *(Eng.)* (n.a.) - *(Dutch: Pluimvoetbijen)*					
Dasypoda hirtipes - Hairy Legged Mining Bee	12-15 mm.		June-August	only composites, e.g. hawkweed, wild chicory, thistles, knapweed, etc.	in sandy soil, on open land, edges of paths between pavement with relatively wide joints: cobble, boulders and cobbles.
(Lat.) **Halictus –** *(Eng.)* **Mining bees** (*Dutch: Groefbijen)*					
Halictus rubicundus	9-11 mm.		May-September (to October)	Diverse; tansy, hemlock, cow parsley, giant hogweed, elder, stonecrop, bryony, sweet william, etc.	in sandy soils often through the joints under the pavement
Halictus tumulorum	f.6-8 mm., m. 7mm.		May-September (October)	small stripe seed, ground ivy, chamomile, sand Argus, simply, tansy, elder, campanula cochearia, mallow, wild radish, blackberry, knapweed, yellow	soil, e.g. edges of urban plantings, parks (including peaty to clayey soils),

				chrysanthemum, summer fleabane, etc. (Koster 2000)	brushwood, gardens.
(Lat.) **Heriades** - *(Eng.)*(n.a) - (*Dutch: Tronkenbijen)*					
Heriades trucorum	5-7 mm.		End May – begin September	mainly composites, e.g. tansy, yarrow, yellow yarrow, yellow chrysanthemum, chamomile, Ragwort, chamomile	in old beetle tunnels in dead wood, dead hollow stems of plants, reeds and reed roofs, bee hotels
(Lat.) **Hylaeus** - *(Eng.)***Yellow-masked bees** – (*Dutch: Maskerbijen*)					
Hylaeus communis	f. 5-7 mm., m. 5-6 mm.		End May-September	Diverse, e.g. sand Argus, wild mignonette, blackberry, hogweed, elder, creeping thistle, carrots, stonecrop, coarse chives.	in hollow dead plant stems, in dead wood and nest logs
Hylaeus hyalinatus	5-7 mm.		Half May-September	Divers, e.g. stonecrop, wild carrot, common hogweed, sedum spurium, sedum reflexum, sedum kamschatium., giant hogweed, white stonecrop, white mignonette, etc.	dry stems of bramble, abandoned nests of other bees, stems of herbaceous plants, reed mats, and cracks and holes in walls and wood.
Hylaeus pictipes	4-5 mm.		End May-half September	Divers, e.g. field cherry, common hogweed, wild mignonette, blackberry, stonecrop, dill, and ground elder, etc.	dry stems of blackberry, loam walls and in the nests of other bees
Hylaeus signatus	6-9 mm.		End May-End August	Mainly mignonette	dead hollow stems of plants (rose, blackberry Koster 1986), holes in walls, beetle tunnels in dead wood.
(Lat.) **Lasioglossum** - *(Eng.)***Sweat bees, mining bees** (*Dutch: Groefbijen*)					
Lasioglossum caceatum	f. 8-9 mm, m. 8-10 mm.		End April-End August	Diverse, e.g. cow parsley, wild radish. ragwort, ground ivy, dark cranesbill, stiff hawkweed, field cabbage, elder, small dandelion, ragwort, etc.	Soil
Lasioglossum leucopus	5 mm.		April-August	Non-scientific observations (Wieringstraat	Soil

				1999)e.g. sand Argus, simply piglets herb, etc.	
Lasioglossum leucozonium	8-10 mm.		May-September (October-November)	Divers, e.g.: preferably composites hawksbeard, simply piglets herb Hedgerow Crane's-bill, (Koster, 2013). sharp buttercup, blackberry, tansy and dandelion Westrich (1989).	Soil
Lassioglossum lucidulum	4-5 mm		June-August (May-September)	e.g. sand Argus (Koster, 2013) yarrow, cabbage, simply knapweed, small hawksbeard and danselion, etc. Westrich (1989)	Soil
Lasioglossum malachurum	8-9 mm		End March-end September	e.g. Cabbage, knapweed, creeping thistle, sand Argus, daisy, blackberry, goat willow, field sage, dandelion, white clover, etc. Westrich (1989).	Soil
Lassioglossum morio	5-6 mm		April-September	e.g. cow parsley, sand Argus, dandelion, celandine, elder, wild radish, field cabbage, water plantain, screen hawkweed, Campanula cochlearifolia, white stonecrop, etc. (Koster 2000)	Soil, sandy
Lasioglossum sexnotatum	f. 10-11 mm. m. 9-10 mm.		April-September	Non-scientific observations: e.g. wild asparagus ordinary rocket, cow parsley and celandine (Koster, 2013). yarrow, big cats tail, sharp buttercup, dandelion, etc. Westrich (1989).	Soil, sandy to loamy
Lasioglossum sexstrigatum	f. 6-7 mm, m.5-7 mm.		April-September	e.g. wild radish, giant hogweed, elder, stiff hawkweed dandelion field cherry, bryony, wild mignonette, field cabbage, rue, white stonecrop, sycamore, common hogweed, etc. (Koster (2000) and Westrich (1989))	Soil
Lasioglossum villosulum	6-7 mm		June-begin August	Non-scientific observations: mostly composites, e.g. simply piglets herb, screen hawkweed, dandelion, field cabbage field cherry, stonecrop (Koster, 2013), knapweed, wild chicory, mouse ear, branched Hawkbit, etc.	Soil

				Westrich (1989).	
Lasioglossum zonulum	f. 10 mm., m. 7-10 mm.		May-September	e.g. yarrow, cabbage, harebell, wild chicory, large hawksbeard, Rockrose, St. John's wort, common daisy, really bitter herb, sharp buttercup and dandelion Westrich (1989)	Soil
(Lat.) **Megachile-** *(Eng.)***Leaf cutter and dauber bees** *(Dutch: Behangersbijen)*					
Megachile centuncularis	f. 9-12 mm; m 8-11 mm		End May-begin August	Divers, e.g. trefoil, spear thistle, wild chicory, knapweed, cats thorn field cabbage, bryony, really bitter herb, shrub and blow pea shrub.	in cavities of old walls, dead wood, plant stems and dead branches, in logs with artificial nesting and bamboo sticks.
Megachile versicolor	f. 11-12 mm; m. 9-11 mm		June-August	Divers	old beetle tunnels in wood, dead plant stems, artificial nests in the form of logs or bundles of bamboo sticks
Megachile willughbiella	f. 14-16 mm., m.12-14 mm.		End June-Half August	Divers	in dead wood or in the ground, weathered or decayed wood with oval leaf pieces, natural and artificial (logs) cavities in wood, plant stems (canes), bamboo sticks.
(Lat.) **Melitta –** (n.a.) *(Dutch:Dikpootbijen)*					
Melitta haemorrhoidalis	11-13 mm.		Begin July-end of August	females in all native and non-native species many campanula, the males in many other plant species: musk mallow, mallow, thyme great, just knapweed, small hawksbeard, Meadow Cranesbill.	Soil, under normal conditions, but with bad weather they remain in flowers.
(Lat.) **Nomada –** *(Eng.)***Wasp bee, cuckoo bees** *(Dutch: Wespbijen)*					
Nomada fabriciana					
Nomada flava					
Nomada flavogutata					
Nomada fulvicornis					
Nomada fuscicornis					

Nomada leucophthalma					
Nomada marshamella					
Nomada panzeri					
Nomada ruficornis					
Nomada rufipes					
Nomada sheppardana					
Nomada signata					
Nomada succinnta					
Nomada goodeniana					
(Lat.) **Osmia – Mason bees –** *(Dutch. Metselbijen)*					
Osmia bicornis	8-12 mm.		End March-end May/begin June	Divers	In all kinds of cavities, old beetle tunnels, dead wood. bundles of bamboo sticks, thatch roofs and reed bundles, logs with pre-drilled holes for screws and plugs, plastic tubes-in-nest, bees hotels etc.
Osmia caerulescens	8-9 mm.		April/May-begin August	Divers, e.g. lavender, tarragon, oregano, vetch, white clover honey, fur crown herb, sage field, ground ivy, Bugle.	plant stems, reed mats, beetle tunnels in dead wood, in walls and clay walls, bundles of bamboo sticks, reed roofs and reed bundles, logs with pre-drilled holes.
Osmia cornuta	11-15 mm.		End April-May	Divers: e.g.goat willow, dandelion, rape, sharp buttercup, creeping buttercup, hawthorn, blackthorn, field maple.	in all kinds of hollow spaces; old beetle cavities in dead wood, cavities walls, stone in whether or not sandy loam walls also bees hotels: bundles of bamboo sticks, logs
(Lat.) **Specodes** – *(Eng.)* (n.a.) cuckoo bees*(Dutch. Bloedbijen)*					
Specodes albilabris					
Specodes crassus					
Sphecodes gibbus					
Sphecodes geofrellus					
Sphecodes longulus					
Sphecodes marginatus					
Sphecodes monilicornis					
Sphecodes pellucidus					

(Lat.) **Stelis** – *(Eng.)*(n.a.) cuckoo bees *(Dutch - Tubebijen)*					
Stelis breviuscula					
Stelis punctulatissima					

Table 25 Urban bee species and their properties. Source: Mostly based on www.denederlandsebijen.nl (Koster, 2013). Other sources are derived from Gathmann and Tscharke, 2002

N.B. The cuckoo bees are not further investigated since they mostly not collect the pollen and nectar themselves. Furthermore they invade nests of other bees, so suitable nesting possibilities for other species will also result in good nesting spaces for cuckoo bees.

Species and forage period

Species	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Apis mallifera - honey bee (Dutch honingbij)												
Lat.) Andrena – (Eng.) Sand bee (Dutch: Zandbijen)												
Andrena barbilabris												
Andrena bicolor												
Andrena carantonica												
Andrena chrysosceles												
Andrena cineraria												
Andrena denticulata												
Andrena flavipes												
Andrena florea												
Andrena fulva												
Andrena haemorrharoa												
Andrena nigroaenea												
Andrena nitida												
Andrena proxima												
Andrena subopaca												
Andrena tibialis												
Andrena vaga												
(Lat.) Anthidium – (Eng.) Mason or potter bee (Dutch: Wolbijen)												
Anthidium manicatum												
(Lat.) Bombus – Bumblebees (Dutch: Hommels)												
Bombus bohemicus												
Bombus campestris												
Bombus hortorum												
Bombus lapidarius												
Bombus pasuorum												
Bombus pratorum												
Bombus terrestris												
Bombus vestalis												
(Lat.) Chelostoma - (Eng.) (n.a.) (Dutch: Klokjesbijen)												
Chelostoma campanularum - Harebell Carpenter Bee												
Chelostoma rapunculi												

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
(Lat.) **Colletes** – *(Eng.)* **Plasterer bees** - *(Dutch:Zijdebijen)*												
Colletes daviesanus												
(Lat.) **Dasypoda** – *(Eng.)* (n.a.) - *(Dutch: Pluimvoetbijen)*												
Dasypoda hirtipes - Hairy Legged Mining Bee												
(Lat.) **Halictus** – *(Eng.)* **Mining bees** *(Dutch: Groefbijen)*												
Halictus rubicundus												
Halictus tumulorum												
(Lat.) **Heriades** - *(Eng.)* (n.a) - *(Dutch: Tronkenbijen)*												
Heriades trucorum												
Lat.) **Hylaeus** - *(Eng.)* **Yellow-masked bees** – *(Dutch: Maskerbijen)*												
Hylaeus communis												
Hylaeus hyalinatus												
Hylaeus pictipes												
Hylaeus signatus												
(Lat.) **Lasioglossum** - *(Eng.)* **Sweat bees, mining bees** *(Dutch: Groefbijen)*												
Lasioglossum caceatum												
Lasioglossum leucopus												
Lasioglossum leucozonium												
Lassioglossum lucidulum												
Lasioglossum malachurum												
Lassioglossum morio												
Lasioglossum sexnotatum												
Lasioglossum sexstrigatum												
Lasioglossum villosulum												
Lasioglossum zonulum												
(Lat.) **Megachile**- *(Eng.)* **Leaf cutter and dauber bees** *(Dutch: Behangersbijen)*												
Megachile centuncularis												
Megachile versicolor												
Megachile willughbiella												
(Lat.) **Melitta** – (n.a.) *(Dutch:Dikpootbijen)*												
Melitta haemorrhoidalis												
(Lat.) **Osmia** – **Mason bees** – *(Dutch. Metselbijen)*												
Osmia bicornis												
Osmia caerulescens												
Osmia cornuta												

Table 26 Forage period urban bees

Case Study VU

Pictures environment VU

Figure 65 North side of the VU Campus, Source: own pictures

Figure 66 East side of the VU Campus, Source: own pictures

Figure 67 South side of the VU Campus, Source: own pictures

Figure 68 West side of the VU Campus, Source: own pictures

Plants VU

No.	Plant species?	Flowering period?	Surface cover %	Specific species	Specific wild bees	Urban bee
1	Pennisetum alopecuroides - 'Hameln' Plume Grass,	September -October (appeltern.nl, 2013)	35% (soil cover of intensive	-	-	-

	China Wolftailgrass, Chinese Pennisetum, Fountain Grass		roof part)			
2	Achnatherum calamagrostis - Silver Spike grass	End May-October (mijntuin.org, 2013)	25% (soil cover of intensive roof part)	-	-	-
3	Gaura lindheimeri - Whirling butterflies	June-September (plantnu.nl, 2013)	15% (soil cover of intensive roof part)	Honey bees, bumblebees and wild bees	Leaf cutter/dauber bees (Megachile versicolor)	Yes
4	Leucanthemum vulgare – Oxe-eye daisy	May-September (wilde-planten.nl, 2013)	15% (soil cover of intensive roof part)	Butterflies, wild bees and honey bees	Plasterer bees (colletes daviesanus)	No
					Sand bees (Andrena flavipes),	Yes
					Heriades truncorum (Heriades truncorum)	Yes
					Mining bees (Halictus rubicundus, Lasioglossum calceolatum, volgens Westrich 1989: H. tumulorum; L. eucozonium, L. malchurum, L. morio, L. parvulum, L. pauxillum, L. villosulum, L. zonulum)	Yes
5	Knautia macedonica – Egyptian Rose	July-September (appeltern.nl, 2013)	15% (soil cover of intensive	-	-	-
	Heester uit de Hortus					
6	Betula pendula - Silver Birch	May-April (onlinegroen.nl, 2013)	(trees, so are in addition to the soil covering plants)	-	-	-
7	Sedum album - White Stonecrop	June-July (wilde-planten.nl, 2013)		Wild bees, bumblebees, honey bees, butterflies	Masked bees (Hylaeus brevicornis, H. communis, H. gibbus, H. hyalinatus),	Yes
					Mining bees (Lasioglossum morio, L. sexstrigatum),	Yes
					Sand bees (Andrena)	Yes
8	Sedum sexangulare - Tasteless Stonecrop	June-August (wilde-planten.nl, 2013)	-	-	-	-
9	Sedum reflexum - Reflexed	June-August (wilde-	-	-	-	-

	Stonecrop, Blue Stonecrop, Jenny's Stonecrop and Prick-madam	planten.nl, 2013)				
10	Sedum spurium - Dragon's Blood Sedum, Two-row Stonecrop	July-August (soortenbank.nl, 2013)	-	-	-	-
11	Sempervivum arachnoideum - Cobweb Houseleek	July-August (tuinophetweb.nl, 2013)	-	-	-	-
12	Sempervivum montanum - Mountain Houseleek	July-August (digituin.tuinadvies.be, 2013)	-	-	-	-
13	Thymus serpyllum - Breckland thyme, wild thyme or creeping thyme	June-September (wilde-planten.nl, 2013)		Bumblebees, butterflies, solitary bees		
14	Origanum vulgare - oregano, wild marjoram	July-September (wilde-planten.nl, 2013)		Butterflies, solitary bees, wild bees, bumblebees, honey bees	Mason bees, (Osmia), Mainly for nectar,	Yes
					zandbijen (Andrena),	Yes
					(Coelioxys),	No
					Wasp bees, cuckoo bees (Nomada),	Yes
					Blood bees, cuckoo bees (Specodes)	Yes
15	Clematis armandii - Armand Clematis or Evergreen Clematis	March-April (appeltern.nl, 2013)	60% (of vertical green)	-	-	-
16	Rubus phoenicolasius - Japanese Wineberry, Wineberry, or Wine Raspberry	May-June (appeltern.nl, 2013)	40% (of vertical green)	-	-	-

Table 27 Plants on VU roof garden, Source: E. Koning (2013)

Questionnaire

Since not all the information in this research could be found in the literature additional interviews with experts are executed. This section gives a short description of the interviewees.

Interviewee 1: Piet van Dugteren, interviewed on September 13th, Rotterdam

Piet van Dugteren studied at the secondary agricultural school (Middelbare Landbouwschool) in the Netherlands and afterwards achieved a college degree in philosophy in Canada. Then he worked for 14 years at the company ‘Koppert biological systems’. He started as production assistant and later he executed research, in particular after mass breeding systems of earth bumblebees. He also did a lot of research after exoskeletons of the varroa-mite. This is the skeleton which remains after mite is consumed by the pseudo scorpion. He researched the relation between the amount of parasites and the amount of exoskeletons (v.Dugteren, 2013).

Interviewee 2: Arie Koster, interviewed on September 10th (by phone)

Arie Koster is urban ecologist (biologist). In 2001 he promoted on urban vegatation in relation to wild bees in the Netherlands. He is specialized in vegetation management, also related to pollinating insects such as bees and butterflies. He used to teach the course ‘urban green’ on ‘Hogeschool Van Hall Larenstein’, now he is an independent entrepreneur, he is consultant, provides workshops, lectures and examines quick scans (Denederlandsebijen.nl, 2013).

Questionnaire Delft, September 2013

This questionnaire will be used for my graduation project for the Master of Science program ‘ Industrial Ecology’ at TU Delft/Leiden University. In this research I want to investigate how green roofs can be used to increase healthy bee populations (honey bees and wild bees in urban areas) in the Netherlands. I think you can be of a good help for me to provide me with some useful information for my reserach, since you are in your profession/as a hobby dealing with bees. Therefore I would like to ask you to answer the following questions. The questions are meant to find information I could not find in the literature. If you don’t know the answer on one of the questions I would like to ask you to make an estimation.

Thank you very much for your cooperation!

Marloes Gout, student Industrial Ecology

Part 1: Questions about parameters individual roof

Question 1: Physical properties individual roof

The orientation of the green roof: is most beneficial when the roof is oriented towards the south, since bees prefer to forage on sunny places. But, what are other beneficial properties of roofs which are beneficial for bees?

1.1 Height of the roof: Up to what height do bees fly, do they collect food and do they nest?

1.2 Slope of the roof: Wild bees nest in flat or somewhat sloping soils. But till what slope do they nest? Do bees also visit vertical green (green facades)?

Question 2: Soil and vegetation

Of local soils is assumed that they are better adapted to local conditions. Transfer plants (plants for bees, English translation?) exist in many different shapes and sizes. In the literature are the following plants are most often listed: Corn, white clover, dandelion, plantain, rapeseed. Meadow-like green roofs are more often visited than sedum-roofs. Also, wild bees like to nest in bare, sandy soils. But how should the ratio be between plants and bare soil?

Distribution/density: Which plant mix is beneficial for bees and how much bare ground should be available?

Question 3: Climatic properties

Honey bees and bumblebees fly out at temperatures between 10 and 35 degrees, with as optimum between 18 and 25 degrees. They prefer to fledge when it is sunny.

3.1 Temperature: Does this temperature also hold for other wild bees?

3.2 Wind: Bees don’t like much wind, but up to which wind speed do they fledge?

3.3 Humidity/rain: The relative humidity of bee hives should not exceed the 90%, but up to which relative humidity of the (city) air do they fly out?

Question 4: Geographical location:

4.1 Geographical location: Does the density of cities (buildings) and the population density have an influence on the behavior of bees?

Question 5: Additional objects on the roof

Bees like to nest in for example old wood, grass pollen, hollow reed, bee hotels, cracks in rocks and unstable slopes

5.1 Extra objects: Are there other objects which bees like to have?

Question 6: Maintenance

6.1: Maintenance: The use of pesticides, especially the use of neo-nicitoids, is considered to be harmful for bees. Does the maintenance of the roof influence the behavior of bees?

Question 7: Pollution

The CO_2 level of the air in bee hives should be less than 0,25% (the average in the air is 0.035%)

7.1 Pollution: Are there other polluting substances (besides pesticides) which negatively affect bees?

Question 8: Additional issues

8.1: Additional issues: Do you advise me to research additional issues which I didn't think of so far?

Part 2: Questions about parameters on roofs on city scale

Question 1: Distance between roofs

Honey bees fly out to 3 km. Wild bees have a smaller scope.

1.1 Distance between the roofs: Does this mean that green areas in cities should also be less than 250 meters separated from each other?

Question 2: Size of roofs

2.1 Surface: What is the minimum size of green roofs to be effective for bees?

Question 3: Type of roofs

3.1 Ratio types roofs: What should be the ratio between intensive and extensive green roofs?

Question 4: Other green in cities

Bees prefer to fly on meadow plants/flowers instead of sedum-species

4.1 Green roofs and other green areas (parcs/gardens): Does this mean that green roofs can be best combined with meadow plants in public green?

Question 5: Additional issues

5.1 Additional issues: Do you have additional parameters which I did not think of?

Part 3: Additional questions

Question 1: Best practices

1.1 Best practices: Do you know ‘ best practices’ concerning bees and green in a city scale?

Question 2: Additional parameters

2.1 Additional issues: Do you have additional parameter which I didn't think of so far?

Thank you very much for participating in this interview!

Addition information influence of CO_2 on bees:

The CO_2 level of a honey beehive should be less than 0,25% (the average content of air is 0,035%) ((Praktijkonderzoek plant & Omgeving Wageningen UR, 2004; Nicolas & Sillans, 1989). It appears that honey bees fly out the most when CO_2 concentrations are the lowest, so when the least fanning activity is needed (Nicolas & Sillans, 1989).

Nicolas and Sillans reviewed existing literature about the effect of increasing environmental CO_2 levels on all kind of insects. It was difficult to give a prediction on how insects react on increasing CO_2 levels. What they did conclude was that enhanced CO_2 levels affected the metabolism of plants. The plants contained more carbohydrates, but had a lower nitrogen and protein content and therefore a lower nutritional value for herbivores. What they Nicolas and Sillans also concluded was that extremely high CO_2 concentrations, when it was used as an anesthetics for any kind of reason, did affect insects in many different ways. Even a short exposure of high CO_2 levels lead to changes in learning capacity and memory, affected their biological clock, their development and their social interactions (Nicolas & Sillans, 1989).

Research done by van Dugteren showed that high CO_2 concentrations affected the reproduction process of bumblebees. Under high CO_2 concentrations bumblebees aged faster than under normal circumstances. Bumblebee queens became in the nest already pubescent, so when they were eventually ready to leave the nest they could not reproduce again (v. Dugteren, 2013). Concerning honey bees it is known that high CO_2 concentrations in honey bee hives lead to more fanning activities of bees, to refresh the air for air with a higher oxygen content (Nicolas & Sillans, 1989).