NATURE-BASED SOLUTIONS FOR CITIES: DEVELOPMENT OF A USER-FRIENDLY CATALOGUE INCLUDING A FLEXIBLE SEARCH TOOL

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Abstract

As a result of both climate change and demographic growth, cities are currently facing major environmental, social and economic challenges. Urban nature-based solutions are increasingly seen as ideal methods to deal with these issues. These have the ability to mitigate the effects of extreme climate events as well as to improve the liveability of the city. In order to promote the use and to increase the understanding of urban NBS, a user-friendly catalogue allowing an efficient search for, and choice of, suited NBS is needed.

One exhaustive definition of urban NBS will be drafted in this master thesis. In addition, a comparative analysis of existing documents about urban NBS will be performed in order to indicate contemporary issues. The target audience of the to-be-drafted catalogue is researched to fully answer to the users' needs. A user-friendly paper version of the catalogue, as well as a digitalised flexible search tool, will be delivered. For this reason, the structure, content and representation of the proposed catalogue are defined in depth. Finally, to provide the user with a more complete catalogue of NBS, innovative solutions which are specifically interesting for Brussels are included as well.

Acknowledgement

First and foremost, we both wish to express our gratitude to our supervisor, Professor Ahmed Z. Khan, for guiding us in the process of delivering a worthy document and for allowing us to become part of the CO-NATURE team. Our interest in sustainable urban planning has continuously grown while working on this master thesis. We would also like to thank him for encouraging us to co-produce this research. The two of us together we were able to combine personal insights and in doing so to clarify the purpose of this thesis. In addition, as member of the CO-NATURE team we were fortunate to attend the first workshop in which we got to meet many actors with similar enthusiasm for the subject. Likewise, we would like to show our gratitude to our co-supervisor, Philip Stessens, for providing us with all necessary information and having enriching discussions on how to improve specific topics.

Furthermore, Helen would also like to recognise the assistance of her father for his many proof readings and discussions on how to better structure the entire document. Lastly, she would like to thank her mother, sisters and other close friends for supporting her throughout her final year of university.

Finally, Salomé is also grateful to her family relatives who supported her for the last five years of hard studying. Specifically, her elder brother Quentin who helped with the design of the Microsoft Excel file related to this thesis. As well, she would like to express a special thanks to the architectural engineering students who always encouraged her and became very close friends.

Specific circumstances

'This master thesis came about (in part) during the period in which higher education was subjected to a lockdown and protective measures to prevent the spread of the COVID-19 virus. The process of formatting, data collection, the research method and/or other scientific work the thesis involved could therefore not always be carried out in the usual manner. The reader should bear this context in mind when reading this master thesis, and also in the event that some conclusions are taken on board'[1].

[1] This is an official text, drawn by the Vrije Universiteit Brussel (VUB) concerning the circumstances in which the master thesis was completed.

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List of acronyms

BCR	Brussels-Capital Region
EC	European Commission
ES	Ecosystems services
GI	Green infrastructure
GS	Green space(s)
IUCN	International Union for Conservation of Nature
NBS	Nature-based solution(s)
SUDS	Sustainable urban drainage system(s)
UGI	Urban green infrastructure
UHI	Urban heat island

1. Introduction

1.1. Challenge

Seventy-five percent of European citizens consider climate change to be a serious problem. More and more extreme weather events such as floods, droughts or heat waves take place. From 1980 until 2016, the economic losses in Europe exceeded 436 billion euros due to extreme climate events (Sturiale & Scuderi, 2019, p. 2). Nature-based solutions (NBS) are increasingly seen as ideal methods to deal with the resulting societal challenges the world is currently facing. They are defined as efforts to mimic nature's function or to directly use nature to harvest its ecosystem services[2] (ES) (Engström et al., 2018, p. 1). NBS provide multiple environmental, social and economic (co-) benefits. The term '(co-) benefits' is used to indicate that one NBS can provide more than one benefit. An example to concretise the link between the used phrases is given in Figure 1.

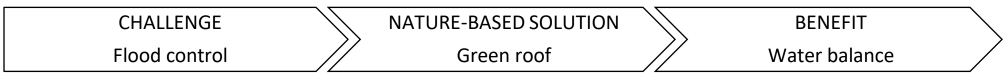

Figure 1: Relation of used phrases

Solutions particularly destined for urban areas are called urban NBS. Green roofs implemented on offices in the city are an example of the so-called urban NBS and provide many (co-) benefits. Aside from the fact that green roofs improve the water balance and thus control flooding, they also provide other benefits: they increase the biodiversity of the city, lower the urban heat island (UHI) effect, improve the air quality, and boost the liveability of the city as they can be used as places of refuge to escape from the bustling city life. Horizon 2020[3] is a framework programme of the European Commission (EC) which invests in projects

[2] Contributions of ecosystems to the well-being of humans.

[3] Horizon 2020 funds numerous climate projects around the world in order to support transfer of knowledge among decision and policy-makers but also among researchers and public entities (Lafortezza & Sanesi, 2019, p. 1).

and initiatives that use NBS in order to ensure sustainable urbanisation across Europe and abroad (Lafortezza & Sanesi, 2019, p. 1).

For the first time in history, more people are living in cities than in the countryside (Sturiale & Scuderi, 2019, p. 1). The percentage of people living in urban areas will increase from 54% in 2016 to 68% by 2050 (Ritchie & Roser, 2018). The increased amount of people living in cities results in a higher demand for habitation and thus more impermeable ground surface. Green solutions thus need to be integrated in urban planning to make the city more resilient to deal with risks of flooding, UHI effects, heat waves and degradation of air quality. Aside from their positive impact on environmental challenges, green infrastructures (GI) are also crucial for the well-being of the inhabitants of cities as they encourage physical activity and offer contact with nature which reduces stress. Moreover, they help to reduce the social inequality (*Green Infrastructure | European Commission*, 2019).

Brussels is experiencing the same kind of societal challenges. Today, more than 1,208,542 people are living in the Brussels-Capital Region (BCR) (*Loop van de bevolking.*, 2019) and a population growth of 106,633 people is expected for 2070 (*Bevolkingsvooruitzichten 2019-2070 | Federaal Planbureau*, 2019). Each year, 632 people die prematurely due to poor air quality in Brussels. This bad quality is partly due to the high level of nitrogen dioxide (NO_2) concentration which constantly exceeds European limits (*Home | CO-NATURE*, 2019). Furthermore, a significant increase of heat waves is expected for Brussels which has a negative impact on the amount of premature deaths as well as on the life expectancy of people (Hamdi et al., 2014, p. 993). Although extremes in precipitation have not increased since 1980, floods do occur more frequently. This can be linked to the higher imperviousness due to urban development (De Bondt & Claeys, 2010). Although Brussels is a green city with large parks, merely a third of the Brussels population has access to good quality green spaces (GS) whereas 21% has insufficient access to any GS and 4% has no access at all (*Home | CO-NATURE*, 2019). Sustainable urban planning is thus necessary to mitigate the effects of extreme climate events and to improve the liveability of our city. Indeed, the integration of natural elements, such as blue and green infrastructure, offers the opportunity to address these societal challenges (Kabisch et al., 2017).

To cope with these challenges, multiple individual organisations and volunteering groups[4] set up projects throughout Brussels to increase the liveability, the biodiversity and the capacity to cope with the extreme climate conditions. These projects include NBS by, for example, planting (fruit) trees and building community gardens for local food production.

In addition to individual initiatives, the BCR drew up a Regional Nature Plan for 2016-2020 (*Natuurplan | Leefmilieu Brussel*, 2017) in which their vision for the development of nature and biodiversity for the Brussels Region in 2050 is explained. For 2020, specific objectives are determined followed by measures that must be taken in order to achieve them. The plan focuses on increasing and connecting green zones in the city, on ensuring good access to GS for all inhabitants and wants to increase the biodiversity of the region (*NATUURPLAN. Gewestelijk Natuurplan 2016-2020 voor het Brussels Gewest.*, 2016, p. 17).

Another project in Brussels is the CO-NATURE[5] project of which this master thesis is a part. The project is funded by Innoviris[6] and is a collaboration between the Cartography and GIS Research Group of the Vrije Universiteit Brussel and the Building, Architecture and Town Planning Department of the Université Libre de Bruxelles (*Vacancy for a PhD Student in the Field of Urban Ecosystem Service Assessment*, 2018). It runs from 2018 until 2022 and aims at exploring the possibility of implementing cultural and regulating ES and nature-based urban design into development plans for Brussels (*Home | CO-NATURE*, 2019). CO-NATURE has three principle objectives which, with their interactions, act as building blocks of the project: an understanding of urban GS use and valuation from the perspective of cultural ecosystem services; the co-production of alternative scenarios in Research-by-Design workshops for

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[4] Bûûmplanters | A citizens' collective that aims at contributing to the liveability and biodiversity of Brussels. They encourage groups to plant trees wherever possible (*About | Bûûmplanters*, n.d.). Pépinière Citoyenne | A participatory project by and for the inhabitants of Brussels that aims at increasing the biodiversity of the city by planting fruit trees (*Pépinière Citoyenne | Urban Ecology*, n.d.). KANAAL Ecologische Corridor Brussel | Led by the organisation called 'Grenzeloze Zenne', the project pleads for more green on and around the canal to increase the liveability, the climate and the biodiversity (*Pleidooi Om Het Ecologisch Potentieel van Het Kanaal in Brussel Te Ontwikkelen | Kanaal Ecologische Corridor*, 2020).

[5] Co-producing scenarios for nature-based urban regeneration (*Home | CO-NATURE*, 2019).

[6] The regional institute for research and innovation of Brussels. Its mission is to connect, stimulate and financially support citizens, companies, research institutes and non-profit organisations (*Home | CO-NATURE*, 2019).

developing nature-based urban design and policy guidelines; and an inventory, classification and suitability mapping of NBS for urban regeneration (*Home | CO-NATURE*, 2019). For the first objective, an online survey was created in order to collect data from the citizens of Brussels about their use and valuation of urban GS. A first co-production workshop has already taken place in January 2020. Thirty participants with different expertise were present. This workshop focused on familiarising the participants with the CO-NATURE project, after which interactive sessions were held. The last objective is what this master thesis will assist in. Following a first draft catalogue created by Marie-Caroline Kawa[7], the goal of this thesis is to further evaluate existing documents about NBS in order to draft a user-friendly and more complete catalogue of NBS which can be consulted for urban design projects in Brussels. These NBS can then be realised at strategic locations throughout the city to make it more resilient to extreme climate conditions and more liveable for its citizens.

[7] An architectural engineer who graduated at the Vrije Universiteit Brussel in January 2020. Her master thesis was also part of the CO-NATURE project.

1.2. State of the art

The aim of this master thesis is to draft a more complete and user-friendly catalogue of NBS which can be consulted for urban design projects in Brussels. State-of-the-art research about the existing concept of NBS and existing documents about NBS was conducted in order to understand the issues to which this thesis will aim to respond.

1.2.1. Existing concept of NBS

In order to gain knowledge on the concept of NBS, literature was first researched. Different definitions of NBS in general were found by, for example, the European Commission (EC) and the International Union for Conservation of Nature (IUCN). More specifically, as the catalogue will be specified for the city of Brussels, the concept of urban NBS will be applied. The concept of urban NBS emerged from two major challenges our society faces nowadays: climate change on the one hand, and demographic growth leading to increasing urbanisation on the other hand. Climate change induces an increase of heat waves, droughts and flooding events and hereby affects both ecosystems and human well-being. NBS appeared as useful solutions to tackle these challenges thanks to their multiple (co-) benefits (Kabisch et al., 2017). Moreover, due to growing urbanisation, cities concentrate buildings, waste and water services, and energy demands. Hence, they are the epicentre of pollution and unsustainable issues, which results in a high pressure of climate change (Kabisch et al., 2017; Nevens et al., 2013). Therefore, applying NBS to urban areas can be much more efficient than applying them to rural areas (Faivre et al., 2017).

Figure 2: Background of urban NBS concept

The advantage of urban NBS is that it constitutes an integrative approach which can be more efficient to tackle societal challenges (Faivre et al., 2017). Indeed, these major challenges cause environmental, but also social and economic, issues, which are simultaneously taken into account by NBS and their (co-) benefits.

1.2.2. Existing documents and tools about NBS

Secondly, as the goal of this thesis is to draft a more complete and user-friendly catalogue of NBS, existing documents of NBS have to be reviewed to get familiar with the structure and content of them, as well as to indicate the to-be-tackled issues. In order to do so, extensive research was performed and several projects and platforms related to NBS were identified. A descriptive list of them is included in Annex 12.1. These provide distinctive deliverables such as paper-version and online catalogues, online atlases referencing NBS and tools to facilitate the use of, and search for, NBS.

NBS catalogues are structured through a defined classification of NBS. However, the projects are each determining distinctive categorisation systems. For instance, the UNaLab project classifies NBS according to their type (University of Stuttgart, 2019), while the CLEVER Cities project defines categories according to the scale of intervention of the solutions (CLEVER Cities, 2019). In comparison, online atlases have a more flexible structure and offer the opportunity for a more flexible search. However, existing atlases provided by Naturvation or Oppla do not provide a clear list of all the solutions they collected (*Case Studies | Oppla*, n.d.; *Urban Nature Atlas*, n.d.). Furthermore, the information given for each NBS varies considerably depending on the project. In order to facilitate the use of and search for NBS, some tools exist. However, they are mainly aimed at professional policy-makers and are not user-friendly for different users. As an example, the *NBS selection tool* developed by the URBAN GreenUP project is designed for governments (*NBS Selection Tool | URBAN GreenUP*, n.d.). The tool asks many detailed questions that some users do not know how to answer.

1.2.3. Problem statement & novelties

Even though the term NBS was only introduced recently, literature on the subject is rapidly increasing. This has resulted in various definitions of the term. One clear definition of urban NBS is currently lacking and will thus be drafted in this master thesis.

Secondly, existing catalogues determine different classification systems and provide divergent information about each NBS. However, in spite of these distinctions, no comprehensive overview of these documents has been performed in the existing literature. Therefore, this thesis will provide an evaluation and comparison of a selection of them.

Thirdly, as new solutions are continuously being discovered, the already long list of urban NBS is still increasing. In addition, the sole structure of the existing catalogues is their way of classifying the solutions. Each category contains multiple solutions but these categories are simply listed one after the other. Both aspects contribute to the result of one large list of NBS that is difficult to efficiently consult and is not user-friendly. Each user has different needs, interests and limitations. An architect who is looking for NBS to apply in a villa has other goals and challenges compared to an urban planner who seeks to find NBS to apply in a certain district of the city. This master thesis will thus explore the different users that will most likely consult the catalogue in order to answer to their needs and interests, and allow a user-friendly search for, and choice of, appropriate urban NBS. The structure of the catalogue will still be defined by the classification of NBS but will be specified to its target audience which will result in a simpler search for NBS. In addition, a flexible search tool will be drafted. This tool will enable the user to narrow down the entire list of urban NBS, thanks to his specifications, to make the search for NBS more efficient.

Fourthly, as the different catalogues do not all provide the same content, it is currently difficult to make a comparison between various solutions. For instance, some of the characteristics concern the economic valuation; however, the catalogues use different units and ways of valuation. Therefore, an economic comparison between the different solutions themselves, as well as with current grey solutions, is laborious. For this reason, a selection of coherent and clear terms is needed to provide detailed information of all NBS. It is this information that will contribute to the final decision-making of the user. The existing catalogues also use various ways of representing the solutions, the challenges or benefits. A coherent and user-friendly visualisation of the provided information is thus needed as well. This will result in an even more user-friendly catalogue.

Finally, as stated before, innovative solutions are continuously being discovered which might result in incomplete catalogues. Therefore, some innovative urban NBS will also be included in the proposed catalogue.

1.3. Objectives

The outcome of this master thesis will thus be a draft catalogue which contains existing, and some innovative, urban NBS nature-based solutions which different users with personal needs and interests can consult. The catalogue will be further improved over the coming two years by other actors and students involved in the CO-NATURE project. Throughout the present thesis, the following aspects will be developed.

Firstly, a more exhaustive definition will be drafted. Secondly, a critical assessment of existing catalogues will be performed. Following this, the target audience of the proposed catalogue will be defined. A corresponding classification of urban NBS will then contribute to a clearly structured and user-friendly catalogue. In addition to the fixed structure of the classification, a flexible search tool which allows different users to indicate their personal needs, interests and limitations will be created. This tool will narrow down the possibilities of urban NBS. Hereafter, the necessary information of each NBS in order to create user-friendly information sheets is defined. Furthermore, a user-friendly visualisation of all the information will be determined. Lastly, a list of several possible innovative urban NBS that could be applied to Brussels is included as well as a more detailed analysis of a limited selection of them.

1.4. Methodology

As this master thesis is part of the CO-NATURE project, their gained knowledge can be used and be built upon for certain to-be-developed elements. CO-NATURE has set up an online survey that asks the citizens of Brussels about GS they regularly visit to identify areas with poor quality GS or areas that have a lack of access to it. In addition to the online version, students will visit community centres and libraries in order to help people without direct access to the internet or people who do not have a computer to fill out the form by providing tablets or laptops[8]. This way the CO-NATURE project hopes to reach as many citizens as possible. Once a year, over the period of 2020 until 2022, a workshop will be held in which citizens, architects, stakeholders and all other people that are interested can participate. The workshop focuses on combining knowledge from different actors and strives to make the clearest and most complete catalogue of NBS nature-based solutions for Brussels as possible by applying Research-by-Design strategies. Furthermore, Philip Stessens[9], a research partner of the CO-NATURE project, will verify and assign new values to certain characteristics of urban NBS in the future. Also, the demand and suitability maps of urban NBS in Brussels that he will create are planned to be used. Finally, one of the analysed catalogues concerns the one of M. Kawa, which was also part of the CO-NATURE project.

This master thesis will start by drafting a more exhaustive definition of urban NBS. For this reason, one of the existing ones will be used as a basis and will be extended. Hereafter, existing catalogues about NBS will be analysed in order to indicate the to-be-tackled issues. Furthermore, the target audience of the proposed catalogue of NBS will be defined after which they will be further detailed using the persona approach. Personas of each target group will be drafted. For this, online research and common knowledge will be used as there is insufficient time to collect data and carry out a full analysis of different users. As a result, a more corresponding structure and content of the catalogue can be determined. The structure

[8] This task was delayed due to Covid-19 but will be performed in the future.

[9] A post-doctoral researcher at the Université Libre de Bruxelles.

of the catalogue will then be defined by the classification method. An existing one will be selected that will be further extended or detailed according to the needs of the personas. The classification will function as a first step in guiding the user to his most suited urban NBS. Furthermore, the personas' needs, interests and limitations will be consulted more in detail in order to find a way to simplify the selection of appropriate solutions even more. This will result in an ideal flexible search tool for urban NBS. In parallel, the necessary information of each solution is defined. This information will contribute to the final choice-making of the user. Existing catalogues will, for this reason, be consulted as well as the drafted personas. A special focus will be on the economic characteristics. For this, indicators provided by existing catalogues will be revised and additional criteria will be defined in order to provide the user with the best budgetary information possible. Moreover, a good visual representation of all the provided information will be presented in order to contribute to a user-friendly catalogue. In addition to the evaluation of existing catalogues of NBS, an online survey was set up to allow different people to indicate what type of visualisation they find the clearest. The penultimate step is to first define what the term 'innovation' means in the case of urban NBS. Herewith, a list of innovative solutions will be given, of which a few will be explained in detail. The search for innovations will mainly be performed by revising existing case studies or current sustainable projects occurring in Brussels. Finally, the flexible search tool will be digitalised using Microsoft Excel. Further down the CO-NATURE project, this excel tool will also become an online application.

2. Nature-based solutions in the urban environment

2.1. Existing definitions of NBS

Urban NBS are NBS that are specifically applied to an urban environment. However, the definition of NBS itself is still being debated (Calliari et al., 2019). The European Commission (EC) and the International Union for Conservation of Nature (IUCN) have both suggested a definition.

The EC considers that NBS, "aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions which are inspired by, supported by or copied from nature." (Horizon 2020 Expert Group, 2015, p. 5). NBS are cost-effective approaches that present multiple (co-) benefits as they have the potential to contribute to economic growth, human well-being and the environment. (Horizon 2020 Expert Group, 2015). Furthermore, in order to better understand and to ease the use of NBS, the European Commission established different goals (e.g. 'enhancing sustainable urbanisation'), and actions (e.g. 'improving well-being in urban areas') (Horizon 2020 Expert Group, 2015, pp. 8–20).

EC (2015)
"NBS are actions which are inspired by, supported by, or copied from nature."

The IUCN suggests to define NBS as, "actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits" (*Nature-Based Solutions to Address Global Societal Challenges*, 2016, p. xii). To support this definition, the IUCN proposes some principles, as for instance 'NBS should embrace nature conservation norms' (*Nature-Based Solutions to Address Global Societal Challenges*, 2016, p. 6).

IUCN (2016)
"NBS are actions to protect, sustainably manage and restore natural or modified ecosystems."

Both institutions consider NBS as providing solutions for societal challenges including climate change and human well-being. Moreover, they focus on the simultaneous effects of the NBS; indeed, these have multiple (co-) benefits (Calliari et al., 2019). However, these definitions also differ in certain ways. For instance, the EC encompasses the fact that NBS can be 'inspired by' nature, which means that it includes biomimicry, while this is excluded from the IUCN definition (Calliari et al., 2019).

2.2.Origin & background of NBS

Although the term NBS is still recent, its origin relates to previous concepts such as ecosystems and their related services, and urban green infrastructure (UGI). The term 'ecosystem' was first introduced in 1935 by Arthur Tansley[10] as he wanted to better understand the nature of life (Millennium Ecosystem Assessment, 2003). As people began to understand that they could benefit from nature, the concept of ES emerged in the 1960s. And, in the early 2000s, the idea that people can proactively regenerate ecosystems arose and the phrase NBS was used for the first time (*Nature-Based Solutions to Address Global Societal Challenges*, 2016). Later on, large institutions adopted this term (Giorgos Somarakis et al., 2019).

As important milestones, the EC has advocated the concept of NBS since 2013, and in 2014 they created an expert group (Horizon 2020) in the scope of the Research and Innovation framework programme (Faivre et al., 2017). This expert group was created to stimulate the use of NBS. The IUCN and The World Bank also endorse the concept of NBS through dialogues and by publishing reports.

The concept of urban NBS then finally emerged, as previously mentioned, from two major challenges our society faces nowadays: climate change on the one hand, and demographic growth leading to increasing urbanisation on the other hand. Urban NBS can be more efficient to tackle environmental, social and economic challenges (Faivre et al., 2017).

[10] Arthur George Tansley (1871 – 1955) is the founder of the ecosystem theory (Anker, 2002).

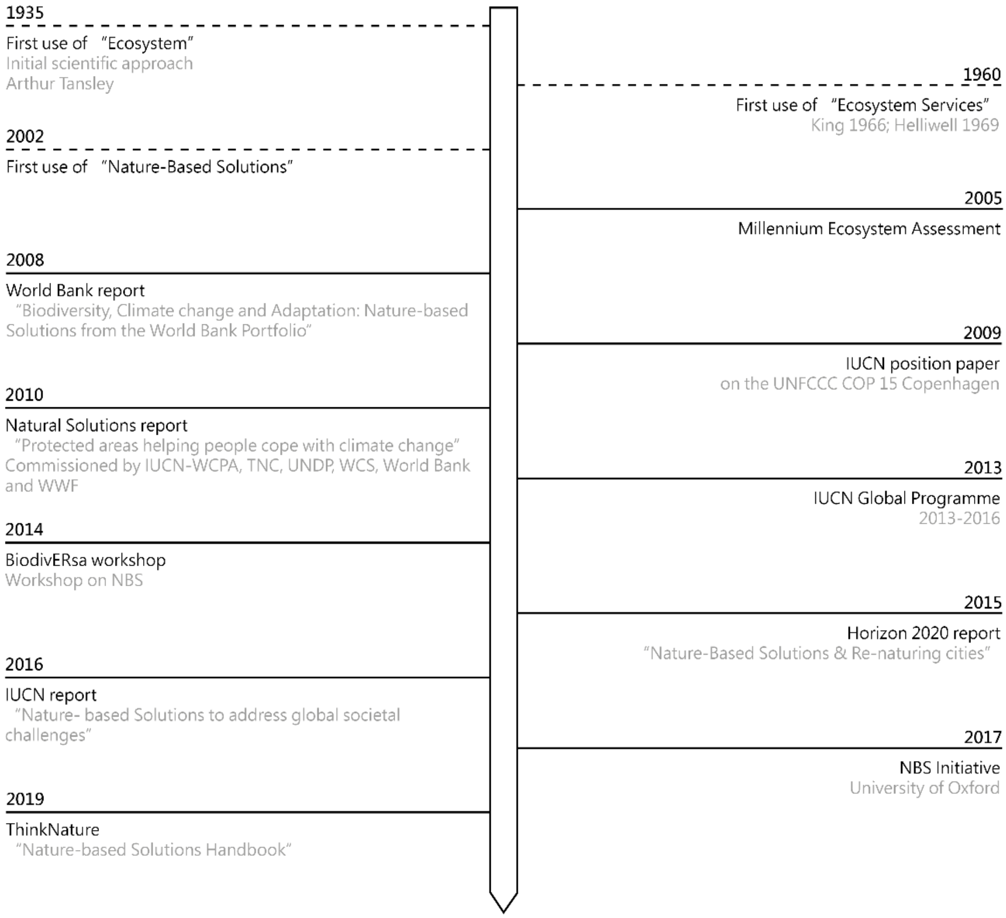

Figure 3: Timeline of phrases (dotted lines) and milestones concerning the concept of NBS (continuous lines)

2.3.Relation to other concepts

By definition, the phrase 'urban NBS' builds upon other concepts such as ecosystems and their services. Indeed, the aim of NBS is to proactively preserve and regenerate ecosystems in order to ensure that ES can happen (Faivre et al., 2017). In cities, most ES are provided through UGI (Kabisch et al., 2017). UGI can be used in urban planning and policy-making in order to create GS networks contributing to NBS. Urban NBS thus rely both on ES and UGI. ES and UGI are two notions developed before NBS. Together with the rising interest in NBS, they are acquiring more and more importance in debates and in urban planning. As the concept of ES might be unclear, the following paragraphs describe the definition of ES as well as the way they can be provided in urban areas.

Ecosystem services, which are provided by nature, are essential for human well-being (Zhang & Muñoz Ramírez, 2019). As the Millennium Ecosystem Assessment defines, ES "are the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005, p. v). In order to be described, ES have been classified according to categories. The most commonly used classification in the literature contains four categories: provisioning services, regulating services, cultural services and supporting services (Zhang & Muñoz Ramírez, 2019).

Provisioning services stand for all the products that can be retrieved from the environment such as food and water. Regulating services are defined as the advantage humans gain from the regulation process of nature, such as water purification or climate regulation. Cultural services account for the abstract and spiritual profits. It involves social relations and recreation. Finally, supporting services are essential to provide the three other services. They have an indirect effect on human life. Among them, soil formation and nutrient cycling are examples (Millennium Ecosystem Assessment, 2003).

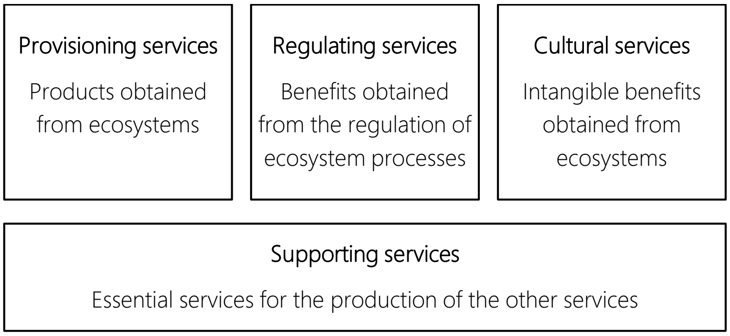

Figure 4: Categories of ecosystem services

Urban ES can be understood as the ES provided within an urban area (Gómez-Baggethun et al., 2013). Compared to rural areas, urban ES are more pressured due to growing urbanisation (T Elmqvist et al., 2015). In an urban context, ES appear in the UGI of the city, meaning green and blue spaces. For instance, urban parks, gardens and green roofs are part of the urban GS, while urban blue spaces encompass lakes, ponds or streams (T Elmqvist et al., 2015; Gómez-Baggethun et al., 2013).

Furthermore, other concepts can also be associated with NBS such as ecosystem-based adaptation, ecosystem approach, natural infrastructure and ecological engineering (Giorgos Somarakis et al., 2019). Therefore, as it is a most recent and extensive approach, NBS is often considered as an umbrella term (Pauleit et al., 2017).

2.4.Difference between grey, green and hybrid solutions

Following the definition of the EC, NBS can be actions inspired by nature (Horizon 2020 Expert Group, 2015, p. 5). This means that the term NBS may also englobe solutions that are constituted by technical components. For the sake of clarity, this section will outline the difference between grey, green and hybrid solutions, as well as which solutions could be recognised as NBS.

NBS are usually considered as green alternatives to traditional grey solutions, meaning human-built structures (Giordano et al., 2020). However, a combination of both natural and conventional solutions also exists. These types of solutions are usually referred to as 'hybrid interventions' or 'nature-based engineered solutions' (Calliari et al., 2019; Giordano et al., 2020; Liquete et al., 2016). In cities where space and time are limiting the fields of action, this combination can be more suitable and effective (Calliari et al., 2019; Giorgos Somarakis et al., 2019).

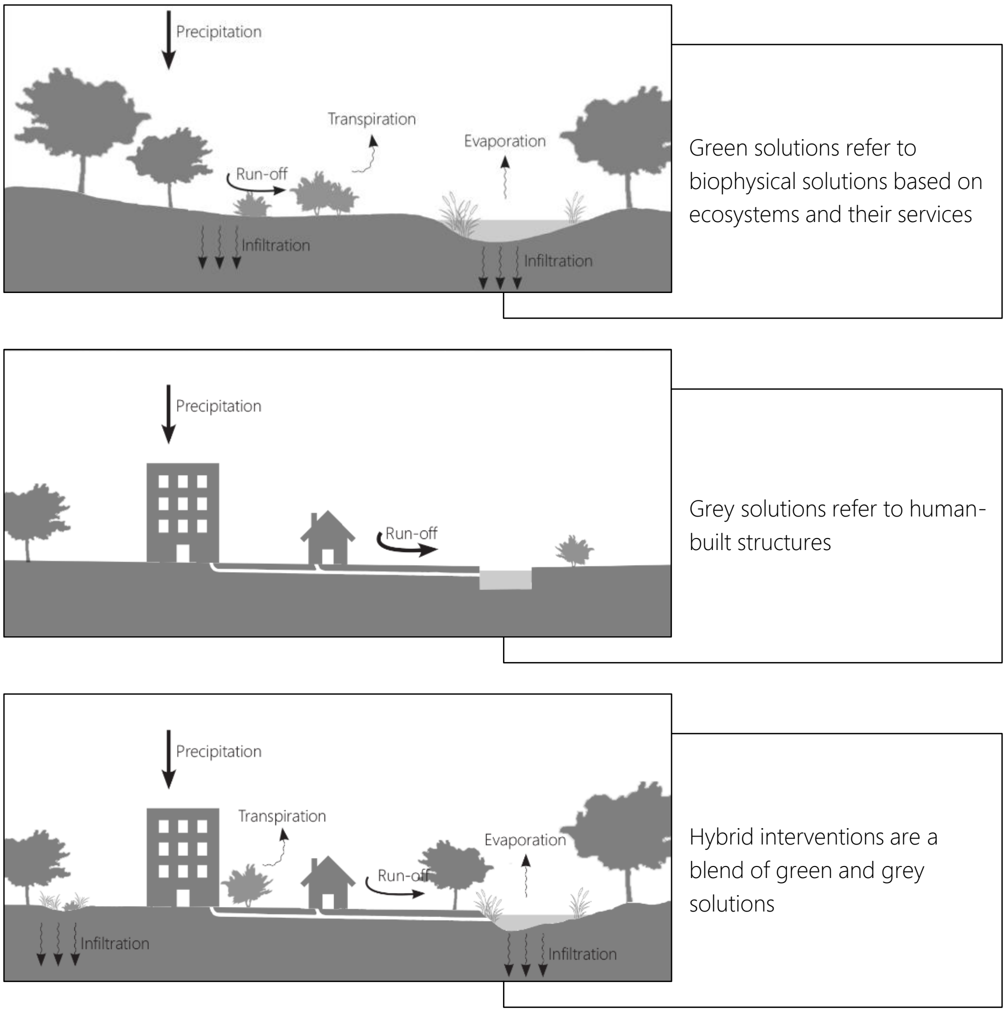

Figure 5: Example of green, grey and hybrid interventions for water management. Adapted from (Depietri & McPhearson, 2017, p. 96)

Compared to conventional grey solutions, hybrid interventions have the advantage to be more resilient to change and to be more flexible. They are also cost-effective solutions as for the presence of (co-) benefits. The advantage of technical components lie in their adaptability to the urban context (Depietri & McPhearson, 2017). Hence, hybrid solutions can be globally more effective than both grey and green solutions to tackle societal challenges within cities (Depietri & McPhearson, 2017). Depending on various characteristics of a city, such as the availability of land, provision of GS or the environmental challenges, the application of hybrid structures can take place in different ways (Raymond, Frantzeskaki, et al., 2017). Furthermore, technical components are already present in cities as, until today, grey solutions are the traditional strategy. This means that the integration of hybrid solutions could be easier, less expensive, and faster to adopt NBS.

Depending on how NBS are defined, hybrid interventions may or may not be included. Indeed, green solutions are indubitably incorporated in the NBS concept. However, it is less clear for hybrid solutions. According to the definition provided by the EC, these can be considered as NBS while the IUCN excludes them. Therefore, the proposed definition of this thesis will need to specify this aspect.

2.5.Exhaustive definition of urban NBS

In order to clarify the concept for the user of the proposed catalogue, a more exhaustive definition of urban NBS is suggested. As a basis, it will incorporate the definition of the EC, as this one englobes biomimicry. This definition includes what urban NBS are, why they are interesting and how they can be applied to an urban environment.

Urban NBS are cost-effective and flexible interventions that are implemented in urban areas and that use nature and its ecosystem services to sustainably tackle societal challenges. These challenges have resulted from climate change and growing urbanisation and include ,for example, mitigating the urban heat island effects, managing heat waves, securing water and floods, and ensuring human health and well-being. Urban NBS provide multiple benefits to the environment, the society, the economy and health. Some solutions are inspired by processes from nature and imitate them using technical components. Others are fully copied from natural processes using only natural resources. Lastly, urban NBS can also be supported by nature which results in a combination of green and grey infrastructure.

3. Existing catalogues about nature-based solutions

In current literature, there is no comprehensive overview of the existing catalogues concerning NBS. Hence, the aim of this chapter is to establish an evaluation and a comparison of some of the existing documents. As previously mentioned, various projects and platforms were reviewed in the scope of this thesis. A preselection, according to various aspects of existing catalogues, was then performed in order to be evaluated. This chapter will first provide the selection criteria used. Hereafter, a description and evaluation of the selected documents is performed, as well as a comparison of them.

To ensure an efficient evaluation, certain requirements were set up to narrow down the selection of documents. These requirements take into account the aim for a user-friendly document which contains detailed information about the solutions. Therefore, the focus is more on catalogues that contain clear lists and descriptions of many NBS rather than on scientific articles, handbooks or websites which only provide some of the wanted aspects. The focus field was then further reduced by only looking at catalogues that contain a clear classification system of NBS. In addition, clear ways of presenting the NBS were searched for. The reliability of the given information is an important aspect as well; references should clearly indicate the source of the used values. Lastly, catalogues which are part of a bigger project and have been published recently were seen as more interesting. The URBAN GreenUP, the UNaLab, the CLEVER Cities and the Klimatek catalogues were then selected out of the revised projects and platforms. The former three are funded by the European Union's Horizon 2020 action programme[11]. The Klima 2050 project is also funded by the European Union, more specifically by their LIFE Climate Action programme[12]. In addition to the abovementioned catalogues, the draft catalogue of M. Kawa will also be evaluated as it is already part of the CO-NATURE project and contains some useful information about Brussels as well.

[11] With eighty billion euros of funding available over seven years (2014 to 2020), it is the biggest European Union Research and Innovation programme ever. The programme aims at smart, sustainable and inclusive growth, and jobs (Horizon 2020, n.d.).

[12] The programme aims at the development of innovative solutions to respond to the challenges resulting from climate change in Europe. The programme provides more than eight-hundred-sixty million euros of funding over a period of six years (2014-2020) (*LIFE Climate Action | European Commission*, 2016).

3.1. Description and evaluation of existing catalogues

A clear description and evaluation of the selected documents is necessary in order to draft a more complete and user-friendly catalogue of urban NBS for Brussels. Therefore, the structure of the catalogues was analysed, as well as the provided information for each NBS. Herewith, an evaluation concerning the positive and negative aspects of the catalogues is included in order to indicate the issues to be tackled for the to-be-provided catalogue.

With the intention to deliver the clearest possible evaluation, compact figures were established for each catalogue. This will enable the reader to easily look back at these where necessary throughout the reading of the thesis.

<table>
<tr><th colspan="2">URBAN GREENUP[13]</th></tr>
<tr><td colspan="2">PROJECT</td></tr>
<tr><td colspan="2">Twenty-five partners from around the world are involved in the project. In order to lower the effects of climate change, improve the air quality and the water management and increase the sustainability of cities through NBS, the project aims at developing, applying, and validating a methodology for Renaturing Urban Plans. The methodology will be demonstrated and validated by implementing NBS in three runner cities[14]. Along these three, five follower cities[15] will enhance the replication potential at European and international level (Urban GreenUP, 2019). The catalogue was published in May 2018 and acts as a central reference in the development of Renaturing Urban Plans. It presents NBS that are built in at least one of the participating cities (CAR, SGR et al., 2018).</td></tr>
<tr><td colspan="2">CATALOGUE</td></tr>
<tr><td>Content
- Concept NBS
- List of challenges and ecosystem services
- NBS index & NBS card
(1) Most important characteristics
(2) More extensive information
- Review of concepts, evidence and use of NBS
Classification: type of NBS
- e.g., 'vertical green infrastructure': 'green fences', 'green noise barriers', 'green façade with climbing plants', 'hydroponic green façade', and 'vertical mobile garden'.</td><td>Information NBS
- General & technical description
- Graphic illustrations
- Challenges: e.g., 'water management', 'green space management', 'air quality' and 'public health and well-being',
& their valuation (0-5 scale).
- Ecosystem services (provisioning, regulating, cultural and supporting): e.g., 'food and fibre', 'fresh water', 'air quality', and 'cultural diversity'.
- Construction & maintenance costs
- Amortisation period
- Scale of intervention
- References</td></tr>
<tr><td>POSITIVE ASPECTS</td><td>NEGATIVE ASPECTS</td></tr>
<tr><td>The classification according to the type of NBS largely reveals what the solution included in a certain category looks like. The technical descriptions and illustrations allow the users to estimate the feasibility of implementing the NBS. The challenges allow the users to focus on NBS that answer to the ones they want to tackle. The additional information about the amortisation period allows the user to have an idea of the reimbursement time of his investment.</td><td>The information given on the index and on the card is different. This makes it necessary to look at both each time which is inefficient. The assigned categories are either too broad or too specific; some of them do not clearly reveal what kind of NBS are included while others only include one solution.</td></tr>
</table>

Figure 6: Compact description and evaluation of URBAN GreenUP

[13] (CAR, SGR et al., 2018)

[14] Izmir (Turkey), Liverpool (United Kingdom) and Valladolid (Spain) (*Urban GreenUP*, 2019).

[15] Chengdu (China), Ludwigsburg (Germany), Mantova (Italy), Medellin (Colombia) and Quy Nhon (Vietnam) (*Urban GreenUP*, 2019).

UNALAB[16]	
PROJECT	
The UNaLab project is contributing to the development of smarter, more inclusive, more resilient and more sustainable cities through the implementation of NBS (*Home | UNaLab*, n.d.). These NBS are demonstrated and evaluated by implementing them in three front-runner cities[17]. These actively collaborate and share their experience with seven follower cities[18] (*Home | UNaLab*, n.d.). The project's outcome will enable the development of a European NBS reference framework on benefits, cost-effectiveness, economic viability and replicability of NBS, which will guide cities in developing and implementing their own co-creative NBS (*About Us | UNaLab*, n.d.). UNaLab has developed its first draft version of a technical handbook of NBS (*Technical Handbook of Nature-Based Solutions | UNaLab*, n.d.).	
CATALOGUE	
Content - General description and explanation of each NBS category defined - NBS information sheets Classification: planning & construction terminology - e.g., 'water sensitive urban design measure': e.g., 'bioswale', 'infiltration basin', 'rain garden', and 'permeable paving system'.	Information NBS - Basic information - Illustrations - Challenges: e.g., 'flooding', 'heat stress', 'health issues', and 'biodiversity loss'. - General description & role of nature - Technical & design parameters - Conditions for implementation - Benefits & limitations - Ecosystem services: e.g., 'cooling', 'water regulation', 'air purification', & their valuation (0-2 scale). - References
POSITIVE ASPECTS	NEGATIVE ASPECTS
The classification according to the type of NBS largely reveals what the solution included in a certain category looks like. The technical and design parameters, as well as the illustrations, allow the users to estimate the feasibility of implementing the NBS. The challenges allow the users to focus on NBS that answer to the ones they want to tackle.	This catalogue presents exclusively the information sheets of the NBS, with only a preliminary list acting as a table of contents. The search for suited NBS is consequently more sophisticated. The use of both 'benefits' and 'ecosystem services' can be confusing, especially since no clear list of 'benefits' is provided.

Figure 7: Compact description and evaluation of UNaLab

[16] (University of Stuttgart, 2019)

[17] Eindhoven (Netherlands), Tampere (Finland) and Genova (Italy) (*Home | UNaLab*, n.d.)

[18] Stavanger (Norway), Prague (Czech Republic), Castellón (Spain), Cannes (France), Başakşehir (Istanbul), Hong Kong (China) and Buenos Aires (Argentina) (*Home | UNaLab*, n.d.)

CLEVER CITIES[19]	
PROJECT	
Thirty-four partners from around the world are involved in the project. It implements NBS in key districts of their front-runner cities. The project aims at driving a new kind of nature-based urban transformation for sustainable and socially inclusive cities. In order to discuss how to adapt NBS for the needs of towns and cities around the world, the front-runner[20] cities share their knowledge with fellow cities[21] (Politecnico di Milano, 2018). The catalogue is the result of collaborative ongoing work conducted with and by students of the Energy & Urban Planning Design Studio at the Politecnico di Milano, and was published in September 2019 (CLEVER Cities, 2019).	
CATALOGUE	
Content - NBS information sheets Classification: scale of intervention - e.g., 'building-scale interventions': 'green roofs', 'green walls', 'nano gardens', 'productive façade system', 'urban rooftop farming', 'algae production system', 'wetland roof', 'vertical farming', 'climate façades', 'living walls', and 'wooden built structures'.	Information NBS - General & detailed description - Illustrations - Scale - Efficacity & lifespan - Addressed themes: 'accessibility', 'energy', 'environment', and 'people'. - Main strategy - Related primary SDG[22] - Related secondary SDG - Construction & maintenance costs - Space usage - Dimensional data - Best practices - References
POSITIVE ASPECTS	NEGATIVE ASPECTS
The classification according to the scale of intervention enables an easier search for various NBS concerning the same application. The addressed themes allow the users to focus on NBS that answer to the ones they want to tackle. The detailed description and the use of best practices allow the users to estimate the feasibility of implementing the NBS.	This catalogue presents exclusively the information sheets of the NBS, with only a preliminary list which does not contain any page numbers. The search for suited NBS is consequently more sophisticated. Furthermore, a clear list of addressed strategies is lacking, and the themes are too broad, thus unclear.

Figure 8: Compact description and evaluation of CLEVER Cities

[19] (Politecnico di Milano, 2019)

[20] Hamburg (Germany), London (United Kingdom) and Milan (Italy) (Politecnico di Milano, 2018)

[21] Belgrade (Serbia), Larissa (Greece), Madrid (Spain), Malmö (Sweden), Sfântu Gheorghe (Romania) and Quito (Ecuador) (Politecnico di Milano, 2018)

[22] Sustainable development goals

KLIMATEK[23]

PROJECT

The Klimatek guide was published in October 2017 and is part of the KLIMATEK programme which is the Basque Government's scheme to support projects that boost the adaption to climate change. This project was founded to meet the objectives of the Basque Climate Change Strategy 2050, also referred to as the Klima 2050 project (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, p. 8). Twenty partners from around the world are involved in the project (*Partners | Klima 2050*, n.d.). The aim of the guide is to provide local authorities with a coherent, clear and easily replicable methodology which allows the authorities to identify and map existing NBS (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, p. 9).

CATALOGUE

Content

- Concept of NBS
- List of climate threats and (co-) benefits
- NBS datasheets & NBS factsheets
  (1) Climate threats and (co-) benefits valuation
  (2) More extensive information
- Methodology
- Case study

Classification: scale or scope of intervention

- e.g., 'interventions in water bodies and drainage systems': e.g., 'sustainable urban drainage systems', 'restoration ponds and lakes', and 'controlled flood plains'.

Information NBS

- General description
- Illustration & representative scheme
- Climate threats: e.g., 'flooding', 'drought', and 'temperature increase', & their valuation (0-3 scale).
- (Co-) benefits (environmental, social, and economic): e.g., 'regulation of the water cycle' and 'health and quality of life'.
- Implementation requirements
- Possible data sources
- Inventory method
- References

POSITIVE ASPECTS

The classification according to the scale of intervention enables an easier search for various NBS concerning the same application. The climate threats allow the users to focus on NBS that answer to the ones they want to tackle, and the (co-) benefits inform the user on other possible advantages. The use of datasheets in addition to factsheets gives a clear overview of specific characteristics.

NEGATIVE ASPECTS

Klimatek does not provide a valuation of benefits; the full list of benefits related to an NBS is given without prioritising some of them. Furthermore, the catalogue focuses on local climate threats and thus is not extensive.

Figure 9: Compact description and evaluation of Klimatek

[23] (*Partners | Klima 2050*, n.d.)

MARIE-CAROLINE KAWA[24]

PROJECT

The catalogue proposed by M. Kawa was developed in the scope of her master thesis, in order to be awarded the master's degree 'M.Sc. in Architectural Engineering' at the Brussels Faculty of Engineering. The aim of this master thesis was to identify and explore NBS by developing a comprehensive typology for classification (Kawa, 2020). It was developed as a part of the CO-NATURE project which is funded by Innoviris and is a collaboration between the Cartography and GIS Research Group of the Vrije Universiteit Brussel, and the Building, Architecture and Town Planning Department of the Université Libre de Bruxelles (Vrije Universiteit Brussel, 2018). It runs from 2018 until 2022 and aims at exploring the possibility of implementing cultural and regulating ecosystem services and nature-based urban design into development plans for Brussels (CO-NATURE, 2019).

CATALOGUE

Content

- Concept of NBS
- List of challenges and (co-) benefits
- NBS database & NBS factsheets
  (1) Defined parameters and (co-) benefits
  (2) More extensive information
- Case studies

Classification: typology or applicability of interventions

- e.g., 'green measures for public space': 'connecting green spaces', 'urban parks and forests', 'green shading structures', 'urban farming', and 'urban bio-filter area'.

Information NBS

- General description
- Illustrations and representative scheme
- Parameters: 'scale', 'degree of intervention', 'investment & maintenance costs'
- (Co-)benefits (environmental, social, and economic): e.g., 'biodiversity', 'health and well-being', and 'local employment';
  & their valuation (0-5 scale).
- Technical design & drawing
- References

POSITIVE ASPECTS	NEGATIVE ASPECTS
The classification according to the scale of intervention enables an easier search for various NBS concerning the same application. The (co-) benefits allow the users to focus on NBS that provide the ones they want to have. The use of datasheets in addition to factsheets gives a clear overview of specific characteristics.	The addressed challenges for each NBS are not provided, although a clear list has been defined.

Figure 10: Compact description and evaluation of the catalogue of M. Kawa

[24] (Kawa, 2020)

3.2.Comparative analysis of existing catalogues

This section contains a comparative analysis of the existing catalogues previously described. For the upcoming chapters, this section will enable identification of which aspects of the to-be-proposed catalogue have to be further examined and properly defined in this thesis.

First, the content of the analysed catalogues differs. URBAN GreenUP, Klimatek and M. Kawa delineate the concept of NBS. This confirms the aforementioned problem stating that NBS is a recent phrase that should be clarified in order to gain more familiarity with the public. Furthermore, these three catalogues also provide a descriptive list of societal challenges to be tackled, as well as of the benefits the NBS deliver. Again, this is found to be crucial as a vast audience is not yet aware of all positive effects of NBS. The different catalogues use different ways of presenting the NBS; some of them only have factsheets, others complement the factsheets with either an NBS index or a database. Lastly, some catalogues elaborate some case studies more in detail in order to clarify their link with NBS.

As outlined in the previous figures, current catalogues of NBS apply different ways of categorising these. The classification of NBS largely defines the structure of the catalogue which makes it an essential aspect to examine. From these five catalogues, two ways of classifying can be distinguished: according to the types of NBS for URBAN GreenUP and UNaLab; or according to the scale of intervention for CLEVER Cities, Klimatek and M. Kawa. The former approach largely reveals what the solutions classified under a certain category look like; 'vertical green infrastructure' implies vertical urban NBS such as 'green fences' or 'green façades'. The latter approach indicates the kind of place in which the NBS can be implemented; 'green measures for public space' includes NBS that can be implemented in the public spaces such as 'urban parks and forests' or 'urban farming'. As a result, choosing the right classification method can help the user to find the searched NBS more quickly.

Furthermore, these documents do not always provide the same characteristics of NBS. However, the information that is provided to the user will influence his choice concerning the implementation of a certain NBS or another. Common characteristics given by all five catalogues are a general and technical description, including graphic illustrations, and references. The technical description is often supplemented with implementation requirements. These technical aspects are interesting as they allow the user to estimate the feasibility of the NBS implementation. Moreover, except from UNaLab, they all give an indication of the scale of the NBS; the ones mentioned are 'building', 'street', 'neighbourhood', 'urban' or 'city', 'region' or 'regional' and 'metropolitan'. A valuation concerning either challenges or climate threats, either benefits or ES, is provided by all catalogues except from CLEVER Cities. Such valuation indicates the performance of the NBS in tackling certain issues and allows the users to focus on NBS that have a high performance towards the challenges they want to resolve. CLEVER Cities is the only one clearly explaining case studies; these case studies can help in convincing the reader of a certain type of solution. Concerning the financial aspects, both URBAN GreenUP and CLEVER Cities indicate the construction and maintenance costs of the solution. In addition, the former catalogue gives the amortisation period of the NBS. The CLEVER Cities catalogue also contains other characteristics that can be, although less directly, linked to economic values. It indicates the lifespan and efficacy of the solutions. Since the information provided for each NBS differs considerably from one catalogue to another, it is imperative to define precisely which information will be part of the proposed catalogue.

Lastly, the catalogues use different terms concerning similar aspects. They have varying terms for both the societal challenges the NBS tackle and the benefits they provide to do so. For instance, the strategies defined by CLEVER Cities can be related to the challenges of the URBAN GreenUP and UNaLab catalogues. The climate threats of Klimatek can also be associated with this topic. In addition, as ES are the "benefits people obtain from ecosystems" (CAR et al., 2018, p. 22), the ones set by URBAN Greenup or UNaLab can be considered as linked to the benefits defined by the Klimatek project or the ones of M. Kawa. A comparison and clear delineation of these aspects is therefore necessary to develop a catalogue for Brussels.

4. Defining user personas

Throughout the process of making a city answer to its societal challenges, various people might access the proposed catalogue of NBS. As stated before, the catalogue will be consulted by people with different interests and whose projects have different goals and limitations. An architect who is looking for NBS to apply in a villa has other goals and limitations than an urban planner who seeks to find NBS to apply in a certain district of the city. Furthermore, two different architects assigned to the same project can have other interests.

In order to clarify these different types of users, and therefore to be able to create a user-friendly catalogue, both the target audience and the more specified personas are defined in this chapter. A target audience is a particular group of people at which a product or service is aimed (Bartolacci, 2020). People who are most likely to consult the proposed catalogue can be grouped into different target audiences. In the case of an NBS catalogue, these target groups are architects and planners, citizens and governmental organisations. In the following sections, each target group will be further analysed by drafting corresponding personas. A user persona is a semi-fictional representative of a certain target audience which is described in more detail (Bartolacci, 2020). A general architect, for example, will work on different projects compared to a landscape architect.

Hereafter, the given specifications of the personas are listed and priority ones are defined. As a result, a catalogue including a clear classification of NBS, as well as a flexible selection tool that answers to different perspectives, can be drafted.

4.1. First target group: architects and planners

Architects and planners have the capacity to clearly express what the future city could look like and can convince others of green and sustainable projects. This group can be subdivided into general architects, landscape architects and urban planners. In order to take into account both the personal objectives of the user and the goals and limitations of their projects, two personas of each are drafted. The personas concern the same project but personal interests differ. Indeed, in practice two general architects can be assigned to a similar project but can have other interests. For the sake of compactness and clarity, these two personas are combined in one table.

 General architect	Paul, 43 years old
Background - Problem-solver - Eager to learn - Interested in carbon-neutral design	Goals: - Grow firm revenue by designing press-worthy properties that elevate reputation - Meet the 2050 challenge to become carbon-neutral
 **General architect**	**Marc, 39 years old**
Background - Organised - Curious about innovative solutions	Goal: - To become a key figure in sustainable design of buildings
Current project - Apartment block of 30 units - Located at Kellestraat 160, 1150 Sint-Pieters-Woluwe - Low density neighbourhood - Pluvial flooding often occurs - Total construction budget of €5,000,000	Reasons for consulting the proposed catalogue - Find cost-effective green solutions that can be applied to the project - Convince staff members of a certain green solution - How can these solutions practically be realised?

Figure 11: Personas of the general architect

 Landscape architect	Simon, 35 years old
Background - Organised - Sociable - Specialised in habitat loss	Goals: - Increase multifunctionality of recreational domains - Start up my own firm within five years from now
 Landscape architect	Louise, 42 years old
Background - Perfectionist - Caring - Specialised in urban green spaces	Goal: - Improve the biodiversity of urban areas
Current project - Increase recreational functions in Bois de la Cambre - Resolve current habitat loss	Reasons for consulting the proposed catalogue - Look for a combination of solutions - Look for solutions that will have a direct positive effect - Do I have the required tools to implement the solution?

Figure 12: Personas of the landscape architect

 Urban planner	Sarah, 29 years old
Background - Punctual - Caring - Firm focuses on social projects	Goals: - Increase accessibility to green spaces in urban areas - Create agreeable resting areas
 Urban planner	Pete, 33 years old
Background - Socially involved - Problem-solver - Curious about innovation	Goals: - Increase the environmental resilience of Brussels - Make Brussels more pleasant for its inhabitants
Current project - Small-scale green zones throughout Sint-Jans-Molenbeek and Anderlecht - Need for pleasant gathering places for the citizens - Increase safety feeling - Total budget is €1,000,000	Reasons for consulting the proposed catalogue - Find cost-effective small-scale green solutions - Look for possibilities to increase the biodiversity

Figure 13: Personas of the urban planner

4.2.Second target group: citizens

Citizens play an important role in the greening of Brussels. Their voice is listened to more and more in order to develop a liveable city for them. This target group can be subdivided into private individuals and citizen or action groups.

 Private individual	Tom, 55 years old
Background - Caring - Always looking for new tasks - Member of a large family	Goals: - Improve the green space area in the middle of our apartment block - Focus on social gathering
 Private individual	Ella, 40 years old
Background - Organised - Values moments of peace - Problem-solver	Goal: - Improve the levels of peace and quietness in our backyard
Current project - Inner courtyard of 100 m² of apartment block of 30 apartments - Currently fully impermeable and hot during summer - Located next to the town hall of Ixelles - Budget depends on participation of landlord and people living here	Reasons for consulting the proposed catalogue - Find ways to increase the percentage of green - Lower the temperatures during summer - Convince other inhabitants to help both physically and economically - Look for less technical solutions which we can implement ourselves

Figure 14: Personas of the private individual

Action group	BRAL, Brussels[25]
Background - Supports citizens' initiatives - Mobilises citizens - Debates with government and other city actors	Goals: - Improve air quality - Aim at a greener economy - Improve urban planning
Action group	**Urban Species, Brussels[26]**
Background - Collaboration with developers, graphic designers, citizens, associations, public authorities - Brings together researchers from ULB and Luca School of Arts	Goals: - Increase urban participation - Create smart urban community interaction blocks
Current project - Median strip (Poincaré – Abattoir) in between the railroad bridge of Brussels South and the Ninoofsepoort - 25,000 m² - This current parking zone could be transformed into a large, linear community garden. This gives more open and green space to the inhabitants of which the need is increased due to the Covid-19 virus (*Voor een 'buurt-tuin' op de middenberm!*, 2020).	Reasons for consulting the proposed catalogue - Find appropriate green solutions from which the citizens can benefit - Use catalogue to convince policy-makers that this is the way to go

Figure 15: Personas of the action group

[25] BRAL is a city movement that aims at a more sustainable Brussels (*Wat doet BRAL?*, 2006).

[26] Urban Species is an action-research group based in Brussels focusing on citizen participation (*About | Urban Species*, n.d.).

4.3.Third target group: governmental organisations

Governmental organisations are important actors with regard to politics, culture and healthcare, and thus have an important role in the development of Brussels. This target group contains: Groen Brussel which is part of the government of the BCR, Beliris which is part of the federal government and has an executive function, and perspective.brussels which has an advisory function towards the region's government.

Governmental organisation	Ecolo-Groen Brussel[27]
Background - Focus on a more healthy, greener, more inclusive and more democratic region	Goals: - A healthy city - A city in which one can grow old - An honest city
Current project - Improve air quality of Brussels - Setting up a new mobility plan to create biking routes, neighbourhood streets and residential areas - Lower number of parking spots in the street	Reasons for consulting the proposed catalogue - Look for green solutions to create calmer and greener infrastructure throughout Brussels - Look for their technical aspects in order to decide whether some of them are feasible or not

Figure 16: Persona of a governmental organisation

[27] Political parties Groen (Flemish) and Ecolo (French) together strive for a city with different language communities and cultures, and unites all inhabitants (*Groen Brussel*, n.d.).

	Governmental organisation	Beliris, Brussel[28]
Background - Realisation of construction, renovation and restoration projects in different fields such as mobility, green spaces, culture and sport		Goal: - Improve image of Brussels as the capital city of Belgium and Europe
Current project - Creation of a new community in the southern zone of the canal (Biestebroeckdok) - Transform industry terrain into a mixed neighbourhood - Implement many green spaces - Per year, a budget of 125 million euros is available for all projects		Reasons for consulting the proposed catalogue - See what options can be implemented to increase the percentage of green spaces in the area - See what challenges need to be tackled in the area

Figure 17: Persona of a governmental organisation

	Governmental organisation	perspective.brussels[29]
Background - Combination of different expertise fields allows the realisation of transversal analyses and strategies - Brussels bureau of planning - Delivers guidelines for projects in the city		Goal: - Propose integrated and future-oriented solutions to improve the region
Current project - Make a proposition plan for the area around the Ninoofsepoort - In between the canal and the small ring around Brussels (busy traffic axis) - Redevelop public spaces to create a new urban environment		Reason for consulting the proposed catalogue - Find solutions that can be implemented on this busy crossing that simultaneously provide more green space and attract people to gather

Figure 18: Persona of a governmental organisation

[28] Beliris is part of the federal government department 'Mobility and Transportation' (*Werking | Beliris*, n.d.).

[29] perspective.brussels is a multidisciplinary expertise centre that helps Brussels in building its future (*Over Ons | Perspective.Brussels*, n.d.-b).

4.4. Specifications given by the personas

Certain given specifications will influence the search for, and the choice of, the most suited urban NBS for the persona's project. Each persona has personal interests and its project has specific goals and limitations. Different features can be identified when analysing them.

Table 1: Specifications given by the personas

User's personal objectives	Project's goals and limitations
Interests:	Goals:
Societal challenges	Location
Additional information:	Societal challenges
Amortisation period	Limitations:
Technical difficulty	Project size
Efficacy of the solution	Location
	Budget

The personal objectives can be subdivided into personal interests regarding societal challenges and the additional information of the NBS. The project's goals are the societal challenges that the project must tackle, or the societal challenges that have been recorded in the surrounding area. The project's limitations include the project's size, the project's location and the user's budget involved. Some of these features should allow the proposed catalogue to better answer to the needs of different users.

Firstly, the project's limitations will eliminate unsuited urban NBS. A first limitation will be the size of the project; a house cannot implement the same solutions as an urban square. The different sizes indicated by the personas are listed in Table 2.

Table 2: Indicated sizes

Apartment block (30 units)	Biking and walking routes
Forest	Streets
Small public spaces	Residential areas
Courtyard (100 m²)	Industry terrain
Median strip (25,000 m²)	Vacant public lot

A second feature concerns the specific location of the project. Every location has its own key societal challenges; flooding can be more prominent in one area whereas the UHI effect can be higher somewhere else. Therefore, not every location needs the same kind of NBS which again eliminates possible solutions. Furthermore, the budget plays an important role in what NBS are feasible or not.

Next to the limitations, the project also has certain goals to reach. Here, the same reasoning for the location of the project can be applied. On top of the corresponding recorded societal challenges, the project might also want to tackle other ones. The ones indicated by the personas are listed in Table 3.

Table 3: Indicated challenges

Lower habitat loss	Reduce heat stress
Increase safety feeling	Create community gardens
Increase recreation	Improve air quality
Increase amount of green spaces	Lower the amount of parking spots

In addition to the project's features, the user of the proposed catalogue might also have personal objectives which affect the user's way of approaching a project and the catalogue. The ones indicated by the different personas are listed in Table 4. They can be linked to societal challenges. Solutions with a high performance to tackle a certain challenge will be better suited for that specific persona. Therefore, the objectives will highly influence the user's choice of NBS. Lastly, certain characteristics of NBS were indicated as being important for the decision-making such as amortisation time, technical difficulty, and efficacy.

Table 4: Indicated personal interests

Carbon-neutral	Heat stress reduction
Lower habitat loss	Participation of citizens
Biodiversity	Improving air quality
Recreation	Healthy city
Social gathering	

4.4.1. Prioritising the indicated specifications

In order to facilitate the search for, and final choice of, possible urban NBS for different users, the abovementioned features will be taken into account in the structure and content of the to-be-proposed catalogue. However, not all features are as important; the technical difficulty of an NBS can still be solved by expanding the staff, while the size of a project cannot be changed.

The main criteria that thus affect the user's search for suited urban NBS are the project's size, the societal challenges specific to the project's location and the user's personal interests. These are all fixed boundary conditions that narrow down the number of appropriate NBS. The former one is defined as the most important one as this is the most fixed feature. Other criteria less affect the search for specific solutions but will facilitate the final decision-making between possible urban NBS. The most crucial one concerns the total budget of the user. Hereafter, other characteristics follow.

These prioritised specifications clarify the way different users will consult the to-be-proposed catalogue. Therefore, the catalogue should take these into account to facilitate the user's search for, and choice of, NBS. In order to do so, the specifications can be linked to characteristics of NBS (see Figure 19).

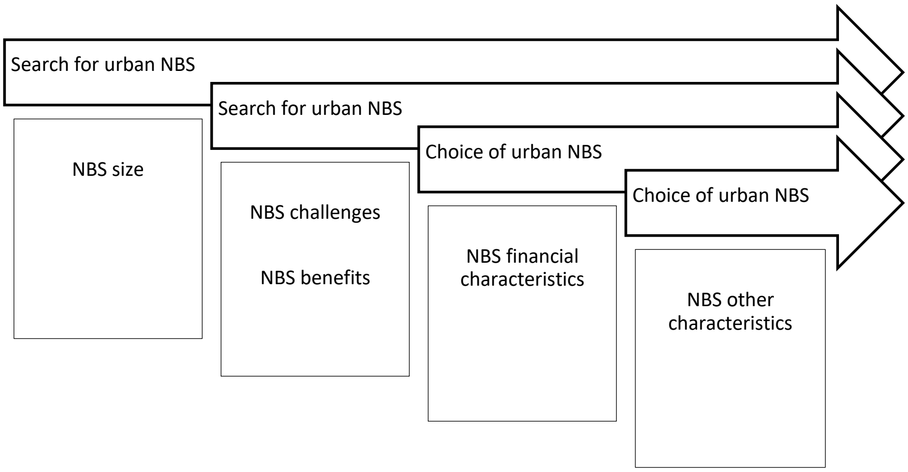

Figure 19: Prioritisation of NBS characteristics

5. User-friendly structure and content

5.1. Fixed and flexible version of the catalogue

After having prioritised the specifications given by the personas, they can be used to define a user-friendly structure and content of the catalogue. A user-friendly catalogue facilitates both the search for, as well as the final choice of, suited NBS for different users. This master thesis will deliver both a paper version of the proposed catalogue as well as a digitalised flexible search tool. The former will have a fixed structure and will contain detailed information of every solutions. The latter will function as an optional preliminary step before consulting the complete information sheets of the catalogue of NBS. The tool will allow the user to indicate the most important aspects of his specific project which will narrow down the search for suited NBS. The final choice can then be made by consulting the detailed information sheets of the paper version.

As mentioned in the previous chapter, the project's size, project's location, and personal interests are the three first prioritised specifications to be indicated that facilitate the user's search. These all concern clearly defined characteristics of an NBS: its size, the challenges it tackles, and the provided benefits to do so. These essential characteristics will need to be clearly indicated in the paper catalogue. Moreover, these can be easily incorporated in the flexible search tool.

Then, the financial characteristics influence the choice of NBS. However, these can less obviously be incorporated in the tool. Indeed, there are different costs, refund periods and subsidies involved. It is difficult to translate these diverse characteristics to one clear price and to then implement this in the tool. Nevertheless, it is an important aspect that influences the user's final choice and will thus need to be clearly displayed in the paper version of the catalogue. Furthermore, other less crucial characteristics also affect the final decision-making.

5.2. Fixed version of the catalogue

This section will define the necessary user-friendly structure and content of the to-be-proposed paper catalogue of urban NBS. In addition, Chapter 6 will specify a user-friendly representation by selecting clear icons, schemes and layouts.

5.2.1. NBS size

The project's size was found to be the most binding specification of each persona. As a result, it is a first way of guiding the user's search for suited NBS. The main structure of the catalogue is defined by the classification of the different urban NBS. A categorisation that answers to the project's size is appropriate here. Therefore, the classification method of existing catalogues was first researched[30]. CLEVER Cities, Klimatek and M. Kawa classify NBS according to their scale or scope.

[30] The categorisation of the evaluated catalogues is reported in Annex 12.2.

Table 5: Categories according to scale/scope

Categories for catalogues classifying according to scale/scope
CLEVER Cities[31] - Building-scale interventions - Public and urban spaces interventions - Interventions in water bodies and drainage systems - Interventions in transport linear infrastructures - Interventions in natural areas and management of rural land - Interventions in ecological and habitat biodiversity
Klimatek[32] - Building-scale interventions - Interventions in the public space - Interventions in water bodies and drainage systems - Interventions in transport linear infrastructures - Interventions in natural areas and management of the rural land - Coastline/coast interventions
M. Kawa[33] - Building-scale measures - Green measures for public space - Measures for linear grey infrastructure - Measures for water bodies and drainage - Measures for natural urban areas

Table 5 illustrates their categories in order to understand the point of origin of the proposed classification. This way of classifying can be used to easily incorporate the project's size. Hence, the categorisation of the proposed catalogue was built upon these projects. However, in order to answer to the user's specific needs, more precise categories need to be specified. Table 2 of Section 4.4 listed the different sizes of the user's projects. These all correspond to different urban planning elements of which buildings, neighbourhood streets, parks and lakes are a few examples. In Table 6, the proposed categories and subcategories can be found. The personas thus help to define user-friendly categories. The categories simplify the user's search, as the user can then simply consult the list of NBS classified in the desired category.

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[31] (Politecnico di Milano, 2019)

[32] (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, pp. 19–21)

[33] (Kawa, 2020, pp. 34–37)

Table 6: (Sub)categories of the catalogue according to urban planning elements

Categories according to urban planning elements	
Buildings	Horizontal elements Vertical elements Surrounding plot[34]
Transport linear infrastructure	Neighbourhood streets Bicycle and pedestrian paths Avenues, boulevards and chaussées
Public squares	
Public green space	Neighbourhood parks Open fields Forests
Waterbodies	Streams Rivers Canals Lakes and ponds

5.2.2. NBS challenges

A second characteristic that facilitates the search for suited NBS concerns the challenges the NBS tackles. On the one hand, the project's location might have specific societal challenges to tackle; the creation of social gathering places can be more vital in one area whereas the need to improve the air quality can be higher somewhere else. On the other hand, the user might also want to focus on some other issues: biodiversity, flooding and recreation are some examples. As this master thesis aims at delivering a catalogue for Brussels, the defined challenges by CO-NATURE will be used (see Table 7) (P. Stessens, personal communication, March 17, 2020). They are subdivided into environmental, social and economic challenges.

[34] Includes gardens, courtyards and private parking.

Table 7: Brussels challenges defined by CO-NATURE

Brussels challenges		
Environmental	Climate adaption	Flood control
		Water quality
		Heat wave impact control
	Climate mitigation	Carbon sequestration
	Nature conservation & management	Biodiversity
	Qualitative living environment	Noise control
		Air quality improvement
Social	Citizenship	Social justice & cohesion
		Participatory planning & governance
		Urban regeneration
	Well-being	Public health & well-being
Economic	Income & costs	Local & diverse employment
		Circular economy against wastefulness
		Lowering energy consumption
		Local budget control (urban infrastructure costs)

5.2.3. NBS benefits

A third characteristic concerns the provided benefits of the NBS. These benefits will explain to the user how a certain NBS tackles a specific challenge. For the same reason as for the challenges, the (co)-benefits defined by M. Kawa, which will also be used in the CO-NATURE project, will be adopted (see Table 8). An explanation of each benefit is included in Annex 12.3.

Table 8: Benefits defined by M. Kawa

Benefits		
Environmental	Water balance	Carbon sequestration
	Water quality	Soil quality
	Heat stress reduction	Biodiversity
	Air quality	Sound
Social	Recreation & proximity	Participation
	Health & well-being	Urban regeneration
Economic	Local employment	Lowering energy consumption

Special care should be given to the valuation of the benefits; UNaLab and M. Kawa provide a valuation of the performance of NBS with regards to these benefits. Hence, an assessment was carried out in order to have reliable values for each NBS.

Firstly, no given values are provided with a clear source which lowers their reliability. In order to provide trustworthy values of performance for all benefits, it is thus necessary to analyse more documents. In the scope of this thesis, values of different analysed catalogues were combined in order increase their reliability. Furthermore, the scale of valuation of M. Kawa is preferred over the one of UNaLab as it allows a more precise comparison of different NBS. Also, negative impacts were indicated; in some circumstances, an NBS might have a negative performance concerning a benefit. For example, when trees are implemented in a narrow heavy traffic street, these affect the natural street ventilation and stack pollution which results in a decreased air quality. The to-be-proposed catalogue will thus be provided with values ranging from -1 to 5.

ASSESSMENT OF EXISTING VALUATION OF BENEFITS	
UNaLab[35]	
Performance of NBS with regards to ecological services	Uses a generalised approach to evaluate the potential performance in suitable conditions: - (1) performance = least good - (2) performance = very good - (-) performance = not applicable However, no explanation of this generalised approach nor linked references are given.
M. Kawa[36]	
Performance of NBS with regards to their (co-) benefits	The data collection is a combination of values obtained from different sources. No linked references to specific values are given. - 0/5 = no effect - 5/5 = excellent performance - -** = negative impact - * = positive effect but impact unknown

Figure 20: Assessment of existing valuation of benefits

[35] (University of Stuttgart, 2019)

[36] (Kawa, 2020)

5.2.4. NBS financial characteristics

After having defined the characteristics that will strongly facilitate the user's search for NBS, other ones will influence the final choice of NBS. The availability of financial characteristics will allow the user to make a comparison between the remaining NBS as well as with grey traditional solutions. Many people might still hesitate to implement NBS as they assume it will be more expensive. Although some solutions might actually be more expensive than the known grey ones, it is currently difficult to make an equal financial comparison as there are more aspects involved than solely the construction costs. This is why a complete set of monetary related information of each NBS is necessary. Therefore, an assessment of existing catalogues was carried out.

In the reviewed catalogues, the URBAN GreenUP, CLEVER Cities and the one proposed by M. Kawa suggest different financial characteristics. A critical assessment of these characteristics was performed and is illustrated in Figure 21. URBAN GreenUP is a reliable source concerning data of the construction costs, maintenance description and amortisation term. They each time provide the market source of the given values[37]. The construction and maintenance costs from CLEVER Cities are not reliable enough as no clear sources are given and the units are too variable to be useful. The investment level proposed by M. Kawa is interesting but no clear distinction is present concerning construction and maintenance costs. Moreover, the provided unit is in €/m² but there is nowhere mentioned how all different units are translated to this one. CLEVER Cities also provides the reader with the expected lifespan and efficacy of each solution. These aspects affect the total cost of the solution. For instance, a solution with less expensive construction costs but with a short lifespan needs to be renewed or repaired sooner than one with higher construction costs that lasts longer. The former might then still have higher total costs. However, as CLEVER Cities is the only catalogue to contain this kind of information, and as they do not explain where these numbers come from, these cannot be used in the financial comparison.

[37] Ideally, these values should be taken from the Belgian market but in the scope of this master thesis the values of URBAN GreenUP were used.

ASSESSMENT OF EXISTING FINANCIAL CHARACTERISTICS	
URBAN GreenUP[38]	
Estimated budget	Refers to construction costs (including costs of materials and labour) - Unit: €/unit of NBS, e.g., €/m², €/m³, €/tonnes - Market source specified for each NBS
Maintenance	Brief description of maintenance operations, but no costs associated
Amortisation term	Refers to the 'period of recovery of the initial economic investment of the NBS' - Short term (0-10 years); medium term (10-20 years); long term (20-50 years); no amortisation - Brief explanation and/or precision
CLEVER Cities[39]	
Construction costs	No specification concerning what is included in the price - Unit: variable for every NBS, e.g., €/m², €/ft², $/ft², $/kg - No clear specific source for these costs
Maintenance costs	No specification concerning what is included in the price - Unit: variable for every NBS, e.g., €/m² per year, $/ft², €/hour - Time range not always provided - No clear specific sources for these costs
Expected efficacy of the measure	No explanation or description - Immediate (<1 year); medium term (10 years); long term (50 years)
Lifespan of the measure	No explanation or description - Short term (<1 year); medium term (10 years); long term (50 years)
M. Kawa[40]	
Investment level	Refers to the initial investment and the maintenance required - Unit: €/m² - Low (€10 - €100/m²); medium (€100 - €800/m²); high (€800 - €3500/m²) - General source indicated, but no specifications for each NBS

Figure 21: Assessment of existing financial characteristics

Reliable financial characteristics which can thus be retrieved from existing catalogues are: the construction costs, the maintenance description and the amortisation term. In addition, other aspects are still to be considered to allow the user to conduct a comprehensive comparison. Therefore, the maintenance costs can have an important influence on the decision-maker. For instance, two solutions with similar construction costs can highly differ in terms of

38 (CAR et al., 2018)

39 (Politecnico di Milano, 2019)

40 (Kawa, 2020)

maintenance. The maintenance description would then complement this cost to understand what is included. Moreover, with the aim of promoting the use of NBS instead of traditional infrastructure, the costs relative to the associated grey solution should be outlined. Finally, local incentives such as premia exist within the city of Brussels. As they can consist in refunds for the implementation of certain green solutions, they should be considered in the decision process because they lower the necessary capital.

The maintenance costs depend on multiple aspects such as the size of the NBS, its complexity and its lifespan. Hence, coherent monetary values will be difficult to define. An extensive analysis of case studies, companies specialised in constructing certain NBS, and expert's articles should be performed.

The cost relative to the associated grey solution is an important characteristic to provide in order to enable a financial comparison between the two. In the scope of this thesis, the associated grey solution is considered to be the infrastructure that would have been traditionally applied to tackle the same main challenge addressed by the NBS with the same type of intervention. For instance, intensive green roofs have multiple benefits but an important one is the water balance regulation (Kawa, 2020, p. 111). In order to tackle a possible overflow of water at the level of the roof, a traditional grey solution would be to install a water harvesting tank. Therefore, the cost of a water tank which would have the same capacity of retention of a green roof can provide a relatively good comparison to the user. Undoubtedly, green roofs as NBS have more benefits that the water tank will not have. This will be mentioned, along with this financial characteristic, so that the user does not disregard this information. Similar to the maintenance costs, this thesis will provide the costs relative to the associated grey solution of the to-be-detailed urban NBS. These values will mainly be searched for by looking at companies specialised in the construction of these solutions.

Concerning local incentives, three levels are possible for the city of Brussels: federal, regional and communal. These three levels were searched via the official websites for housing related or environment related subsidies. A summary of interesting subsidies which can be related to the use of NBS is given in Annex 12.4. However, as these incentives are altered over time, it is advised to always verify on the official websites if the incentive is still valid, or if there are new ones. As an example, according to URBAN GreenUP values, a green roof's cost is in between €60-80/m² (CAR et al., 2018, p. 43). In Uccle, for the installation of a green roof a refund of

20€/m² is applicable for the first 10 m² (*Les Primes Environnementales Communales | Commune d' Uccle*, n.d.). This would then lower the necessary capital to 40-60€/m² for the first 10 m² of a green roof, which corresponds to a non-negligible decrease of costs.

On top of the abovementioned financial characteristics, an economic valuation of the benefits provided by the NBS should be performed. Indeed, through some benefits savings may actually inconspicuously happen. For instance, as green spaces improve human health and well-being (Kawa, 2020, p. 103), indirect health cost savings occur. However, these savings are almost impossible to define which is why they will not be included in the provided information for the urban NBS.

The financial characteristics that will be included in the proposed catalogue are summarised in Table 9 with specification of the used sources for each of the characteristics. The most decisive one will be the construction costs of the NBS, as this relates to the initial capital necessary. This characteristic will thus need to be clearly indicated in the catalogue. Hereafter, the maintenance costs, as well as the amortisation period of the initial investment, define future costs. Some urban NBS will be provided by incentives which can also convince the user of applying the solution. Lastly, the cost of the traditional grey solution is given to allow the user to make the comparison between the two.

Table 9: Financial characteristics

First concern	Construction costs	URBAN GreenUP (various European Market)
Second concern	Maintenance costs and description	Case studies, companies specialised in constructing certain NBS, experts' articles
	Amortisation term	URBAN GreenUP
	Local incentives	Official websites of the BCR and of the 19 communes within the BCR
	Costs of associated grey solution	Companies specialised in constructing these

5.2.5. NBS other characteristics

In addition to the financial characteristics, other ones also contribute to the user's final decision. The ones mentioned by the personas are the technical difficulty of the implementation of an NBS and its efficacy. The given characteristics for each catalogue were previously presented in the descriptive figures of Section 3.1. This section will assess the remaining characteristics in order to complete the selection of necessary characteristics for the to-be-proposed catalogue. Figure 22 includes the reliability of the given information; (1) stands for linked references given; (2) stands for no linked references given.

ASSESSMENT OF OTHER CHARACTERISTICS			
URBAN GreenUP[41]		**UNalab[42]**	
General & technical description	(1)	Basic information	(2)
Implantation	(2)	Illustrations	(1)
Graphical illustrations	(1)	General description	(2)
Scale of intervention		Role of nature	(2)
		Technical and design parameters	(2)
		Conditions for implementation	(2)
		Limitations	(2)
CLEVER Cities[43]		**Klimatek[44]**	
General & detailed description	(2)	Graphic illustration	(1)
To what it responds	(2)	Implementation requirements	(2)
Related primary SDG[45]	(2)	Implementation of conditioning factors	(2)
Related secondary SDG	(2)	Information availability/possible data sources	(2)
Dimensional data	(2)	Inventory method	(2)
Space usage			
Illustrations	(2)		
Scale of application	(2)		
Best practices	(2)		
M. Kawa[46]			
Graphic illustration	(1)		
Scale			
Degree of intervention	(2)		
Description	(2)		
Technical design	(2)		
Notes	(2)		

Figure 22: Assessment of other characteristics included in existing catalogues

[41] (CAR et al., 2018)

[42] (University of Stuttgart, 2019)

[43] (Politecnico di Milano, 2019)

[44] (*Partners | Klima 2050*, n.d.)

[45] Sustainable development goals

[46] (Kawa, 2020)

Many given characteristics can be combined into one; a comprehensive technical description can cover the abovementioned 'technical description', 'technical and design parameters', 'dimensional data', 'detailed description', and 'technical design'. Furthermore, in order to create compact information sheets some of the less decisive characteristics will be neglected. These also include characteristics such as 'role of nature' which is indirectly included in the technical description or *to* 'what it responds' which is linked to the benefits of the NBS. Lastly, some of the catalogues mention the scale of the NBS. However, this will be omitted in the to-be-proposed catalogue as it overlaps with the newly created categories of urban planning elements. In addition, since it overlaps, it does not add any value to the catalogue as it does not further facilitate the search for, and choice of, urban NBS for different users. As a result, four main groups of information can be distinguished from Figure 22: description and visualisation aspects as well as best practices and references (see Table 10).

A general issue that concerns all given characteristics of NBS in every existing catalogue is the fact that they only include a list of all the used references at the end of the NBS sheet. As a consequence, it is difficult for the user to verify the reliability of the given information. This issue should be tackled in the to-be-proposed catalogue by finding a way to include linked references whilst still providing compact information sheets.

Table 10: Other characteristics

Other characteristics	
Description	General Technical (incl. implementation requirements)
Visualisation	Graphic detail Graphic illustration (example)
Best practices	
References	

5.3. Ideal flexible version

After having defined the NBS characteristics to be included in the paper version of the catalogue, the flexible search tool will be developed. This tool will function as a preliminary step before consulting the paper version. Based on the user's input it will narrow down the selection of suited urban NBS. Hence, it facilitates the search for the right NBS considering the continuously growing number of available NBS. The three priority specifications given by the personas defined in Section 4.4.1 will be used in the tool: the user's project's size, the user's project's location and the user's personal interests. The output of the tool will be a selection of urban NBS which the user can then further compare using the detailed information given in the paper catalogue to make the final choice.

This section defines the ideal version of the flexible search tool while Chapter 8 develops the realised digitalised tool of this master thesis. Today, an Excel spreadsheet was drafted functioning as tool. In the future, this spreadsheet can be translated into a web application in order to improve its visualisation and accessibility.

5.3.1. User's project's size

The project's size is a first way of eliminating unsuited urban NBS. This aspect is taken into account by the categories, defined according to different urban planning elements. Hence, these categories are the first filter of the flexible search tool. When consulting the tool, the user will be able to indicate one or more categories. The entire list of possible NBS will then be shortened a first time by only selecting the NBS which are classified under the chosen categories.

5.3.2. User's project's location

A second filter of the flexible search tool is the location of the user's project. Each location has specific societal challenges. This filter needs to be developed with the help of the CO-NATURE project. Indeed, CO-NATURE is creating demand and suitability maps for NBS in Brussels (see Figure 23). This way, the most effective NBS for a certain location can be found. The maps first take into account the global value of importance given to each benefit by the inhabitants of Brussels. This information was collected thanks to an online survey. The values of importance range from 0 to 5. Secondly, they take into account the societal challenges that need to be addressed in a certain location. These challenges were defined for Brussels by CO-NATURE (P. Stessens, personal communication, March 17, 2020). The performance of the NBS type to each benefit is incorporated as well, also having values ranging from 0 to 5 as defined by M. Kawa. Lastly, the maps take into consideration the possible obstructions for the implementation of the NBS which lower its performance. A composed map for each benefit is then created, after which the final demand and suitability map of an NBS type is set up by combining the different spatial maps of each benefit provided by the concerned NBS.

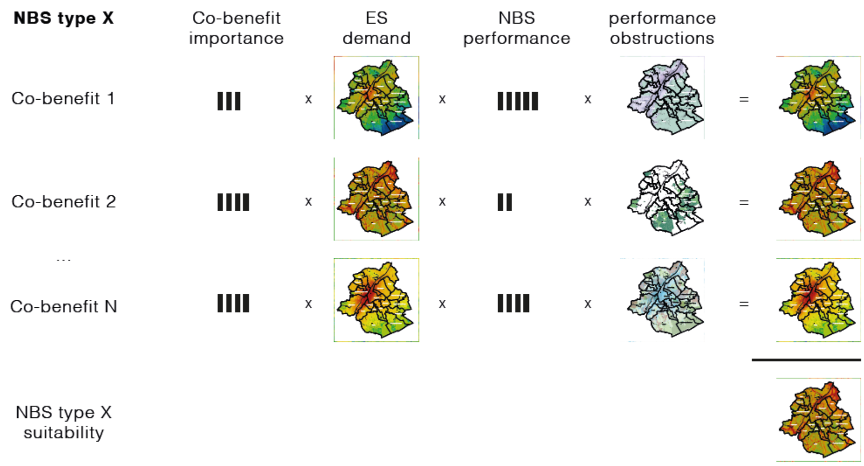


Figure 23: Demand and suitability mapping of the CO-NATURE project (P. Stessens, personal communication, March 17, 2020)

The final map of each NBS type will give its total efficiency at a certain location; the colour codes stand for values going from 0 to 1. These spatial maps can then be used to eliminate ineffective urban NBS at the chosen location. When the user indicates the project's location the model will start drafting a list, going from NBS with no efficiency at all in this area to NBS with high performances. This ranked list can then be shortened by only selecting NBS with an efficiency higher than 70%. If the user does not have personal interests or other challenges to be tackled, the remaining urban NBS will be shown to the user. These can then be further compared to each other, consulting the additional information in the information sheets of the catalogue.

5.3.3. User's personal interests

In addition to these recorded local societal challenges, the user might only want to focus on specific ones. The user should be able to combine his personal interests with the recorded challenges specific to the project's location. As previously mentioned, the model of the demand and suitability maps considers the global value of importance for the inhabitants of Brussels. When filling out the tool, this benefit importance, indicated by the second column in Figure 23, could be indicated to the user as default values going from 0 to 5. However, these could then be changed by the user according to his given significance to certain benefits. These newly assigned values would then generate new values of efficiency for each NBS type which include personal values of importance. Hereafter, the model will rank urban NBS from low to high efficiency and will then only display solutions with an efficiency higher than 70%. The user will then receive both a ranked list of urban NBS that answer to his personal objectives, as well as the initial value of the efficiency of each NBS, according to data gained by CO-NATURE. This way, the user has all the needed information to decide whether he values his own objectives or the global ones of Brussels the highest.

Figure 24 shows the process of the flexible search tool; the entire list of possible urban NBS is narrowed down using the user's input.

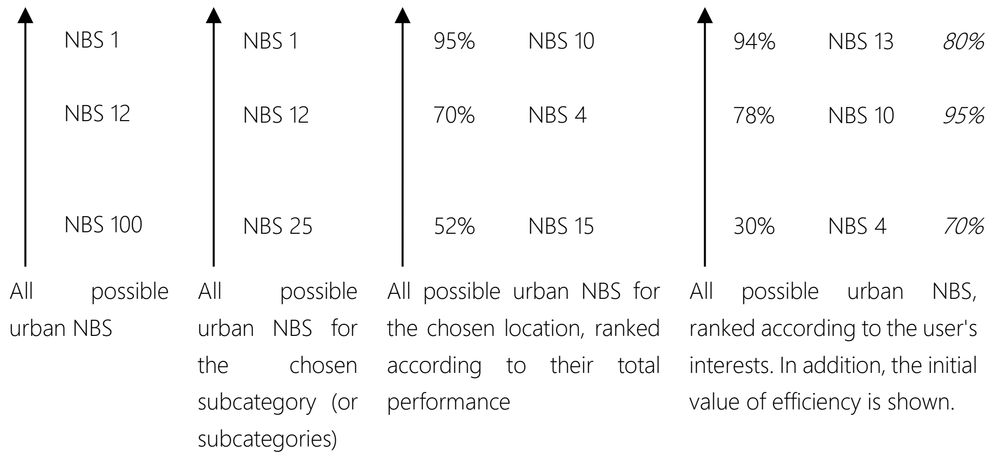


Figure 24: Filters acting on the list of urban NBS

5.3.4. Advantage of flexibility of the search tool

The advantage of the flexibility lies in the fact that it can be adjusted to contemporary challenges. A demand and suitability mapping as well as an online survey can be performed again in ten or twenty years, after which new data can be implemented in the model. Furthermore, it is flexible in a way that each user can assign its own values of importance to different benefits.

6. User-friendly representation

The structure and information to be provided in the proposed catalogue has now been defined. However, in order to have a user-friendly interface, the representation of this data within the catalogue is an important aspect to consider as well. Indeed, the representation defines the readability and the accessibility of the provided information. Two criteria are to be assessed: the layout of the catalogues, and the visualisation of certain elements. The former differs among existing catalogues in terms of the exposed levels of information. The latter varies concerning the visualisation of the solutions and their (co-) benefits.

A selection of the catalogues to be evaluated has been performed similarly to the abovementioned selection in Chapter 3. However, concerning specifically the representation, this selection will vary as the assessed criteria are different. The majority of the reviewed catalogues and projects only contained a visual representation through several icons but did not provide any sheet compiling all the data for each NBS. However, this is a necessary feature to allow an efficient comparison of the catalogues. Therefore, the projects which do not provide it were not considered in the following analysis. A second criterion is the provision of different levels of information; this might result in a more efficient search for NBS. Hereafter, the visual representation of both the NBS themselves and the (co-) benefits they provide was found to be important. Lastly, catalogues containing additional icons or graphic representations were found to be interesting as these allow a more exhaustive analysis. Taken into account the abovementioned criteria, the URBAN GreenUP, the UNaLab and the Klimatek catalogues were chosen to analyse, as well as the one of M. Kawa.

6.1. User-friendly layout of the catalogue

6.1.1. Advantages of the distinct levels of information and corresponding layouts

There exist various possible levels of information within the catalogues, and each one has its own advantages. The UNaLab project proposes a catalogue containing only one level of information, which are the NBS factsheets. All of the provided data is listed in these factsheets. In comparison, URBAN GreenUP, Klimatek and the catalogue of M. Kawa suggest two distinct levels of information. Indeed, in addition to the factsheets, the URBAN GreenUP project suggests an NBS index, while the Klimatek project and M. Kawa advocate the use of NBS datasheets. The index consists of small sheets that provide limited information for each NBS, while the datasheets consist of concise lists of the proposed NBS with mention of specific characteristics. The main advantage of having different levels of information is the increased accessibility of relatively more important data. Indeed, the datasheets enable the user to have a more global view of all the proposed NBS together with some defined crucial information. The index, on the other hand, gives a bit more information which facilitates the comparison of various NBS to each other. This could be a way to preselect some solutions before looking at the detailed NBS factsheets. It is worth mentioning that the index of URBAN GreenUP and the datasheets of Klimatek are complementary levels of information. This means that among these catalogues, three potential levels of data can be defined: datasheets listing the proposed NBS; an index consisting of a small overview of the NBS; and elaborated factsheets.

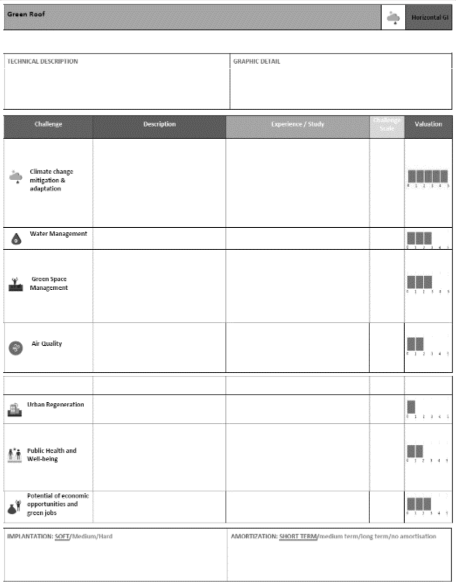
The abovementioned levels of information are introduced by the catalogues via predefined formats and arrangements of the data. This facilitates the comparison of NBS to each other, as the same information is provided for each NBS within the same level of information of a catalogue. These formats are illustrated in the following figures for each level of information through the example of the green roof. As it can be seen, the format used by each project to present a factsheet[47] of an NBS is similar. The three catalogues use A4 pages; the one of M.

[47] The empty spaces of the factsheets of URBAN GreenUP and UNaLab were reduced in order to obtain a condensed figure.

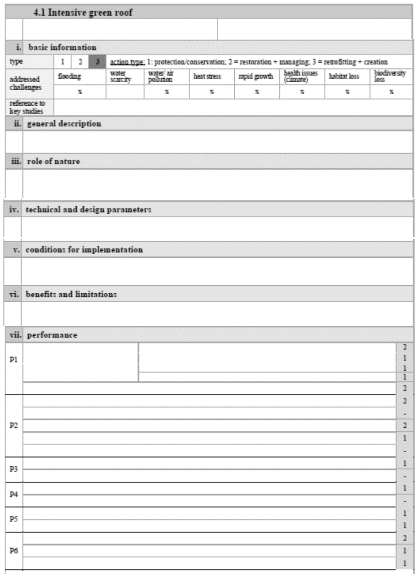
Kawa is condensed to only one smaller page. The latter is visually preferable as it allows a better readability. Concerning the datasheets, Klimatek proposes lists of NBS on A4 pages, but each feature is defining a new list. Alternatively, M. Kawa suggests a database which combines all the defined features in one list. This allows the user to have all the provided information concerning a specific NBS on the same page, which is more suited. Finally, the index proposed by URBAN GreenUP is, for each NBS, approximately a third of an A4 page. No other catalogue includes this level of information.

FACTSHEETS

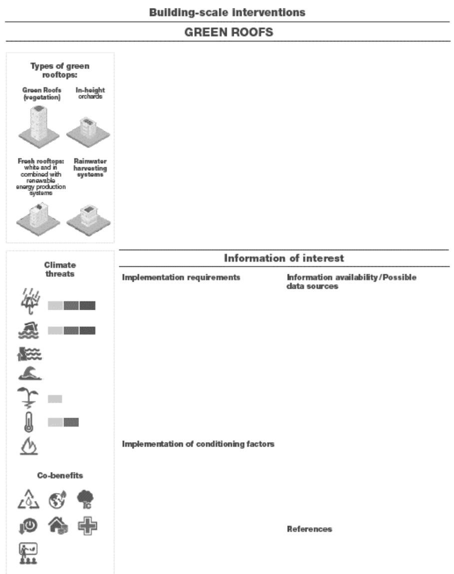
URBAN GreenUP[48]



UNaLab[49]



Klimatek[50]



M. Kawa[51]

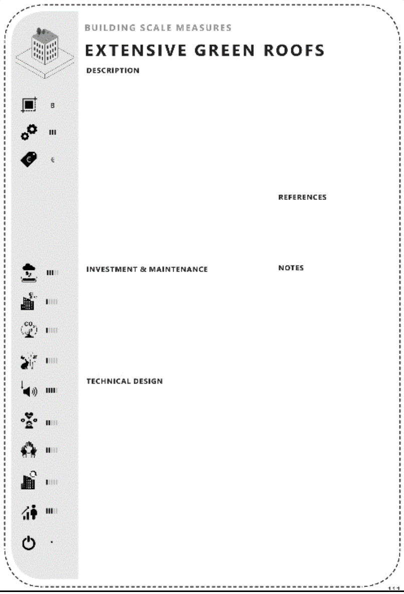


Figure 25: Existing representations of a factsheet

48 (CAR et al., 2018, pp. 167–170)

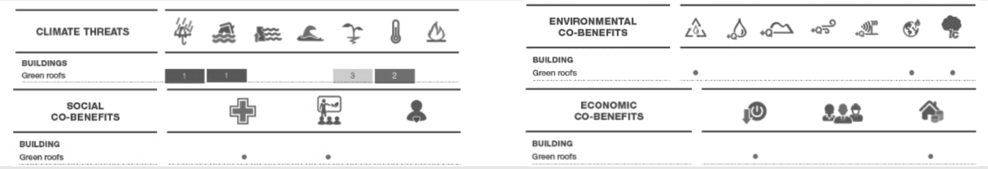
49 (University of Stuttgart, 2019, pp. 38–40)

50 (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, p. 65)

51 (Kawa, 2020, p. 111)

DATASHEETS

Klimatek[52]



M. Kawa[53]

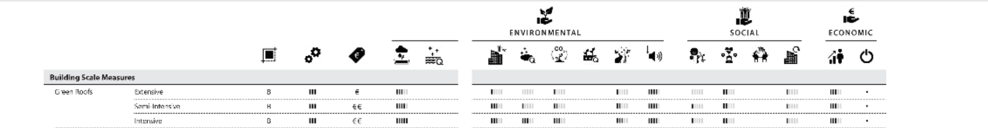


Figure 26: Existing representations of datasheets

INDEX

URBAN GreenUP[54]

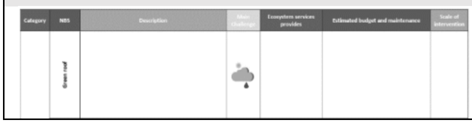


Figure 27: Existing representation of an index

6.1.2. User-friendly levels of information

Since the abovementioned levels of information are complementary to each other and each have their own advantages, the use of three levels was chosen for the to-be-produced catalogue in order to allow a user-friendly search for, and choice of, NBS. They are defined as datasheets, overview sheets and factsheets. These levels will follow the prioritisation indicated by the personas in Section 4.4.1.

The datasheets will be based on the ones developed by M. Kawa. They will be presented as a list of all NBS included in the catalogue, classified by their urban planning element, as defined in Section 5.2.1. Moreover, since the challenges addressed, the (co-) benefits and the budget were defined as priority features by the personas, these will be incorporated in the datasheets. However, in order to keep the layout compact and not to confuse the user with

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[52] (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, pp. 24–27)

[53] (Kawa, 2020, pp. 102–103)

[54] (CAR et al., 2018, p. 43)

excessive information, only the main challenge will be mentioned, as well as only the construction costs. Nevertheless, all (co-) benefits and their related NBS performance will be drafted in the datasheets. This first level of information will be useful to outline all the NBS and their possible effects. The overview sheets will be developed for each NBS and will be presented on small sheets with a similar format to the index of URBAN GreenUP. This overview will include the data provided in the datasheets, with the addition of a brief general description and a graphic illustration. Indeed, at this level, it should be clear for the user what the solution consists in. This level of data will then enable an easy comparison of various NBS with respect to decisive criteria, and a preselection of NBS could be done at this level. For this reason, the overview sheets should ideally be used as the outcome results of the flexible version of the catalogue. Finally, the factsheets will gather all the NBS characteristics as defined through Chapter 5. However, in order for the user to be able to still recognise the priority information, this information will be highlighted by means of a grey coloured background. The factsheets will be presented on a similar format used by M. Kawa. Thanks to this elaborated level, a proper decision can be made on whether the NBS is suitable for the desired project.

The data present on each level of information is reported in Table 11. In bold is the additional data compared to the previous level of information.

Table 11: Data for each level of information developed

Characteristics		Datasheets	Overview sheets	Factsheets
Category	Urban planning element	X	X	X
Description	General description		Brief	X
	Technical description			X
	Implementation requirements			X
Illustrations	Graphic detail			X
	Graphic illustrations (examples)		X	X
Challenges	Main challenge (Brussels)	X	X	X
Benefits	Main benefit		X	X
	Co-benefits	X	X	X
Financial characteristics	Construction costs	X	X	X
	Maintenance costs & description			X
	Amortisation term			X
	Local incentives			X
	Costs of associated grey solution			X
Best practices				X
References				X

6.2.User-friendly visualisations

6.2.1. Advantages of various visualisation methods

In order to provide a visually effective catalogue, not only the different levels of information but also the use of images, icons or schemes have to be considered, as they contribute to the global representation of the catalogue. Indeed, the use of icons significantly improves the clarity of the data, as it is easier to recognize a symbol compared to words or sentences. It facilitates the comparison of different solutions to each other. Moreover, it enables a more condensed final layout.

All three evaluated catalogues incorporate a picture of the NBS as well as some more technical details of it. This way, concrete examples of applications of NBS can be shown. In addition, some of the catalogues also present icons and schemes. URBAN GreenUP uses icons that were defined by the EKLIPSE project, and which concern the addressed challenges. In contrast, Klimatek defines its own icons for several parameters: the addressed climate threats, the (co-) benefits and the implementation criteria. Moreover, the Klimatek project is the only one to propose additional schemes to represent the types of urban NBS. They explicitly illustrate the type of NBS in presence thanks to these schemes. These schemes have a coherent layout and give a relatively good idea of how the concerned NBS can be expressed. The proposed catalogue of M. Kawa also makes use of schemes for the types of urban NBS, which are inspired by the Klimatek project. Her catalogue also contains icons for the different (co-) benefits, which differ from the ones used by Klimatek, as well as for the type of benefits (environmental, social and economic).

6.2.2. User-friendly visualisations

In order to achieve a clear and concise representation of the suggested catalogue, the use of an image and additional technical details of the NBS will be adopted. This enables the provision of concrete examples of applied NBS. In addition, schemes for the types of NBS will be included to improve the global readability of the catalogue. The schemes of M. Kawa will be used for this purpose[55]. In the event that additional NBS are provided in the proposed catalogue, new schemes will be developed in accordance with the existing ones. Furthermore, from existing catalogues, two types of icons could be defined for the proposed catalogue: icons for the challenges of Brussels; and icons for the benefits provided. However, as the challenges and the benefits defined are particularly analogous, defining icons for both of them could appear confusing for the user. For this reason, it was decided to define icons for the benefits, and as only the main challenge is provided it can be defined in words without obstructing the readability of the catalogue.

Concerning the benefit types, only M. Kawa defined icons, and therefore these will be reused. However, various catalogues suggest different icons which can be linked to the list of (co-) benefits defined in Section 5.2.3. In order to choose the most user-friendly ones, a survey was performed to verify which ones were considered to be the most representative and understandable. This survey was performed online using Google Forms and was spread through social networks. People from different backgrounds, not specifically related to urban design, were asked to choose the clearest icon between different existing ones in relation to the name of the benefit. In total, 75 answers were collected. The content of this survey, as well as the detailed results and a brief discussion, are reported in Annex 12.6. According to the results of the survey, some of the chosen icons were redrawn in order to obtain a coherent design.

Besides, to further increase the readability, icons to represent the phrase 'main challenge addressed' and 'construction costs' were defined. A summary of the used icons within the catalogue is in Figure 28.

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[55] The list of schemes developed by M. Kawa is reported in Annex 12.5.

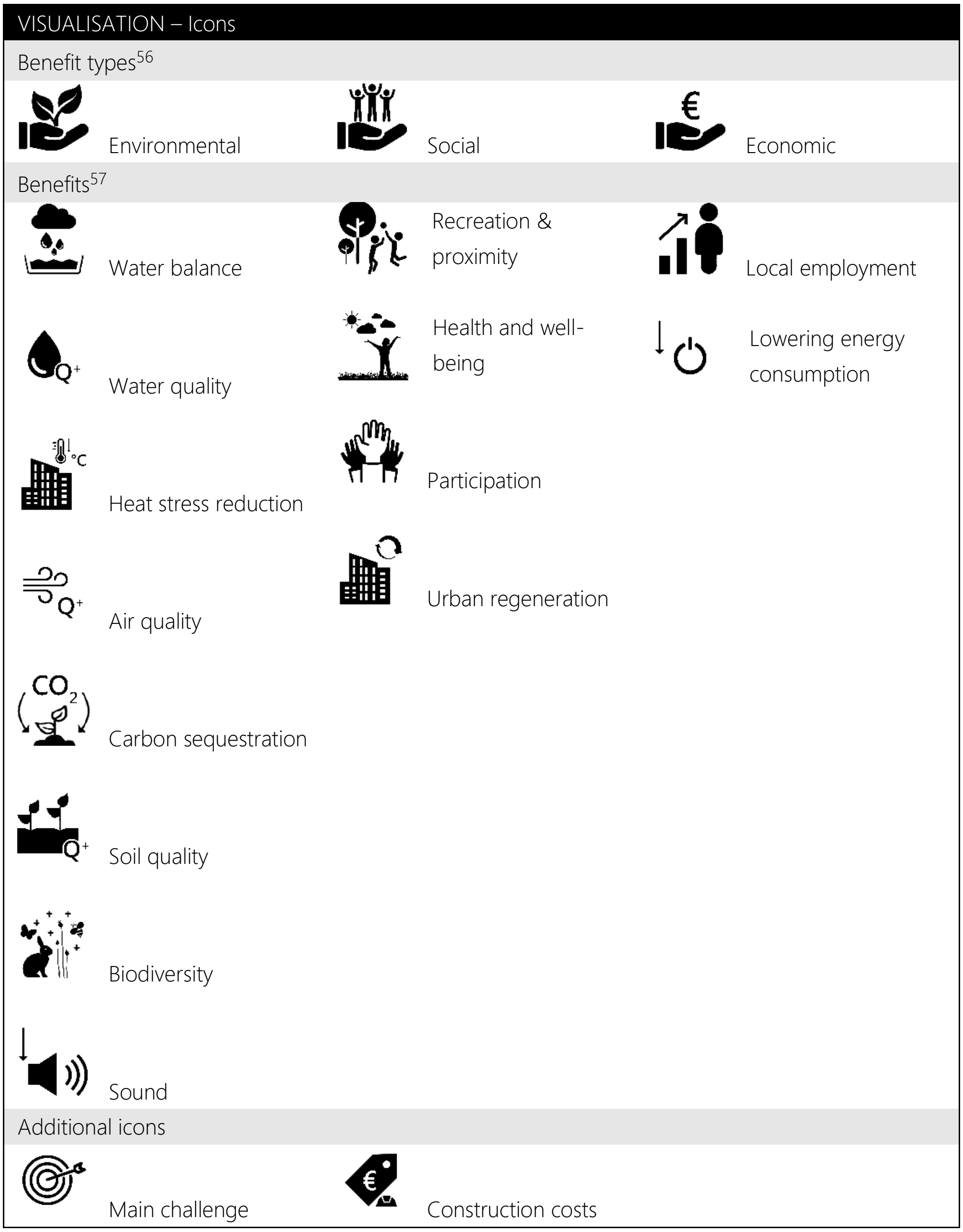


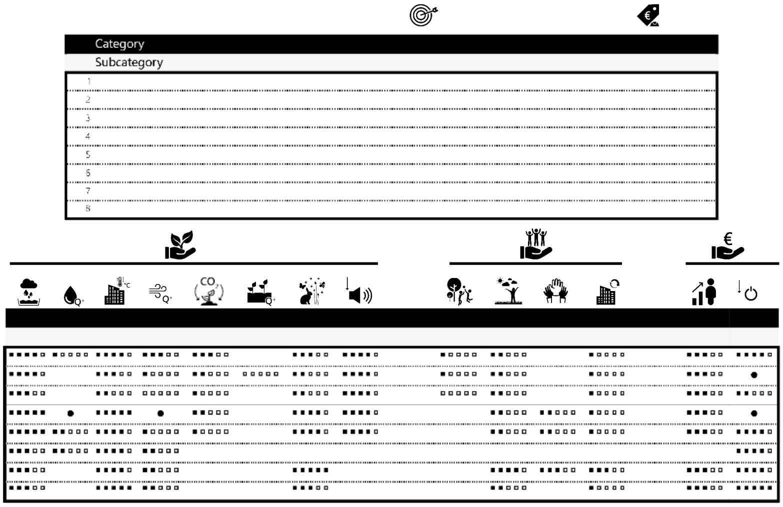
Figure 28: User-friendly icons

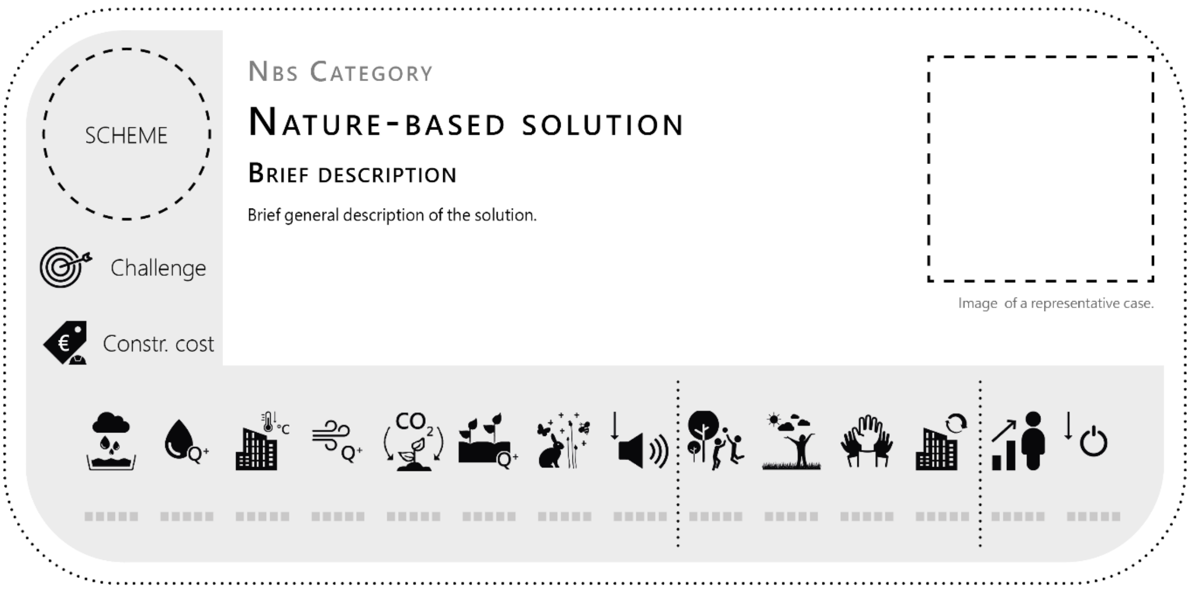
[56] (Kawa, 2020, p. 41)

[57] From survey results (see Annex 12.6).

6.3.Representation proposal

Thanks to this analysis, the final representation proposal for the datasheets, the overview sheets and the factsheets could be developed. An empty sample of each of these levels of information is presented in this section.





SCHEME

Challenge

Constr. cost

NBS CATEGORY - NBS SUBCATEGORY

NATURE-BASED SOLUTION

GENERAL DESCRIPTION

General description of the solution.

TECHNICAL DESCRIPTION

Technical description of the solution, including implementation requirements.

FINANCIAL CHARACTERISTICS

Financial characteristics, including construction costs, maintenance costs & description, local incentives, and costs of the associated grey solution.

BEST PRACTICES

Brief description of one or two case studies.

SOURCES

Sources used for the general information provided.

Image of a representative case.

Graphic detail of the NBS.

7. Innovative NBS

As the concept of NBS is quite recent, new solutions can still be categorised as urban NBS every day and improvements of them are expected. A search for the newest innovations in the field of NBS, to then include these in the proposed catalogue, is thus interesting. The aim of this chapter is therefore to provide a description of several possible innovative NBS, with a limited selection to be detailed. In order to do so, a clear delineation of the term 'innovative' is first required. Following, the descriptive list of innovative NBS will be classified according to their respected urban planning element so as to correspond with the defined structure of the proposed catalogue (see Chapter 5). The description will cover the possible effects of these innovative solutions on their environment through various benefits, as well as the main challenge they address. Some solutions will be supported by case studies or ongoing projects, and illustrations or graphic schemes are also desired to clarify these innovative NBS. Hereafter, a selection of solutions to be detailed will be performed with the aim of providing their overview sheets and factsheets, as defined in Section 6.3.

7.1. Delineation of 'innovative'

In order to define and develop innovative NBS, a clear delineation of the term 'innovative' is first required. For the broader meaning, as defined by Collins dictionary, innovation is "the introduction of new ideas, methods, or things" ; something innovative is "new and original" (*Collins Online Dictionary | Definitions, Thesaurus and Translations*, n.d.). In previous times, innovation was only related to technology (Edwards-Schachter, 2018). However, nowadays this is not the only topic where innovation can take place. Indeed, this term is associated with invention, novelty and change, e.g., in social, green or even public contexts (Edwards-Schachter, 2018). In her paper, Edwards-Schachter also refers to "hybrid innovation" which combines approaches on technology, society and culture (Edwards-Schachter, 2018). In the context of NBS, various interpretations of how innovative NBS can be achieved are to be found in various documents. Depietri and McPhearson imply that innovation for NBS lies in the combination of natural elements and the grey infrastructure. There is indeed, as mentioned in Section 2.4, a possibility to complement nature with technology (Depietri & McPhearson, 2017) to then provide hybrid interventions. Horizon 2020 is also in line with that reasoning as they suggest a combination of living elements with hard engineered work (Horizon 2020 Expert Group, 2015). Accordingly, hybrid interventions can thus be considered as innovative NBS. Considering another perspective, Cohen-Shacham et al. mention that innovative governance and new partnerships can conclude to create innovative solutions through a multi-scale co-management approach (*Nature-Based Solutions to Address Global Societal Challenges*, 2016). This implies that various actors working on different urban scales[58] can work together to create innovative NBS.

To summarise, innovative NBS can be defined as: new solutions, which are then not provided in existing catalogues; hybrid interventions; and multi-scale combinations of solutions. Since innovative solutions are now clearly delineated, a clear search of innovative NBS can be

[58] As defined by M. Kawa, urban scales are: Building, Street, Neighbourhood, Urban and Regional (Kawa, 2020, pp. 38–39)

performed. Already developed innovative NBS will be searched by revising NBS atlases such as Naturvation and Oppla[59], looking for hybrid and multi-scale solutions. Some projects developed in Brussels were also reviewed in order to reveal possible case studies.

In addition to this search for existing innovative NBS, new suggestions of NBS can be proposed. For this, inspiration was drawn from ongoing projects such as the Plan Canal[60], the PRDD[61], or projects present on the BouwmeesterMaitreArchitecte[62] website. Innovative NBS could then be generated to answer to the objectives of these projects. Thanks to both a search and a generation of solutions, several innovative NBS which could be applied to Brussels were identified. These are listed in the following section.

Furthermore, in order to incorporate these newly found solutions in the catalogue, they will be classified according to their respected urban planning element. However, some identified innovative NBS have a transversal approach and combine multiple urban planning elements, which demands a new division. For this reason, a new category will be added to the proposed catalogue: 'Transversal NBS'.

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[59] Naturvation and Oppla are both online platforms compiling case studies of NBS. More information is given in Annex 12.1.

[60] The BCR initiated the Plan Canal with the aim to develop economic activities, to create housing and public spaces, as well as to provide functional variety (*Plan Canal*, n.d.).

[61] Regional plan for sustainable development (plan régional de développement durable).

[62] The bouwmeester maître architecte publishes public calls for tender and current topics with the aim to guarantee quality in terms of architecture, urbanism and public spaces (*About | bma*, n.d.).

7.2. Identified innovative NBS

This section outlines the identified innovative solutions, classified according to their urban planning element. For each one, a preliminary definition of the underlying concept is provided, in addition to a specification reporting why this solution is considered as innovative. Following this, a description of the various elements constituting the NBS is developed. The contribution of the NBS through its benefits as well as the main challenge addressed are summarised. Finally, each innovative NBS is illustrated through a more detailed, newly drafted, scheme to support the description.

ACCESSIBLE AND EDUCATIVE GREEN SCHOOL GROUNDS

As mentioned in the introduction of this thesis, Brussels currently lacks accessible green spaces (*Home | CO-NATURE*, 2019). In parallel, part of the regional development plan focuses on schools through the medium of *contrats d' école/schoolcontracten* in order to better connect them with their environment and their neighbourhood (*Contrat École | Perspective.Brussels*, n.d.-a). As a response to both problematics, there is the opportunity to generate a new solution that would address the current need: Accessible and educative green school grounds. The idea would be to rehabilitate school grounds with the implementation of green elements and urban NBS. Furthermore, after school hours, this newly revitalised green space could be accessible to the wider public.

School grounds demand practical recreation space which can be used for sport activities such as basketball or a football pitch. Therefore, they are usually mainly imperviously paved. For this innovative solution to be implemented, part of the school grounds will be covered with pervious pavements to provide the school with this specific need. However, another part of the site will be used for natural and educational purposes. Green spaces with trees and eco-urban furniture, as well as small semi-natural ponds, could be implemented in order to provide greener spaces and to offer the possibility to educate the children about nature and its benefits. As an additional element, one could consider implementing vegetable gardens on the roofs of the school. This could induce an added value in terms of education of the children and in terms of local food production.

This solution would provide the neighbourhood with recreational proximity green spaces, which would improve the health and well-being of the inhabitants. By the provision of green roofs, pervious pavements and small ponds, the water balance of the area would be enhanced. The main challenge addressed by this innovative solution would certainly be social justice and cohesion.

Accessible and educative green school grounds

Social justice and cohesion

Possible benefits

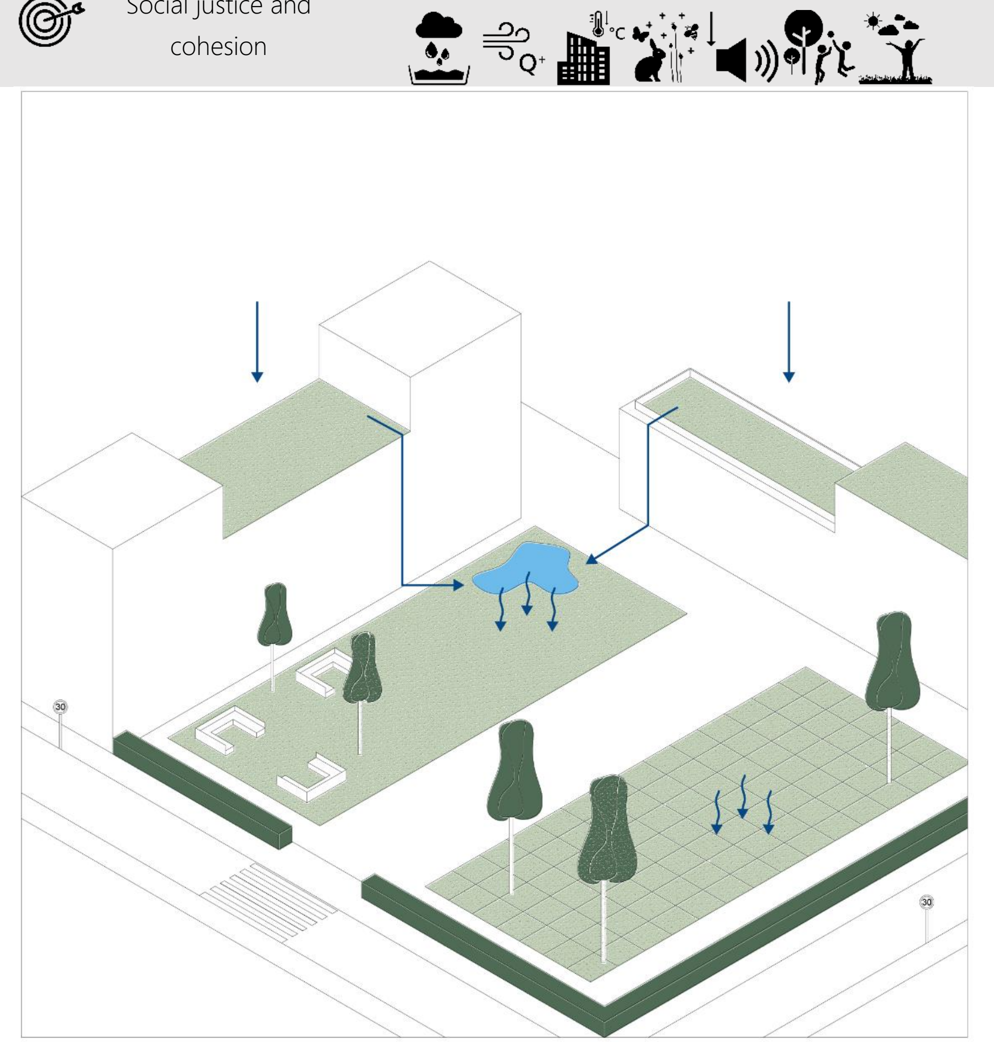

Figure 29: Accessible and educative school grounds. The blue arrows are illustrating the water flow.

BUILDING – SURROUNDING PLOT

PRODUCTIVE AQUAPONICS BUILDING

As its name indicates, the aim of a productive building is to offer several nature-based products through solutions applied to a building. Productive NBS already exist, but systems combining these are less common. No such systems are referenced in the existing evaluated catalogues. However, various productive systems could be applied to buildings. The productive aquaponics[63] building is one example.

A productive aquaponics building was already developed: the *Abattoir Foodmet*, also designated under the label *Ferme Abattoir*, located in Anderlecht, Brussels (*Food Processing Center and Markets, Brussels*, n.d.). This project consists in a market with an urban farm as a roof. It includes outdoor gardens, greenhouses, and fish farms. These produce vegetables and fruits, as well as fish that supply the local market located on the ground floor of the building. Moreover, the water management of this project is worthy of mention. Indeed, rainwater is harvested (1) thanks to a rainwater tank (2) in order to supply the fish tanks (3). Hereafter, the water originating from these fish tanks, which is now rich in nutrients from the fish's waste, is filtered through a bio-filter (4) before being used to fertilise the greenhouses. In addition, a system enables the collection of water condensation coming from the evaporation of water (5). This water is then returned to the system, complementing the rainwater harvested. (*About | BIGH Farms*, n.d.).

Thanks to this ingenious water loop, water balance and water quality are two main benefits brought by this solution. Moreover, the numerous types of vegetation will help for carbon sequestration, and the urban farming will demand local employment (Beckers, 2019). Furthermore, addressing the challenge of circular economy against wastefulness is at the core of the system.

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63 "Aquaponics is a mixture of hydroponics and aquaculture. Hydroponics is a method of growing plants without using soil, and aquaculture is the practice of farming fish." (*About | BIGH Farms*, n.d.)

Productive aquaponics building

Circular economy against wastefulness

Possible benefits

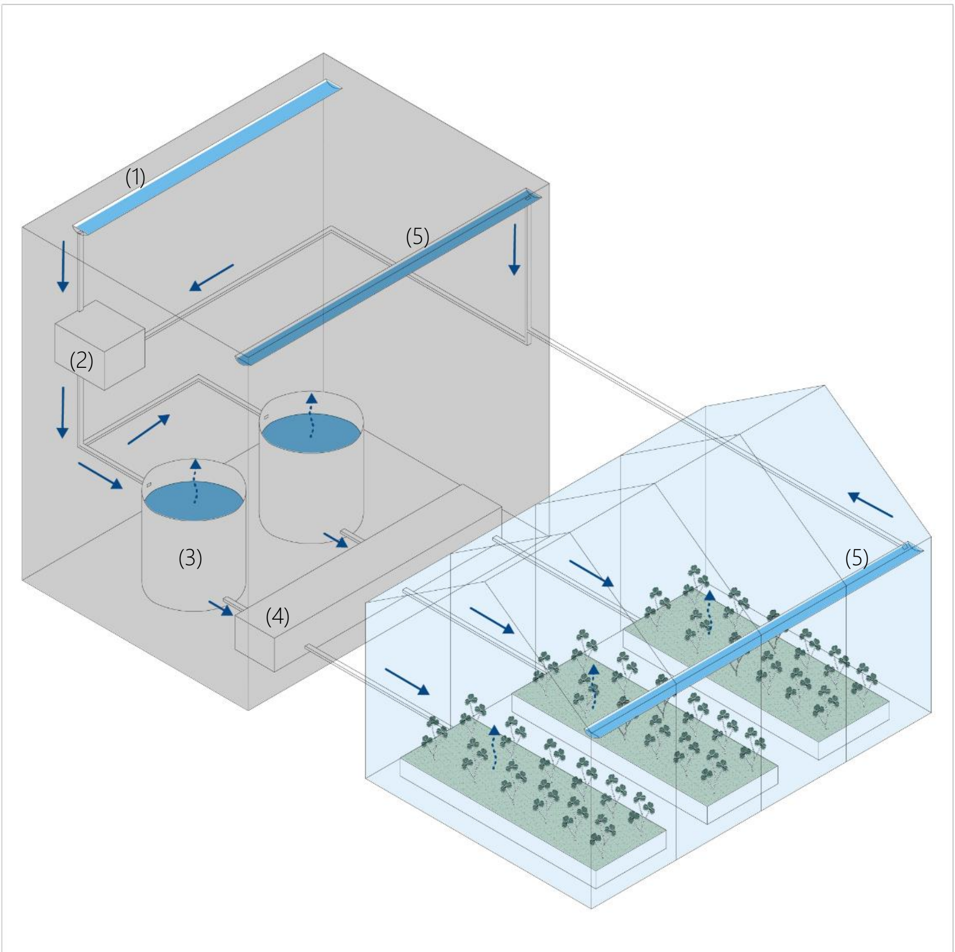


Figure 30: Productive aquaponics building. The blue arrows are illustrating the water flow.

PRODUCTIVE HONEY BUILDING

As previously mentioned, the aim of a productive building is to offer several nature-based products through solutions applied to a building. Various productive systems could be applied to buildings; the productive honey building is a second example integrating rooftop beehives. Neither this system, nor the rooftop beehives are referenced in the evaluated catalogues. A newly generated solution was then developed.

At the centre of this solution, beehives will be implemented on the flat roof of the building. Rooftop beehives are already present in the urban landscape. As an example, two beehives were installed by BeeOdiversity[64] on the rooftop of the main building of the European Economic and Social Committee located in Brussels (*Urban Bees | EESC*, 2018). This company can provide the project with recommendations and with beehives, whose maintenance will be ensured by professional beekeepers. In order to sustain these beehives, it is important to provide a large variety of plants (*Apis Bruoc Sella*, n.d.). Possible plants are edible aromatic herbs, vegetables and fruits. Examples are chives, parsley, basil, lettuce, cabbages, chickpeas, tomatoes, and various berries (*Apis Bruoc Sella*, n.d.). For this reason, an urban rooftop for growing vegetables and fruits will be implemented. In addition to that, the façades of the building will be covered by floral and diverse pollinator plants. This will allow the bees to pollinate the flowers and to produce honey. Moreover, water will be needed for the bees, as well as to water the plants. Therefore, a more conventional system to harvest the rainwater can be installed, with part of the storage left open sky for the bees.

In addition to the production of vegetables and honey, this system would provide various benefits such as water balance, carbon sequestration, biodiversity, and heat stress reduction. The main challenge addressed by this solution is biodiversity.

[64] BeeOdiversity is a Belgian company which aims at restoring biodiversity through environmental monitoring, recommendations, and implementation of bee colonies and bug hotels on site (*Home | BeeOdiversity*, n.d.).

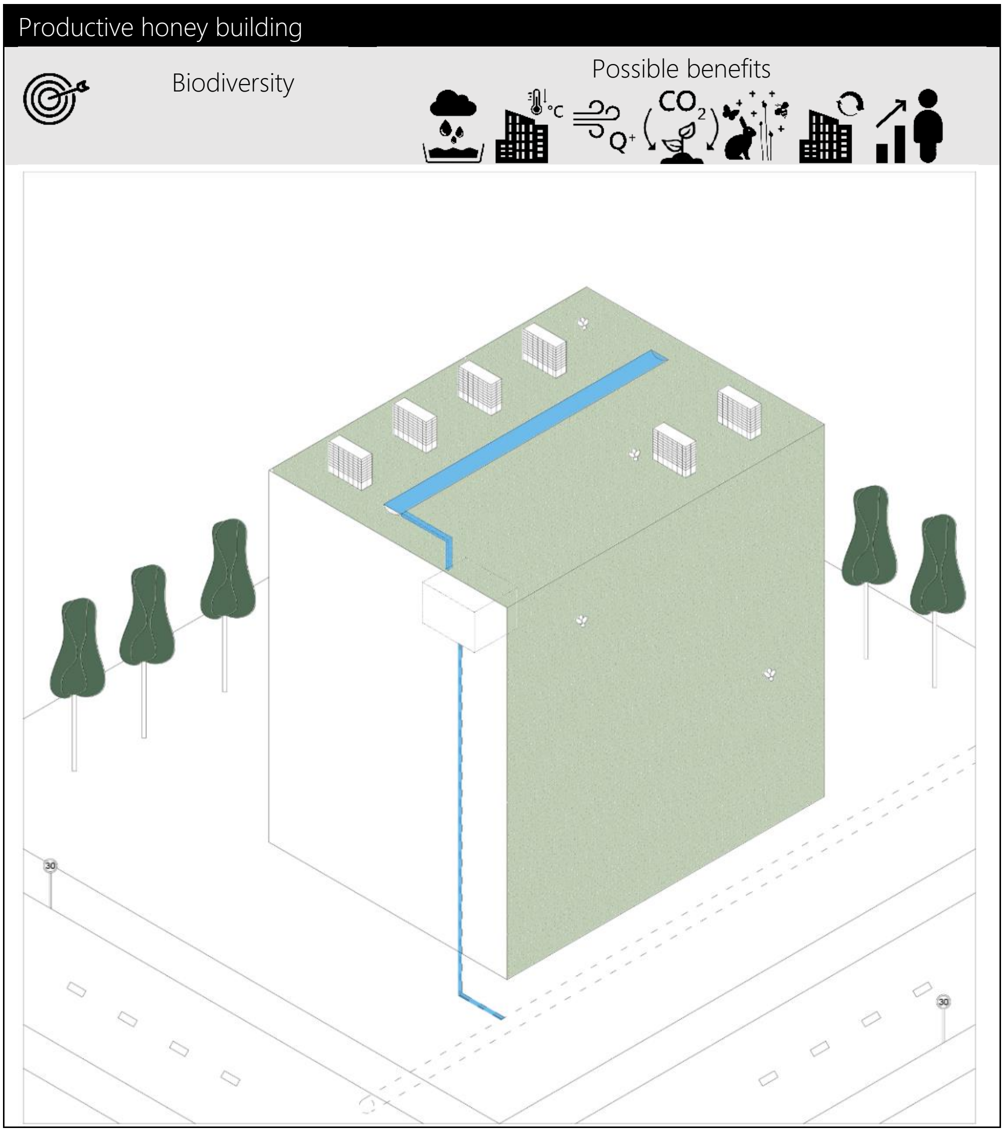


Figure 31: Productive honey building

VERTICAL FOREST

The idea lying behind a vertical forest is to use buildings to develop greenery. Indeed, towers are built with the intention of gaining usable surfaces, thanks to their height, without occupying excessive ground surface. Therefore, the same concept could be used for greenery. This way, considerably more green spaces can be implemented in a dense city. This nature-based concept has already been developed, however it is not referenced in the existing evaluated catalogues.

This innovative solution was first realised in Milan as the *Bosco Verticale* (*Vertical Forest*, n.d.). This project redefines the expression of green façades by implementing various types of trees, plants and shrubs on large green balconies. A technical installation complements the system by monitoring the needs of the plants and by remotely managing the centralised irrigation system (*Vertical Forest*, n.d.). In order for this solution to be efficient, the choice of species to be integrated is important. For instance, the chosen plants should be resistant to wind and should not stimulate allergies. Moreover, they should be placed on the façades according to their best orientation (Giacomello & Valagussa, 2015).

This system offers numerous benefits such as heat stress reduction, air quality improvement, but also human well-being and lowering energy consumption (Giacomello & Valagussa, 2015). The expected main challenge addressed would be air quality improvement.

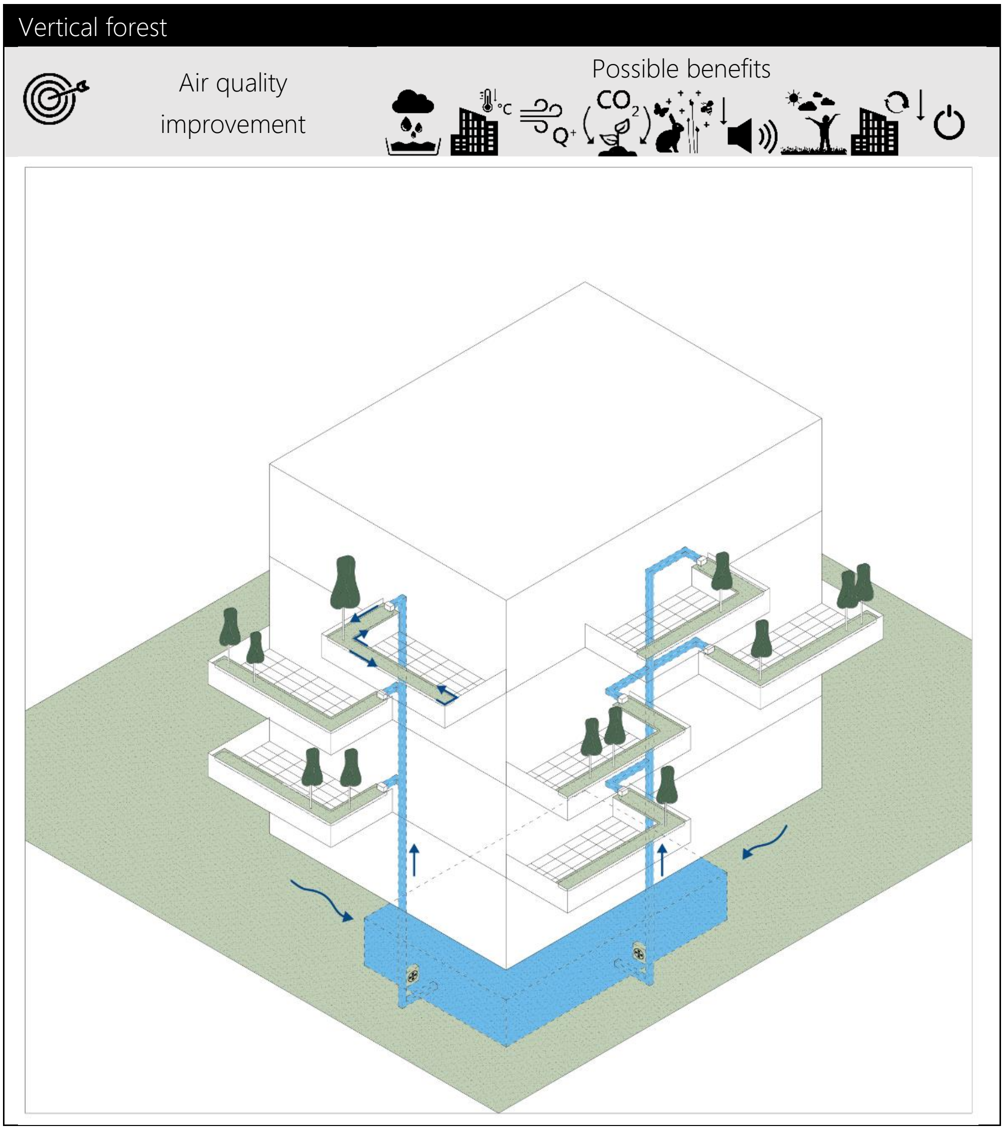


Figure 32: Vertical forest. The blue arrows are illustrating the water flow.

TRANSPORT LINEAR INFRASTRUCTURE – NEIGHBOURHOOD STREET

CAR-FREE RESIDENTIAL STREET

Concerning the urban planning element of transport linear infrastructures, various types of nature-based local neighbourhood streets can be defined. These types can be considered as innovative by the combination of multiple elementary NBS. Moreover, except from a mention provided in M. Kawa's database, no other evaluated catalogues include street typologies. A first example is the car-free residential street.

This solution would concern streets from which cars are banned. An example of such a street is provided by the Groentool of Antwerp: the Rijke Beukelaarstraat, Antwerp (*Green Measures / Groentool*, n.d.). This example presents a combination of street trees, shrubs and deciduous hedges placed throughout the street. This provides a general green feeling (*Green Measures / Groentool*, n.d.). However, the proposed street typology could be further defined. Residential streets will only be accessible to pedestrians and bicycles. Therefore, the street can be entirely paved with pervious pavements in order to increase its permeability. Moreover, the use of eco-urban furniture throughout the street is desired to provide green resting areas. The street becomes then a pleasant green space for the inhabitants and passers-by to enjoy.

Benefits from this street typology are multiple. The Groentool of Antwerp defines the four more important benefits to be recreation and proximity, heat stress reduction, sound, and biodiversity (*Green Measures / Groentool*, n.d.). As the main challenge, urban regeneration would be addressed.

Figure 33: Car-free residential street

SLOW-TRAFFIC STREET

As previously mentioned, various types of nature-based local neighbourhood streets can be considered as innovative solutions. A second example is the slow-traffic street.

In order to generate this solution, one of the current topics discussed on the bma website can be used as an inspiration: *Espace · Publiek* (Bouwmeester maître architecte (BMA), 2019). Through this topic, ten suggestions were developed concerning the design of local streets (Bouwmeester maître architecte (BMA), 2019), which helped to define this street typology. The slow-traffic street will consist of a two-way road which will occasionally be obstructed by eco-urban furniture in order to slow down the traffic. This will also allow for the creation of parklets and green resting areas. Along this road, parking spaces, with adjacent street trees, will be delineated by the use of pervious pavements. Thanks to the proximity between the trees and the porous pavements, the rainwater would filter directly to the roots. This typology provides thus wider space for the pedestrians to enjoy, various water management elements and a more limited space for cars.

In this case, the Groentool of Antwerp does not consider this typology of street. However, benefits could be identified as similar to the previous example, with a lesser importance for recreation and proximity. The main challenge can also be defined as urban regeneration.

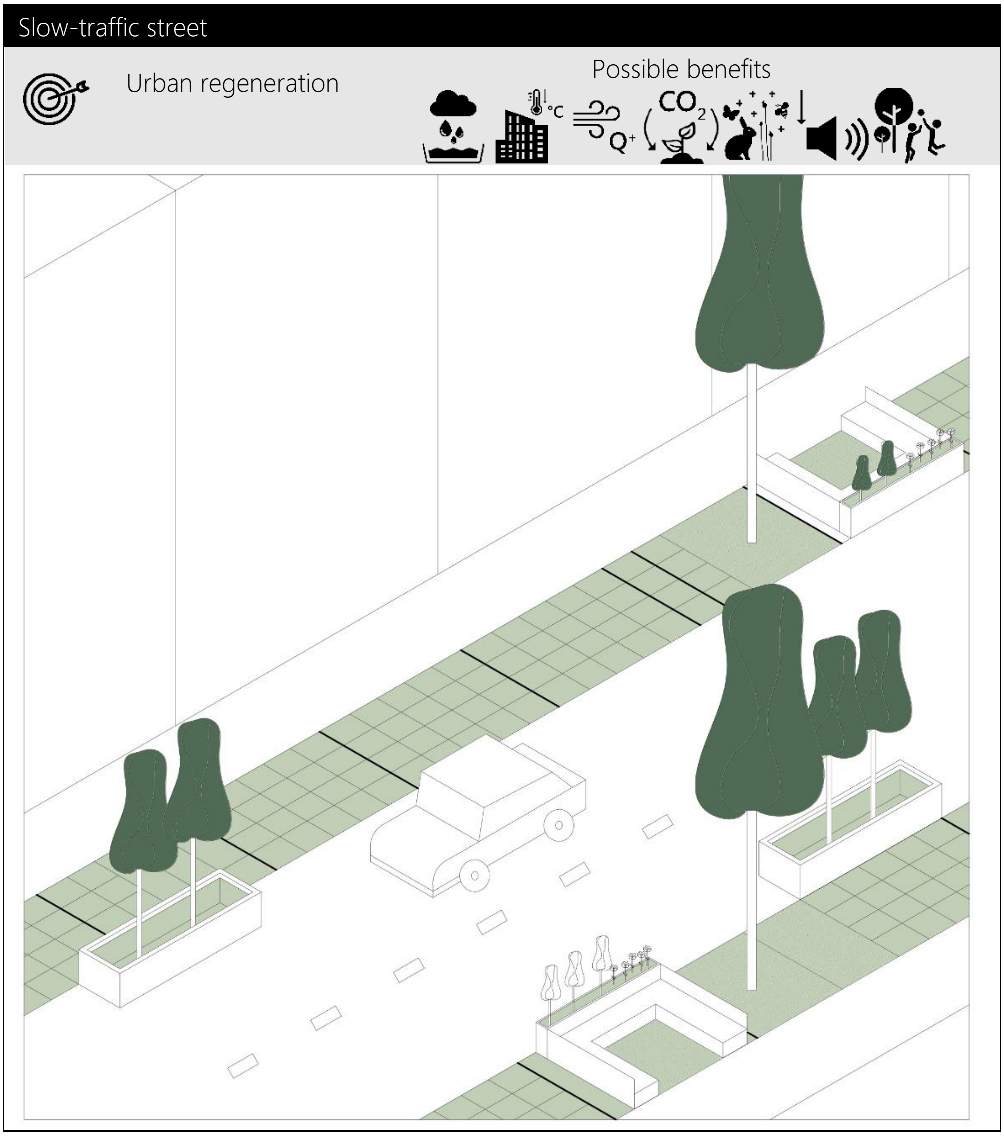


Figure 34: Slow-traffic street

MULTIFUNCTIONAL COMMUNITY GARDEN

Community gardens have been present in Europe since 1814 (Cabral et al., 2017, p. 239). Indeed, they are not new solutions. However, innovation can still occur within a community garden by providing an increased multifunctionality.

As an example, *la Ferme du Chant des Cailles* in Watermael-Boitsfort (Brussels) is a citizen cooperative constituted by an innovative community garden. It is constituted by various parcels: an urban orchard producing vegetables, fruits and flowers; a dairy sheep farm; an aromatic and medicinal plants garden; and a parcel open to experimentations of the public to garden or grow their own vegetables. In addition, close to this site, a henhouse with a compost hub is complementing this multifunctional system. The site is freely open to the public for walks and events which are regularly organised (*La Ferme du Chant des Cailles*, n.d.). This system offers a wide range of products: vegetables and fruits are sold through a subscription system which grants revival of the local economy and employment; the sheep's milk is transformed into cheese, yogurt and ice-cream; and the wool is sold as knitting yarn. Everything is produced and sold locally to promote local circularity. As part of the circularity, it is worth mentioning that the solid waste produced by the sheep, as well as dead leaves from the trees, are reused to fertilise the soil for the orchard (*La Ferme du Chant des Cailles*, n.d.).

The benefits of such a garden are diverse. The plants improve the air quality and help for water balance and carbon sequestration. Moreover, as the garden is freely accessible, recreation and proximity as well as health and well-being would be improved (Cabral et al., 2017). Definitely, social justice and cohesion is the main challenge addressed with this kind of solution.

Figure 35: Multifunctional community garden

AIR QUALITY GARDEN

An air quality garden consists of a small urban garden where plants which are sensitive to ozone pollution are placed. The leaves of these plants are discolouring when the pollution level is too high (University of Leeds, n.d.). This solution was already developed but is not referenced in any of the evaluated catalogues.

This innovative use of plants enables monitoring of air pollution, as well as raising awareness about air quality to the public. For instance, these gardens could be implemented in public green spaces near important traffic zones to illustrate to the inhabitants the effects of pollution. In order for this solution to be efficient, the choice of plants to be integrated in the air quality garden is crucial. Examples of sensitive plants and herbs are snap beans, wheat, and white clover. High levels of pollution will appear on these plants respectively through bronze, yellow and white spots discolouring the leaves (University of Leeds, n.d.). An air quality garden thus provides an indication of the pollution level, but also provides local production of food if growing edible herbs. As an example, such garden was implemented in the Sheffield Botanical Garden, United Kingdom (University of Leeds, n.d.).

The benefits provided would be water balance and carbon sequestration, thanks to the plants. By indication of air pollution, it can also indirectly affect health and well-being. This solution can be promoted in order to address the challenge of air quality improvement by educating the population.

Air pollution garden in Sheffield Botanical Garden, United Kingdom

Figure 36: Air quality garden

PERI-URBAN ECO-PRODUCTIVE PARK

As a combination of various elementary NBS, a peri-urban eco-productive park can be considered as an innovative solution. This park, as its name indicates, would be present at the periphery of Brussels and would locally produce food for the city and the neighbourhood.

Inspired by a project developed within Brussels[65], a peri-urban eco-productive park can include various types of intervention. Urban farming systems including greenhouses and orchards are intended for local food production. In addition, the park would include water management elements such as systems harvesting rain and water infiltration complemented by waterfalls. Recreational spaces, along with cycle and pedestrian lanes, can be foreseen. Moreover, in order to connect the peri-urban park with the surroundings, a green bridge for wildlife is planned (Loeckx et al., 2016, pp. 94–111).

This solution would have several positive impacts such as biodiversity increase and improved health and well-being by enhancing quality of life of local residents. A decrease of flooding risk is also expected thanks to water balance (Loeckx et al., 2016, pp. 94–111). This solution is an innovative way to tackle circular economy against wastefulness.

[65] Metropolitan landscapes – "Le relief de la vallée du Molenbeek comme base d'un parc productif / Het reliëf van de Molenbeekvallei als basis voor een productief park".

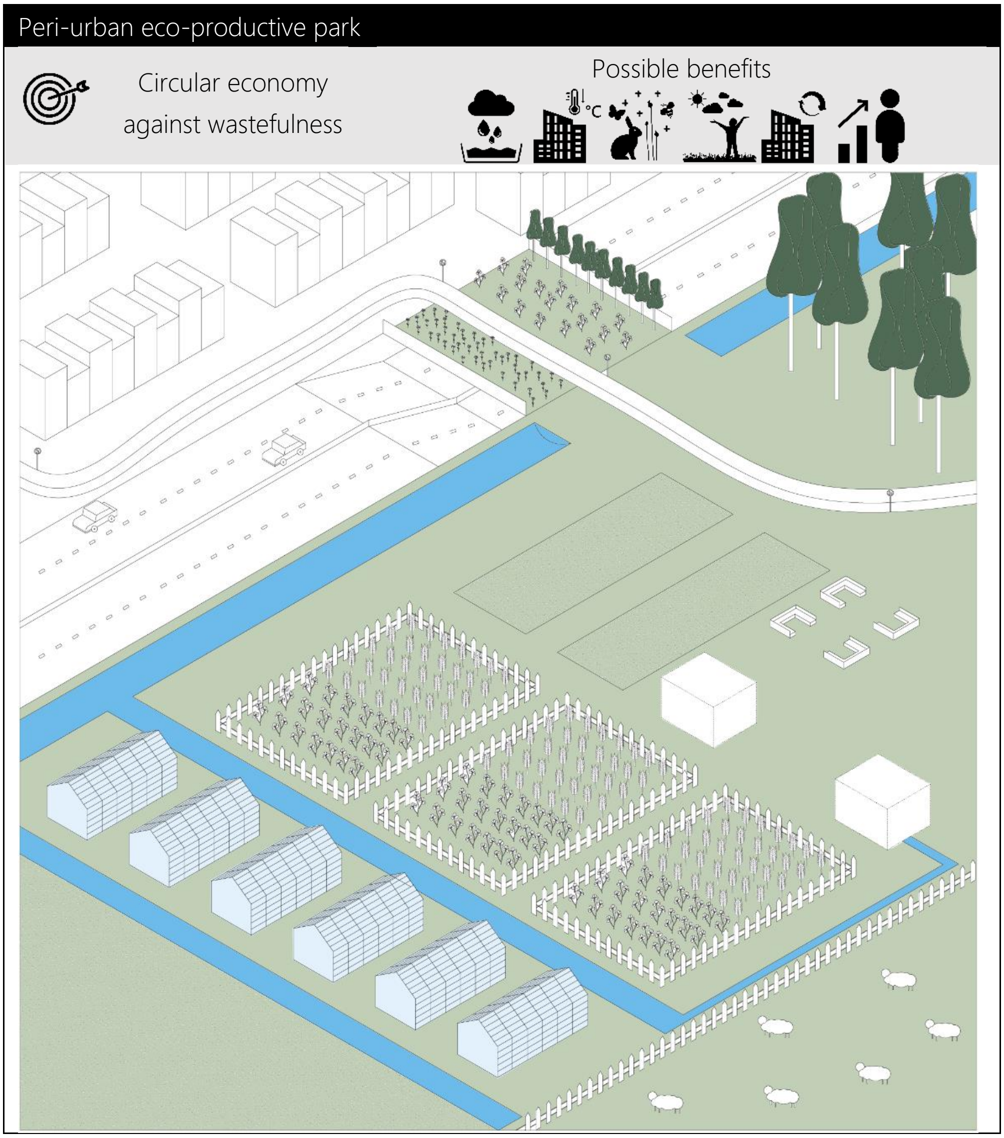


Figure 37: Peri-urban eco-productive park

SEMI-NATURAL UNDERGROUND INFILTRATION SYSTEM

Public green spaces offer the opportunity to apply underground infiltration systems. A case study of an ongoing project developed in Brussels enabled identification of this solution, which is not referenced in the existing evaluated catalogues.

This solution was identified through the project *Tour & Taxis Park* designed by Bureau Bas Smets architects (*TOUR & TAXIS PARK*, n.d.). As part of the design of the park, they integrated an underground infiltration system. This system consists of a semi-natural buffer volume that allows the water to infiltrate slowly into the ground. This buffer volume was created by an underground stone-pocket complemented on the surface by a grass field to increase the permeability and to allow the system to be efficient (De Bruyne & de Harven, n.d.; *Parc Tour & Taxis | Opalis*, n.d.). This idea of a stone-pocket arose from the fact that the parcel of land to be transformed into a park consisted mainly of stones and gravel, as the site used to be an important railway connection. The soil was then sieved in order to reuse these materials. The bigger stones were used to create the infiltration system, and the smaller gravel, as well as the rest of the ground, contributed to the shaping of the relief of the park (*Parc Tour & Taxis | Opalis*, n.d.).

As benefits, this system undoubtedly increases the water balance of the area. Moreover, thanks to the grass field, recreation and proximity space is provided for inhabitants. One could install a semi-natural underground infiltration system in order to answer the issue of flood control.

Semi-natural underground infiltration system

Flood control

Possible benefits

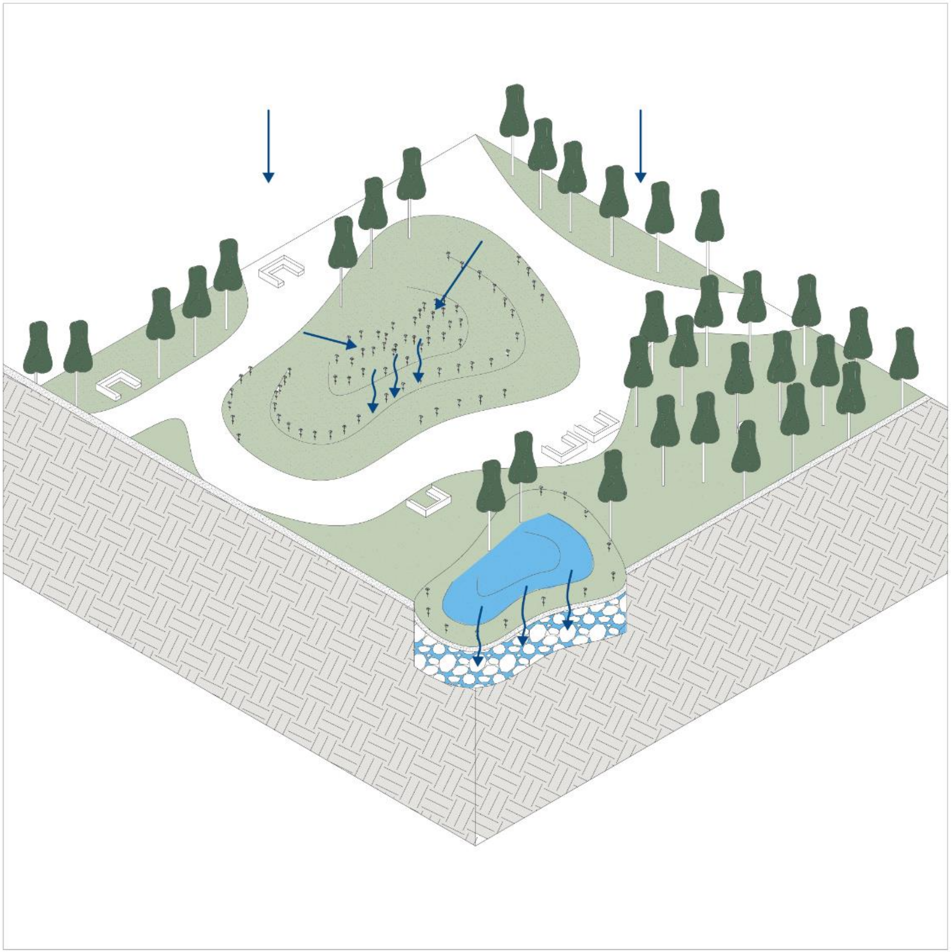


Figure 38: Semi-natural underground infiltration system

URBAN EDUCATIONAL TRAIL

The urban educational trail is an innovative solution that was identified thanks to an existing case study in Germany. It combines various solutions for natural and educational purposes and is not reported in any of the evaluated catalogues.

In Münster (Germany), an existing promenade has been rehabilitated with the aim of enforcing the site with various NBS, as well as educating citizens about these solutions. This trail provides a green corridor which connects the city with the adjacent green spaces (*Educational Nature Trail*, 2017b). Thanks to the rehabilitation of the trail, pervious pavements were used for the paths and new urban trees were planted. The trail is bordered by hedges and meadows are available either as recreational space, or as livestock grazing for larger ones. The educational purpose is achieved thanks to informative stations explaining the roles of the various natural elements (*Urban Ecology Trail*, n.d.). This solution could be further developed by the integration of rain gardens to illustrate how nature can act as a water management element. Implementing this kind of trail in public green spaces could be a good manner to sensitise the population about NBS, as well as to incorporate and combine them there.

Benefits such as biodiversity, urban regeneration and recreation and proximity would be provided through this solution. Urban regeneration can be defined as the main addressed challenge.

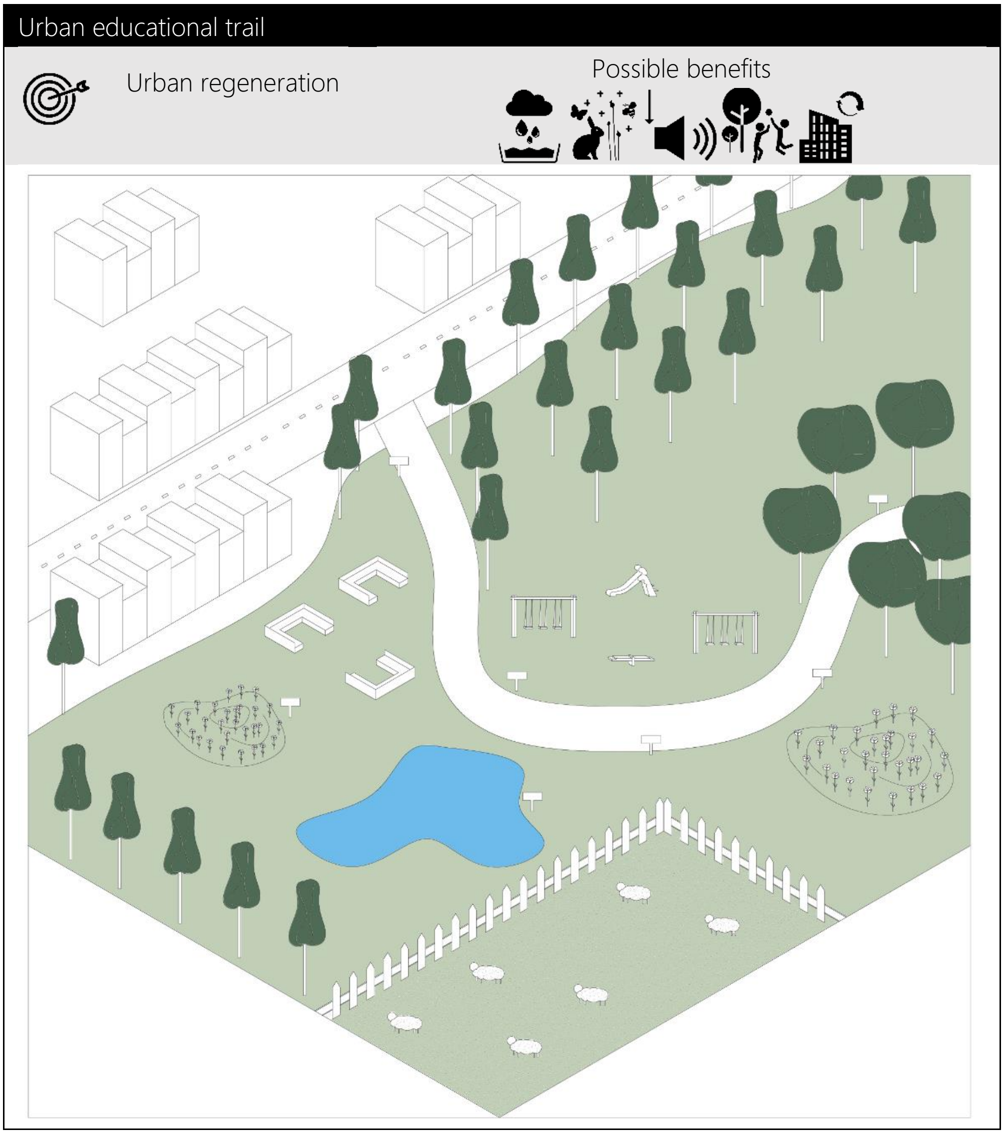


Figure 39: Urban educational trail

TRANSVERSAL NBS

BLUE-GREEN ECO-DISTRICT

An eco-district implies the application of NBS at every urban planning element comprised within a district. It is probably for this reason that this solution is left out of many catalogues since it is then more difficult to be categorised. Various typologies of eco-districts can be defined as, for instance, the blue-green eco-district.

As an example, the *Hammarby Sjöstad* district in Stockholm combines buildings with green roofs and green courtyards, and streets with pedestrian and bicycle networks. Micro-gardens, small greenhouses and bigger parks constitute the green network of the district which is linked by an eco-duct to the close natural reserve. In addition to that, several water management measures are allotted throughout the district with a high aesthetical quality. Moreover, various technical systems were installed concerning the collection of household waste which is locally incinerated to create bioenergy and electricity (*Hammarby Sjöstad*, 2017a; Ignatieva & Berg, 2014). This combination with technical grey systems strengthens the innovative character of this solution.

The transversal solution of the eco-district offers the opportunity to address various challenges the area is facing. In the case of the blue-green eco-district, the main challenge addressed is flood control. Several benefits such as water balance, heat stress reduction, carbon sequestration and urban regeneration are provided through a blue-green eco-district.

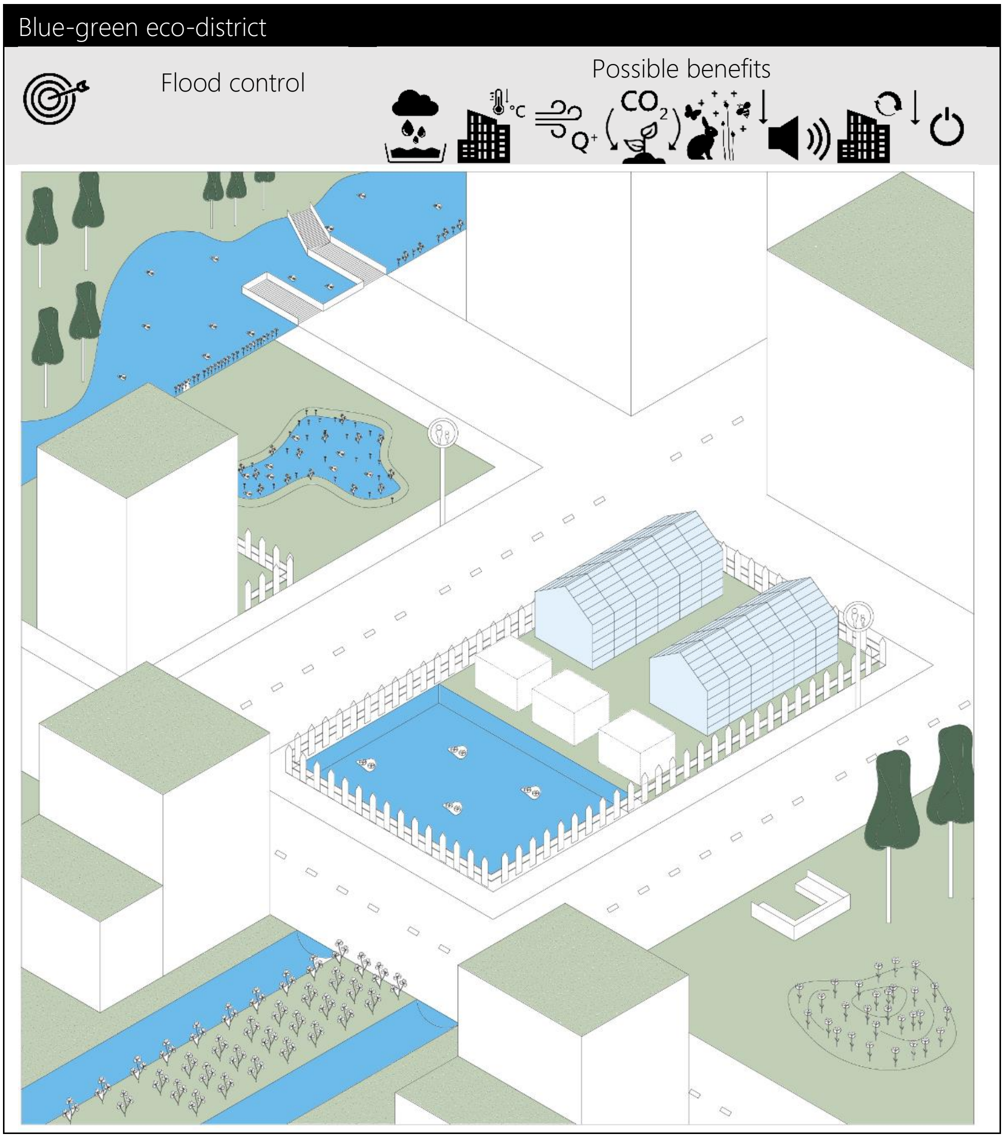


Figure 40: Blue-green eco-district

TRANSVERSAL NBS

HOUSE-STREET-PARK CASCADE

Sustainable urban drainage systems (SUDS) are an example of progressively well-known innovative NBS. They consist in a combination of various measures regarding the drainage of water (Poleto & Tassi, 2012). Various SUDS have already been developed and they are already present in existing catalogues. However, they consist in broad solutions within which several typologies could be defined. The house-street-park cascade, as well as the following solution, constitute two examples tailored to the denser fabric of Brussels. Both of them are partly inspired by typologies developed by P. Stessens (Stessens, 2018, pp. 157–195).

The house-street-park cascade typology would consist in a combination of NBS applied, as its name indicates, at three levels. Private buildings would integrate green roofs as the first element for managing rainwater by slowing it down. The water could then either be collected and reused inside the building (e.g., rainwater can be reused for flushes), or be redirected to the street. There, street swales would collect and infiltrate the water. These could be implemented by replacing some parking spots. Left parking spaces could also be covered by permeable pavements to complement the system. If overflow occurs, the surplus water originating from the swales would be redirected to neighbourhood parks where a floodplain would have been developed.

This system would have many benefits in addition to water balance, such as biodiversity and heat stress reduction. The aim of SUDS is to address the flood control challenge.

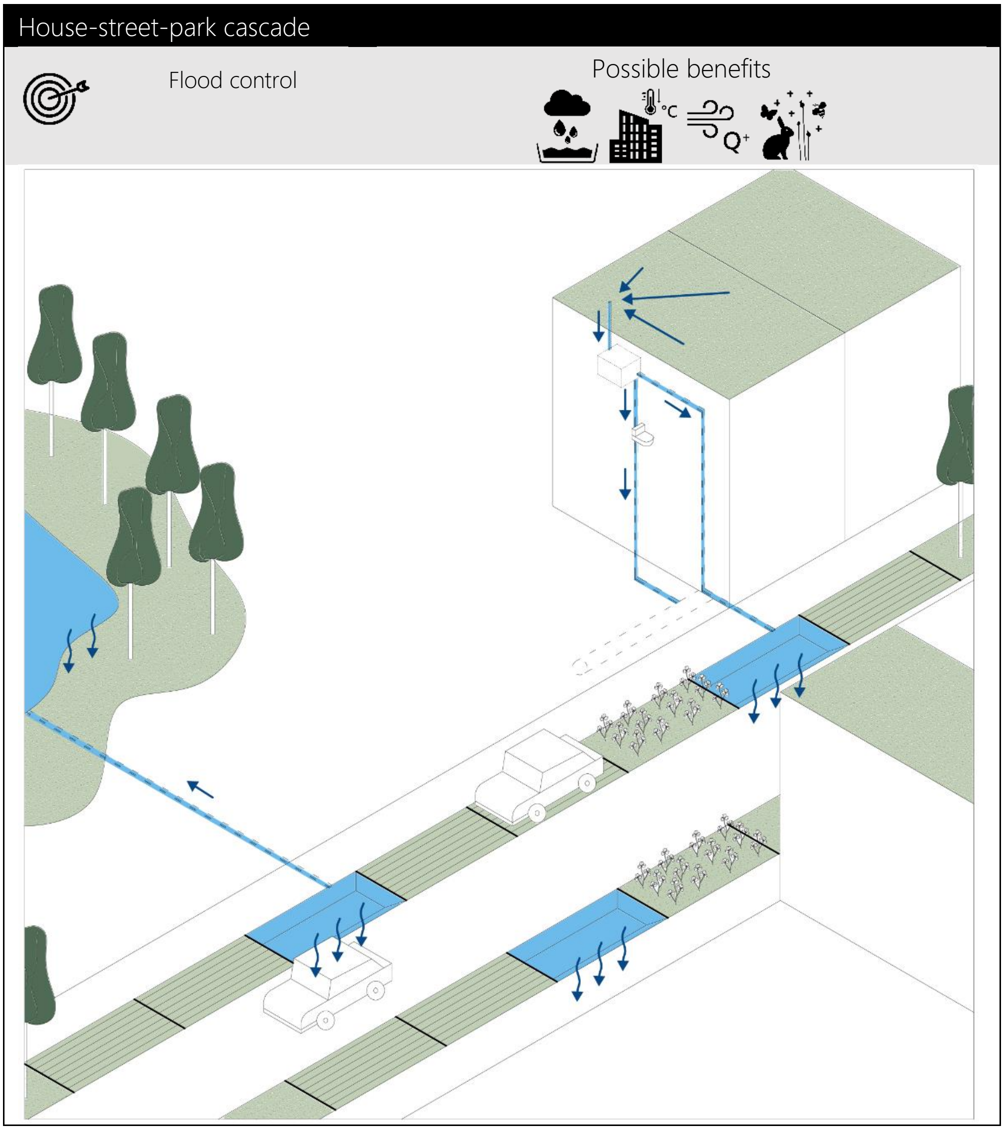


Figure 41: House-street-park cascade. The blue arrows are illustrating the water flow.

TRANSVERSAL NBS

HOUSE-BLOCK-STREET CASCADE

As mentioned in the previous solution, this transversal NBS is a specific typology of SUDS tailored to the dense fabric of Brussels. However, this one considers an additional level: the building block. Indeed, several neighbourhoods of Brussels are constituted by green intra-island building blocks which offer other opportunities.

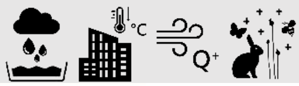
Such as the house-street-park cascade, private buildings would integrate green roofs as the first element to slow down the water, to collect it and eventually redirect it to the inner block gardens. There, small ponds and bioswales could be installed to further collect and infiltrate the water. However, as gardens are generally private, it could be too ambitious to consider that inhabitants would implement these solutions. A solution could then be to implement a common semi-private green space within the building block. This concept could be supported by local incentives. In order to complete the system if overflow occurs, street swales and porous pavements for parking spots would help collect stormwater.

This system would have similar benefits to the previous solution. The aim of SUDS is to address the flood control challenge.

House-block-street cascade

Flood control

Possible benefits



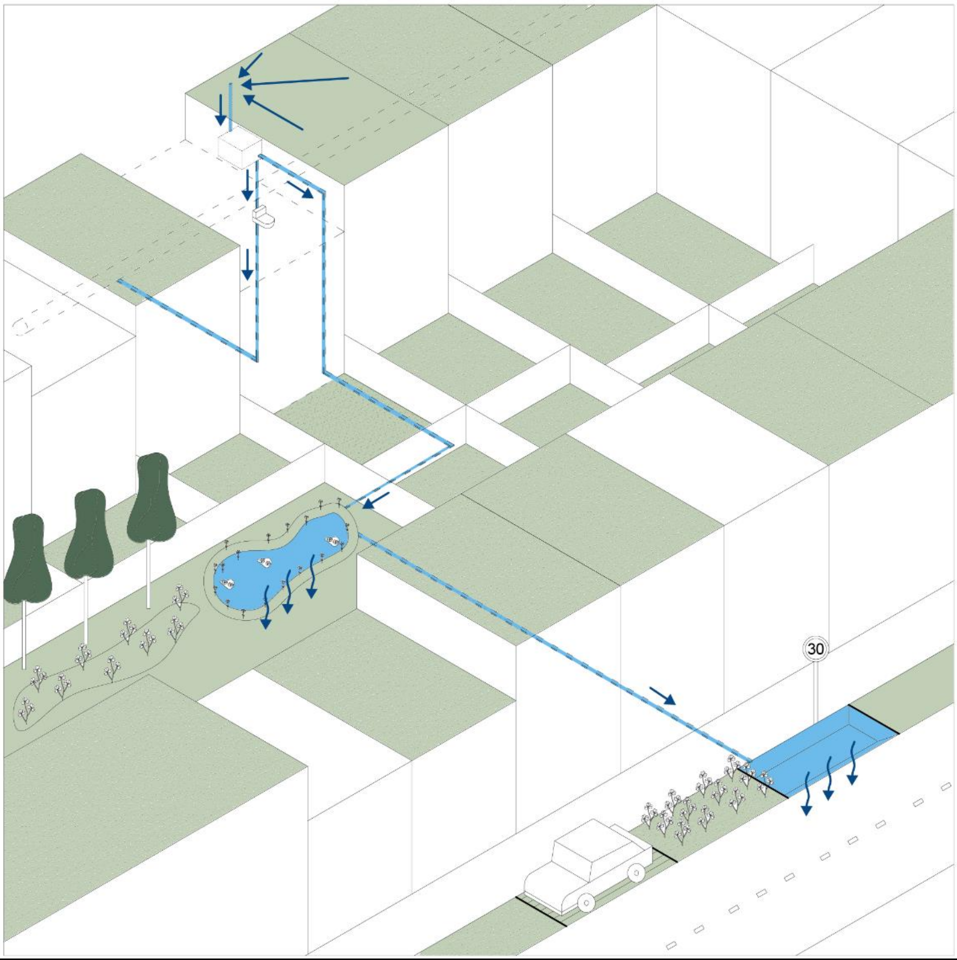


Figure 42: House-block-street cascade

URBAN FOOD PRODUCTION SYSTEM

The idea lying behind the previously mentioned peri-urban eco-productive park could be applied to a denser network inside the city, and generate an urban food production system. This system would aim at providing food to the city from its core by implementing various NBS at different urban typologies.

This innovative NBS could be composed at buildings by urban rooftop farming with an adjacent beehive rooftop garden and vertical farming occurring on the façade. In the streets, fruit trees may be planted. Their flowers could be pollinated by the bees to produce fruits and honey. Finally, public green spaces or squares could integrate community gardens and compost hubs complemented by urban orchards to complete the system.

This kind of system would have similar impacts to the peri-urban eco-productive park, which contributes to water management, biodiversity and human well-being. However, by this implementation in the urban context, this NBS could better address the challenge of local and diverse employment.

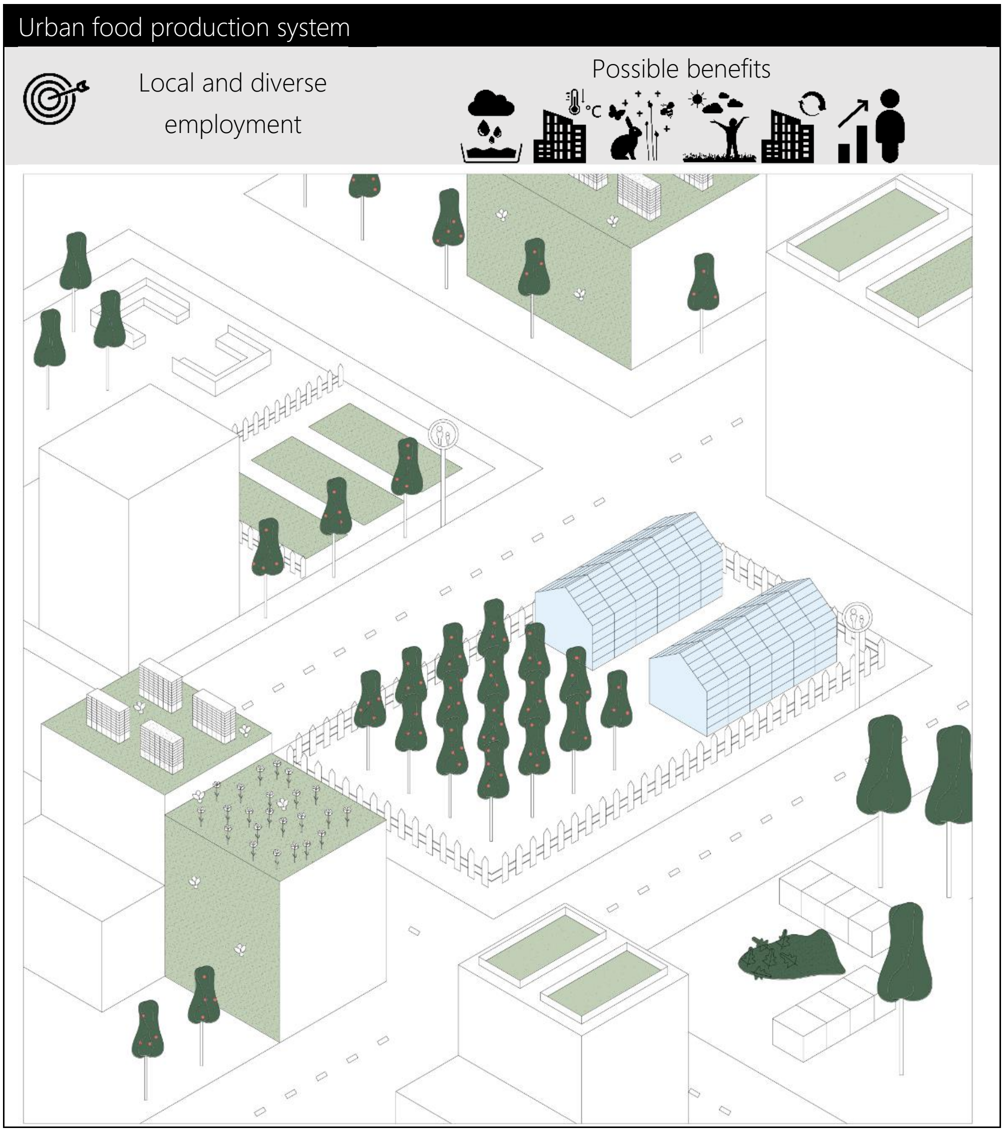


Figure 43: Urban food production system

7.3. Detailed innovative NBS

As previously mentioned, a selection of innovative NBS to be detailed is presented in this section. This selection was performed according to various criteria: the solutions can be directly applied to Brussels; they were not developed in existing evaluated catalogues; and enough data can be collected on them. As a result, the three following solutions will be developed further: productive aquaponics building, vertical forest, and car-free residential street. The aim is to develop the overview sheets and the factsheets of these solutions, as defined in Section 6.3. Therefore, a summary of the additional information required is exposed in this section.

7.3.1. Productive aquaponics building

This NBS was identified through the project *Ferme Abattoir* located in Anderlecht, Brussels. As previously mentioned, this project was developed by BIGH Farms and designed by Org Architects. Therefore, additional characteristics could be defined thanks to information from their respective websites (*About | BIGH Farms*, n.d.; *Food Processing Center and Markets, Brussels*, n.d.). From these, a general and technical description, including the implementation requirements, were retrieved. Graphic details and illustrations are also delivered through these websites. Concerning the (co-) benefits, a report on aquaponics was reviewed (Beckers, 2019). However, it only mentions some benefits without any valuation of them.

For further development of the productive aquaponics building, a correct performance of the NBS should be retrieved for each benefit by monitoring on site the effects of such a solution. In addition, the economic characteristics will also have to be compelled and adjoined to the factsheet.

7.3.2. Vertical forest

Additional information about vertical forests could be determined through the reference project of *Bosco Verticale*, first developed in Milan. This project was designed by the architect Stefano Boeri and has now been adapted worldwide (*Vertical Forest*, n.d.; *Vertical ForestING*, n.d.). Thanks to these multiple examples, a general and technical description, as well as illustrations, could be retrieved. Moreover, a book on vertical greenery is compiling various data on vertical forest (Giacomello & Valagussa, 2015). This book helped to complement the technical description with further implementation requirements. Benefits of such solutions, however without their respective performance, are provided. In addition, a detailed maintenance description is given with partial information on the maintenance costs. In order to complete the factsheet of the vertical forest, additional research on economic characteristics, such as the construction costs or the amortisation term, should be performed.

7.3.3. Car-free residential street

As a typology of neighbourhood streets, the solution of residential street can be supported by the *Rijke Beukelaarstraat* located in Antwerp, which is referenced on the Groentool of Antwerp (*Green Measures | Groentool*, n.d.). Thanks to this tool, a general description, as well as a graphic illustration, are provided. In addition, the benefits with their respective performance are outlined by the tool. Moreover, as this solution is combining various elementary NBS, a more technical description including the implementation requirements could be retrieved thanks to the ones delivered for the separate elements. For this, as mentioned in Section 5.2, data from evaluated catalogues were used. Construction costs as well as maintenance costs and description were obtained the same way. However, the amortisation term is concerning the whole solution and therefore it should be further investigated in the future in order to be able to adjoin this information to the catalogue.

8. Digitalisation of the flexible search tool

As previously mentioned, with the purpose of providing a user-friendly catalogue, a digital flexible search tool will be complementing the paper version of the catalogue. The ideal search tool should include three filters: the user's project's scale, the user's project's location, and the user's personal interests. These specifications were highly prioritised according to the personas. After filling out the tool, the user would get a list of the few very effective urban NBS obtained by these filters. However, in the scope of this thesis, the local performance of each NBS will not be included since the demand and suitability maps have not been realised yet by CO-NATURE. Hence, the realised search tool will only consist of two filters. In order to develop this tool, Microsoft Excel was used. The aim is that the proposed tool will act as a basis that can be used for further developments throughout the CO-NATURE project, which lasts until 2022. This chapter will encompass the example demonstrating the methodology of the tool and future possible improvements of it.

8.1. Example demonstrating the tool's methodology

When a user runs the model, the aim is to provide the best suited solutions. For that purpose, this model takes into account the urban planning element corresponding to the project's size as well as the user's personal interests. Thanks to these specifications, the model will select the suited solutions and will rank them from the least performant one to the most.

After receiving the list of possible NBS, the user can consult the overview sheets in the paper version of the catalogue containing the most important characteristics of each solution. This allows a first and quick comparison. In the case that this does not yet make his choice final, he can further consult the factsheets to look up more detailed information.

In order to demonstrate the methodology of the Excel file both from the user's point of view and from the tool's point of view, one of the personas is used.

Urban planner	Pete, 33 years old
Background - Socially involved - Problem-solver - Curious about innovation	Goals: - Increase the environmental resilience of Brussels - Make Brussels more pleasant for its inhabitants
Current project - Small-scale green zones throughout Sint-Jans-Molenbeek and Anderlecht - Need for pleasant gathering places for the citizens - Increase safety feeling - Total budget is €1,000,000	Reasons for consulting the proposed catalogue - Find cost-effective small-scale green solutions - Look for possibilities to increase the biodiversity

Figure 44: Example of the urban planner persona

The priority specification given by Pete is the size of the project he is working on; small-scale green zones throughout the city. As a first step, he will need to indicate this size by selecting one subcategory[66] from a list. The urban planning elements corresponding to his project are *avenues, boulevards and chaussées*, *public squares*, *neighbourhood parks* and *transversal NBS*. In this case, the first subcategory will be indicated (see Figure 45). The tool will then solely continue with the urban NBS categorised under this subcategory. Once Pete has checked these boxes, he can assign his value of importance to each benefit. Since the maps of CO-NATURE cannot be implemented yet, the methodology to take into account Pete's interests slightly differs from the ideal version. The tool will multiply the performance of the NBS towards each benefit with the value of importance given to each benefit by Pete. These values can range from 0 to 5 corresponding to respectively no importance at all to high importance[67]. This way, a weighed total performance of each NBS is calculated. Pete will thus assign a value of 5 to 'recreation and proximity' and to 'biodiversity'. Furthermore, he can assign a value of 3 to 'health and well-being' and 'urban regeneration' (see Figure 46). If he does not want to take into account the other benefits, he assigns the value 0 to them or leaves the cell blank. Once done, he hits the button 'APPLY' and the list of suited NBS is

[66] In the future, he should be able to indicate more subcategories. However, this is not possible in the current tool.

[67] These values were chosen to correspond to the scale of valuation of the performance of the benefits.

returned. This list is ranked according the total efficiency of the solution in response the user's personal valuation (see Figure 47).

	Buildings : Horizontal elements	Buildings : Vertical elements	Buildings : Private surrounding plot	Transport linear infrastructure : Neighbourhood streets	Transport linear infrastructure : Bicycle and pedestrian paths	Transport linear infrastructure : Avenues, boulevards and chaussées	Public squares
Indicate the project's size						X	
						X	

Figure 45: Indication of the subcategory. Remaining subcategories are cropped from this figure.

Importance of Benefits from 0 to 5	
Water balance	
Water quality	
Heat stress reduction	
Air quality	
Carbon sequestration	
Soil quality	
Biodiversity	5
Sound	
Recreation & proximity	5
Public health & well-being	3
Participation	
Urban regeneration	3
Local employment	
Lowering energy consumption	

0 1 2 3 4 5

APPLY RESET

Figure 46: Indication of the valuation of the benefits

NBS	Main challenge	Construction Cost	Local employment	ering energy consumption	Efficiency Solutions
Eco urban furniture	Social justice & cohesion	160/m²	4		61
Line of tall trees	Heat wave impact control	4-12000/tree	2		60
Single tall tree	Heat wave impact control	4-12000/tree	2		55
Green resting area	Public health & well-being	40-60/m²	4		55
Green noise barrier	Noise control	600-900/m²	2		52
Rain garden	Flood control	40/m²	2		50
Single small tree	Heat wave impact control	4-12000/tree	2		50
Single medium high tree	Heat wave impact control	4-12000/tree	2		50
Line of small trees	Heat wave impact control	4-12000/tree	2		50
Line of medium high trees	Heat wave impact control	4-12000/tree	2		50
Bioswale	Flood control	10-60/m³	2		45
Green tree lane with front yards	Heat wave impact control				40
Mobile living wall	Heat wave impact control	550/m²	3		38
Green shading structure	Heat wave impact control	900-1000/m²	3		34
Decidious hedge	Flood control	10-100/m²			30
Green-blue two-way street with central r	Heat wave impact control				30
Evergreen hedge	Flood control	10-100/m²			20
Vegetated fence	Noise control	10-100/m²			20
Mobile living room	Heat wave impact control				20
Vegetated grid pavement	Flood control	30-90/m²	3		19
Vegetated modular pavement	Flood control	20-95/m²	3		15
Green bus shelter	Lowering energy consumption	14500/shelter		3	15
Mobile moss wall	Air quality improvement				10
Permeable asphalt	Flood control	10-100/m²			0
Smart soil as pavement substrate	Air quality improvement	50-80/m³			0
Green-blue wide street with water eleme	Flood control				
Green tram infrastructure	Heat wave impact control				

Figure 47: Resulting ranked list of suited urban NBS. The last column indicates the total weighed efficiency of each solution. The inner columns showing the other benefits are hidden in this figure.

Hereafter, Pete can consult the overview sheets and factsheets of the proposed solutions. If he wants to do a new search, he can hit the button 'RESET' and all the input is emptied for him to start again.

In order for this to work, a separate sheet, which will be locked for Pete, includes the datasheets. It contains the entire list of urban NBS with their corresponding urban planning element, their main addressed challenge, their construction costs and the performance of each concerning the benefits. All assigned values can be easily adapted in the future if needed.

Figure 48 and Figure 49 give a summary of the procedure from both the user's point of view and from the tool's point of view.

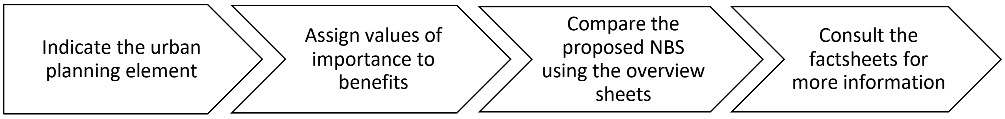


Figure 48: Step-by-step procedure from the user's point of view

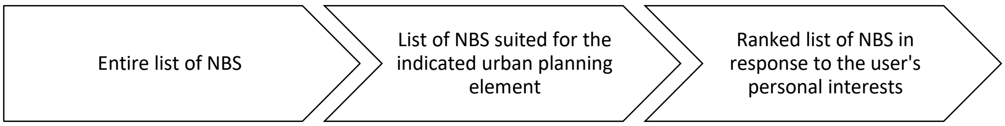


Figure 49: Step-by-step procedure from the flexible search tool's point of view

8.2.Future improvements

Future improvements include the implementation of the data of the CO-NATURE project regarding the location's challenges. This way, both the recorded challenges as the user's personal objectives can be taken into account. Moreover, the implementation of this data allows the indication of the default values of importance for each benefit. The user can then specifically choose to change these. In addition, the total weighed efficiencies of the NBS should ideally be translated to percentages. This then allows the tool to only select solutions that have a total weighed efficiency higher than, for example, 70%. As a result, low efficiency solutions would not be shown to the user. Once the Excel file runs perfectly, the flexible search tool can be translated to a web application. This application can then better visualise the proposed NBS and can create direct connections to the overview sheets, the factsheets and the datasheets.

9. Proposed catalogue of NBS

9.1. Datasheets

Datasheets allows the user to have a global view on all urban NBS. It solely contains the user's prioritised information: the main addressed challenge, the (co-) benefits and the construction costs.

This section contains the datasheets including hundred urban NBS that can be applied to a city, or more specific to Brussels. The NBS of every analysed catalogue were critically compared to each other. NBS which are unsuited for Brussels were omitted such as 'coastal interventions'. Furthermore, solutions such as 'sustainable urban drainage systems' were omitted as well because these are a combination of different types of NBS and do not represent one clear solution. In addition, some catalogues use different phrases for the same type of NBS, which is why some of them were combined into one solution for the to-be-proposed catalogue. Lastly, NBS that were not provided with enough information were neglected. Nonetheless, an exhaustive Excel file has been prepared that allows an easy completion of missing information in the future.

Furthermore, the performance of an NBS with regards to its (co-) benefits was analysed. Values of performance towards certain challenges coming from URBAN GreenUP were linked to the defined benefits. In the case of UNaLab, the scale of valuation was adjusted to the defined scale for the to be drafted catalogue. CLEVER Cities does not provide a scale of valuation. Here, values of 3 and 2 were assigned to respectively the main and secondary given strategy. Klimatek on the other hand does give the performance with regards to benefits but does not assign any number. In this case, the performance was indicated to be positive. However, Klimatek does mention the performance with regards to climate threats. Values of 5, 3 and 2 were assigned to respectively 'very high', 'high' and 'medium' performances. Finally, M. Kawa applies the same scale as defined for the to-be-proposed catalogue which allowed an easy indication of performance.

Thirdly, the found construction costs are given as well. These are shown in €/m² and have different ranges. Hence, these need to be further specified through additional research.

In the drafted datasheets, empty cells do not imply a zero cost or performance but indicate unfound values. Furthermore, none of the analysed catalogues clearly indicate references of the given values. In order to provide reliable information, values of different catalogues were combined. In the future, the given values can be further verified and new ones can be added through expert assessment and research.

Legend			
Benefits		Performance of benefits	Additional information
Water balance	Recreation & proximity	▫▫▫▫▫ Zero performance	Main challenge
Water quality	Public health & well-being	▪▫▫▫▫	
Heat stress reduction	Participation	▪▪▫▫▫	Construction cost
Air quality	Urban regeneration	▪▪▪▫▫	
Carbon sequestration		▪▪▪▪▫	
Soil quality		▪▪▪▪▪ Excellent performance	Environmental
Biodiversity	Local employment	• Positive unknown effect	Social
Sound	Lowering energy consumption	– Possible negative effect	Economic

Figure 50: Legend of the datasheets

Buildings																	
Horizontal elements																	
1	Intensive green roof	Heat wave impact control	€350/m²	■■■■□	■□□□□	■■■■□	■■■□□	■■■□□		■■■□□	■■■■□	■□□□□	■■□□□		■□□□□	■■■□□	■■■■□
2	Semi-intensive green roof	Heat wave impact control	€250/m²	■■■■□		■■■□□	■□□□□	■■□□□	□□□□□	■■□□□	■■■■□	■□□□□	■■□□□		■□□□□	■■■□□	●
3	Extensive green roof	Heat wave impact control	€75/m²	■■■□□		■■□□□	□□□□□	■□□□□		■■□□□	■■■■□	□□□□□	■■□□□		■□□□□	■■■□□	■■□□□
4	Semi-intensive smart blue-green roof	Flood control	€100-800/m²	■■■■■	●	■■■■■	●	■■□□□		■■■■□	■■■■□		■■□□□	■■□□□	■□□□□	■■■□□	●
5	Extensive smart-blue green roof	Flood control	€60/m² (excl. Inst)	■■■■■	■■□□□	■■■■□	■□□□□	■□□□□		■■■■□	■■■■□		■■□□□	■■□□□	■□□□□	■■■□□	■■■■□
6	Extensive wetland roof	Flood control		■■■□□	■■□□□	■■■■□	■■□□□										■■■■□
7	Pollinator green roof	Biodiversity	€60-90/m²	■■■□□		■■■■□	■■□□□			■■■■■			■■■■□	■■■□□	■■■□□	■■■□□	■■■■□
8	Green covering shelter	Lowering energy consumption	€60-100/m²	■■■□□		■■■■■	■■□□□			■■■□□			■■□□□		■□□□□	■■■□□	■■■■■
Vertical elements																	
9	Ground connected green facade	Air quality improvement	€80-150/m²	■■□□□	■■■□□	■■■□□	■■■□□	■■□□□	●	■■■□□	■■□□□	■■□□□	■■■■□		■■■■□	■■■□□	■■■■□
10	Independent green facade	Air quality improvement	€450-750/m²	■□□□□		■□□□□	■□□□□	■□□□□		■□□□□	■■■□□	■■□□□	■■■■■		■■■■□	■■■□□	□□□□□
11	Pollinator green facade	Biodiversity	€250-800/m²			■■■■□	■■■■□			■■■■■			■■■■■		■■■■□		■■■■□
12	Hydroponic green facade	Air quality improvement	€250-800/m²			■■■■□	■■■■■			■■■■□			■■■■■		■■■■□	■■■□□	■■■■□
Private surrounding plots																	
13	Evergreen hedge	Flood control	€10-100/m²	■■■■■		■■□□□	■□□□□	■■□□□	●	■□□□□	■■■□□	■■■□□					
14	Decidious hedge	Flood control	€10-100/m²	■■■■□		■■□□□	■□□□□	■■□□□	●	■■■□□	■■□□□	■■■□□					
15	Vegetated fence	Noise control	€10-100/m²	■□□□□		■□□□□	■□□□□	■□□□□	●	■■□□□	■■□□□	■■□□□					
16	Green paved parking	Flood control	€30-90/m²	■■■■□	●	■■□□□	■■□□□						■■□□□		■■■□□	■■■□□	
17	Electro wetland	Water quality	€150/m²	■■■■□	■■■■□	■■■□□	□□□□□			■■■□□		□□□□□			■□□□□	■■□□□	
18	Biofilter for air purification	Air quality improvement	€3000-3500/m²			■■■■□	■■■■□						■■■■□		■■□□□	■■□□□	
19	Biofilter for water purification	Water quality		■■■□□	■■■■□					■□□□□							
20	Wood chips pavement	Flood control	€10-100/m²	■■■□□		□□□□□	□□□□□	□□□□□		■■□□□	■■□□□	□□□□□					
21	Accessible and educative green school grounds	Social justice & cohesion		●								●	●				
22	Productive aquaponics building	Circular economy against wastefulness		●	●	●		●		●			●			●	●
23	Productive honey building	Biodiversity		●		●		●		●							
24	Vertical forest	Air quality improvement		●		●	●	●		●	●		●		●		●

Transport linear infrastructure																	
Neighbourhood streets																	
25	Vegetated grid pavement	Flood control	€30-90/m²	■■■□□	■□□□□	■□□□□	□□□□□	□□□□□		■■□□□	■■□□□	□□□□□		■■□□□	■■■□□	■■■□□	
26	Permeable asphalt	Flood control	€10-100/m²	■■□□□	■□□□□	□□□□□	□□□□□	□□□□□		□□□□□	■□□□□	□□□□□					
27	Vegetated modular pavement	Flood control	€20-95/m²	■■■■□	●	■■□□□	■■□□□						■■□□□		■■■□□	■■■□□	
28	Green shading structure	Heat wave impact control	€900-1000/m²	■■■□□		■■■■■	■■□□□			■■■□□		●	■■□□□		■□□□□	■■■□□	
29	Smart soil as pavement substrate	Air quality improvement	€50-80/m³	■■■□□	●		■■■■□	■□□□□									
30	Green one-way street with front lawns and street gardens	Heat wave impact control		■■□□□		■■■□□	■■□□□	■■□□□		■■■□□	■■■□□						
31	Green two-way street with front lawns	Social justice & cohesion		■■■□□		■■□□□	■■□□□	■■■□□		■■■■□	■■□□□	■■■■□					
32	Green-blue one-way street	Flood control		■■■■■		■■■□□	■■□□□	■■■□□		■■■■□	■■□□□	■■■■□					
33	Green-blue two-way street	Flood control		■■■■■		■■■□□	■■□□□	■■■□□		■■■■□	■■□□□	■■■■□					
34	Residential street	Urban regeneration		■■□□□		■■■□□	■■□□□			■■■□□	■■■□□	■■■■□					
35	Slow-traffic street	Urban regeneration				●				●	●	●					
Bicycle and pedestrian paths																	
36	Cycle and pedestrian green pavement	Flood control	€60-100/m²	■■■□□	●	■■□□□	■■□□□						■■■□□		■■■□□	■■■□□	
37	Cycle and pedestrian green route	Public health & well-being	€40/m²	■■□□□	■□□□□	■■■□□	■■■■□					■■■□□	■■■■■		●		
38	Linear green corridor	Biodiversity		■■□□□	■□□□□	■■□□□	■■■■□			■■■■□		■■■■□	■■□□□				
Avenues, boulevards and chaussées																	
39	Bioswale	Flood control	€10-60/m³	■■■■□	■■■□□	■■■□□	■■■□□	■□□□□	●	■■■□□	□□□□□	■■■□□	■■■■□		■□□□□	■■□□□	
40	Rain garden	Flood control	€40/m²	■■■■□	■■■□□	■■□□□	■■■■□	■□□□□	●	■■■■□	□□□□□	■■■□□	■■■■□	■■■□□	■□□□□	■■□□□	
41	Single small tree	Heat wave impact control	€4-12000/tree	■□□□□		■□□□□	■■□□□	■■□□□ –		■■■■□	■□□□□	■■■□□	■■■■□		■□□□□	■■□□□	
42	Single medium high tree	Heat wave impact control	€4-12000/tree	■□□□□		■□□□□	■■□□□	■■□□□ –		■■■■□	■□□□□	■■■□□	■■■■□		■□□□□	■■□□□	
43	Single tall tree	Heat wave impact control	€4-12000/tree	■■□□□		■■□□□	■■□□□	■■□□□ –		■■■■□	■□□□□	■■■■□	■■■■□		■□□□□	■■□□□	
44	Line of small trees	Heat wave impact control	€4-12000/tree	■□□□□		■■■■□	■■■□□	■■■□□ –		■■■■□	■■□□□	■■■□□	■■■■□		■□□□□	■■□□□	
45	Line of medium high trees	Heat wave impact control	€4-12000/tree	■□□□□		■■■■□	■■■□□	■■■□□ –		■■■■□	■■□□□	■■■□□	■■■■□		■□□□□	■■□□□	
46	Line of tall trees	Heat wave impact control	€4-12000/tree	■■□□□		■■■■■	■■■□□	■■■□□ –		■■■■■	■■□□□	■■■■□	■■■■□		■□□□□	■■□□□	
47	Green tree lane with front yards	Heat wave impact control		■■■■■		■■■□□	■■□□□	■■■□□		■■■■□	■■□□□	■■■■□					
48	Green noise barrier	Noise control	€600-900/m²	■□□□□		■■□□□	■■■□□	■□□□□		■■■□□	■■□□□	■■□□□	■■■■■	■■□□□	■■■■□	■■□□□	
49	Mobile living room	Heat wave impact control				■■□□□				■■□□□		■■□□□					
50	Mobile living wall	Heat wave impact control	€550/m²			■■■■□	■■■■□			■■■■□	■□□□□		●	■■■■■	■■■■□	■■■□□	
51	Mobile moss wall	Air quality improvement				■■□□□	■■□□□					■■□□□					
52	Green bus shelter	Lowering energy consumption	€14500/shelter							■■■□□							■■■□□
53	Eco urban furniture	Social justice & cohesion	€160/m²	■■■□□	●	■■■■□	■■■■□		■■■■■	■■■□□	●	■■■■■	■■■□□	■■■■■	■■■■□	■■■■□	
54	Green resting area	Public health & well-being	€40-60/m²	■■■■■		■■■■■	■■■■■		■■■■■	■■■■■			■■■■■	■■■■■	■■■■■	■■■■□	
55	Green-blue two-way street with central reservation and parking	Heat wave impact control		■■■□□		■■■■□	■■■□□ –	■■■■□		■■■□□	■■□□□	■■■□□					
56	Green-blue wide street with water element	Flood control		■■■■□		■■■■□	■■■□□ –	■■■■□		■■■■□	■■□□□	■■■■□					
57	Green tram infrastructure	Heat wave impact control		■■■□□		■■■□□	■■□□□ –	■■■□□		■■■□□	■■□□□	■■■□□					

	Public squares																
58	Living green construction	Heat wave impact control		■■■□□		■■■□□	■■□□□			■■□□□		■■□□□	●				
59	Green roundabout with multiple trees	Heat wave impact control		■■□□□		■■■■□	■■□□□	■■□□□		■■■■□	■□□□□	■■■□□					
60	Green crossing with adult trees	Heat wave impact control		■■■■■		■■□□□	■■□□□	■■■□□		■■■□□	■■■■□	■■■■□					
61	Multifunctional community garden	Social justice & cohesion		●			●	●				●	●				
	Public opportunity plots																
62	Climate-smart greenhouse	Air quality improvement	€110-120/m²	■■■■□		■■■■□	■■■■□										
63	Community orchard	Social justice & cohesion		■■■■■		■■■■■		●	●	■■■■■		●	●		■■■■□	■■■■■	
64	Community compost hub	Local & diverse employment	€0-50/m²												■■■□□	■■■■■	
65	Small-scale urban livestock	Local & diverse employment	€ 500												■■■□□	■■■■■	
66	Beehive garden	Biodiversity	€ 400							■■■□□							
67	Hotel for insects	Biodiversity	€0-20							■■■□□							
68	Pollinator green zone	Biodiversity	€3-10/m²			■■■□□	■■■□□			■■■■□							
69	Algae production system	Carbon sequestration	€9/kg					■■■□□									■■■□□
	Public green spaces																
	Neighbourhood parks																
70	Smart soil	Carbon sequestration	€1-17/kg	■■■□□		■■■□□	■■■□□	■■■□□									
71	Residential park	Flood control		■■■■■	■■□□□	■■■■□	■■■■□	■■■□□	●	■■■■□	■■■□□	■■■■■	■■■■□		■□□□□	■■□□□	
72	Natural pollinator's module	Biodiversity	3400	■■■■□			■■■■■			■■■■■		●					
73	Compacted pollinator's module	Biodiversity	2380	■■■■□			■■■■■			■■■■■		●					
74	Air quality garden	Air quality improvement		●			●	●					●				
	Green plots																
75	Floodable plain	Flood control	€15-25/m²	■■■■□	■■□□□	■■■■□	■■■■□	■■■□□		■■□□□	□□□□□	■■□□□	■■□□□	■■■□□	■□□□□	■□□□□	
76	Green filter area	Water quality	€100/pe	●	■■■■■	■■■□□	■■■□□	■■■□□		●		●			■■■■□	■■■□□	
77	Natural wastewater treatment	Water quality	€275-450/pe	●	■■■■■	■■□□□	■■■□□			●					■□□□□	■■■□□	
78	Peri-urban park	Flood control		■■■■■	●	■■■□□	●	●	●	■■■□□	●	●	●			●	
79	Urban flower field	Biodiversity		■■■■□		■□□□□	□□□□□	■□□□□		■■■□□	■□□□□	■□□□□					
80	Agrarian field (grass, herb, heath)	Biodiversity		■■■■■		■□□□□	□□□□□	■□□□□		■■■■□	■□□□□	■■■□□					
81	Peri-urban eco-productive park	Circular economy against wastefulness			●						●			●			
82	Urban educational trail	Urban regeneration								●		●			●		
83	Semi-natural underground infiltration system	Flood control		●								●					
	Forests																
84	Decidious forest	Flood control		■■■■■		■■■■■	■■■□□		●	■■■■□		■■■■■	■■■■□	■■■□□	■□□□□	■■□□□	
85	Coniferous forest	Flood control		■■■■■		■■■■■	■■■□□		●	■■■□□		■■■■■	■■■■□	■■■□□	■□□□□	■■□□□	
86	Mixed forest	Flood control		■■■■■		■■■■■	■■■□□		●	■■■■□		■■■■■	■■■■□	■■■□□	■□□□□	■■□□□	

No.	Nature-based solution	Target	Cost	[Env: water retention]	[Env: water quality]	[Env: temperature]	[Env: air quality]	[Env: CO_2]	[Env: soil quality]	[Env: biodiversity]	[Env: noise]	[Soc: recreation]	[Soc: nature]	[Soc: community]	[Soc: urban regeneration]	[Econ: employment]	[Econ: energy]
	Waterbodies																
	Streams																
87	Daylighting	Flood control		■■□□□	■■□□□	■□□□□				■■■□□		■□□□□					
	Rivers and canals																
88	Reprofiling/Extending flood plain area	Flood control		■■■■□	■■□□□	■□□□□				■■■■□		■■■■□					
89	Branches	Flood control		■■■■□	■■□□□	■□□□□				■■■□□		■■□□□					
90	Channel widening and length extension	Flood control	€100-300/m	■■■□□	■□□□□	■□□□□				■■□□□							
91	Green mound	Biodiversity	€25-30/m²	■■■□□			■■□□□			■■■□□		■■■□□	■■□□□				
92	Floating garden	Biodiversity	€150-200/m²	■■■■□	■■■■□	■■■■□	■■■■□			■■■■■	□□□□□	■■■■■			■■■■□	■■■□□	
93	Bank reinforcement	Flood control		■■□□□	■□□□□	■□□□□				■■■□□							
94	Diverting and deflecting elements	Flood control		■■□□□	■■□□□					■■□□□		■■■■□					
	Lakes and ponds																
95	Water retention pond	Flood control	€10-60/m²	■■■■□	■■■□□	■■■□□	■■■■□			■■■□□			■■■■□		■□□□□	■■□□□	
96	Wetland	Flood control		■■■■□	■■■□□	■■■□□			●	●		■■■□□			■□□□□	■■■□□	
	Transversal NBS																
97	Blue-green eco-district	Flood control		●		●		●							●		
98	House-street-park cascade	Flood control		●		●				●							
99	House-block-street cascade	Flood control		●		●				●							
100	Urban food production system	Local & diverse employment			●						●			●			

9.2.Overview sheets

As previously mentioned, the overview sheets have for an aim to enable the user to have a rapid overview of an urban NBS and to easily compare different ones. Therefore, this level of information comprises the prioritised characteristics as well as a brief description and a picture of an applied example.

Thirteen overview sheets are compiled in this section. These were either developed on the basis of the factsheets provided by M. Kawa, either created in the case of the three innovative solutions that were previously detailed. Naturally, the final aim would be to produce overview sheets for every NBS of the catalogue.

Heat wave impact control

€ 350/m²

Building

Intensive green roof

Brief description

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The intensive green roof is the most advanced type of green roof supporting a broad range of species from herbs to small size trees.

European Parliament Wilfried Martens, Brussels © Ecoworks

CO_2

Heat wave impact control

€ 250/m²

Building

Semi-intensive green roof

Brief description

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The semi-intensive green roof system supports a variety of vegetation ranging from succulents and herbs to tall grasses. The system is relatively low maintenance but plant selection and roof design strongly affect this aspect.

LAAD semi-intensive green roof, Heverlee © Canopy Green Roofs

CO_2

Heat wave impact control

€ 75/m²

Building

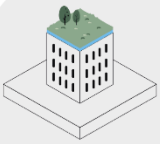
Extensive green roof

Brief description

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The extensive green roof system is relatively lightweight and usually does not entail much maintenance. It can be installed on both flat and sloped roof structures up to 45 °.

Lightweight green roof, Grimbergen © Ecoworks

CO_2



Building

Semi-intensive smart blue-green roof

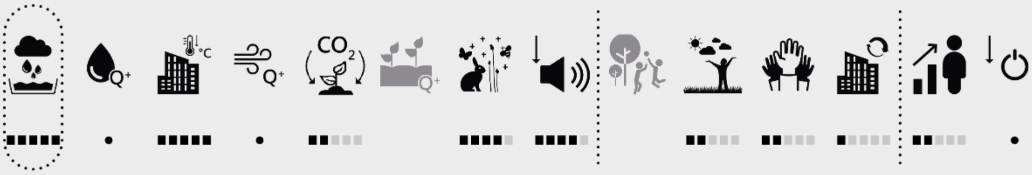
Brief description

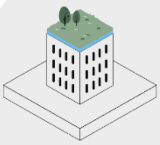
Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The smart blue-green roof system is based on water storage with a capillary irrigation system. Precipitation is captured and stored in a specific layer beneath the substrate and vegetation, equipped with an integrated fibre technology for capillary irrigation. Water travels up and is evenly distributed for absorption, making that the plants have permanent access to water and nutrients.

Semi-intensive smart blue-green roof, Amsterdam © RESILIO

Flood control

€ 100-800/ m²





Building

Extensive smart blue-green roof

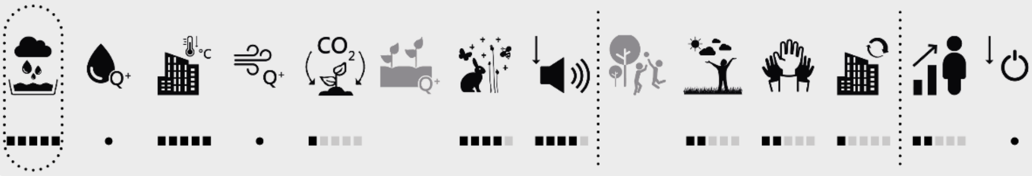
Brief description

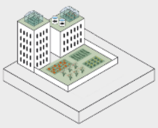
Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The smart blue-green roof system is based on water storage with a capillary irrigation system. Precipitation is captured and stored in a specific layer beneath the substrate and vegetation, equipped with an integrated fibre technology for capillary irrigation. Water travels up and is evenly distributed for absorption, making that the plants have permanent access to water and nutrients.

Extensive smart blue-green roof, Amsterdam © RESILIO

Flood control

€ 60/m²





Building

Productive aquaponics building

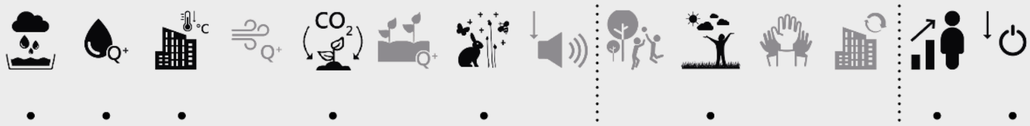
Brief description

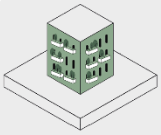
Three main features constitute a productive aquaponics building: a fish farm, greenhouses, and an outdoor garden. These features can be implemented either on the roof of the building or on the surrounding plot. Products as vegetables, fruits, aromatic herbs and fresh fish are delivered through this solution. The particularity of aquaponics is the opportunity to turn a waste product into something useful thanks to efficient water management. For instance, the water rich in nutrients from the fishes' solid waste is reused as fertiliser for the plants.

Ferme Abattoir, Anderlecht © BIGH-Isopix

Circular economy

-





Air quality

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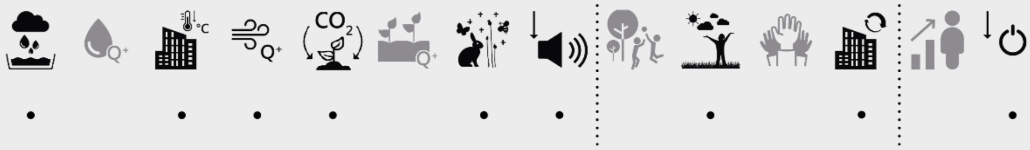
Building

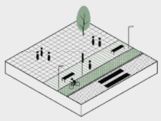
Vertical forest

Brief description

Space on ground level is scarce in urban areas. Such as towers are built with the intention to gain usable surfaces thanks to their height without occupying excessive ground surface, the same concept can be applied to greenery. The vertical forest consists in a high building covered by large green-cantilevered balconies from the façades. Various types of trees, plants and shrubs are implemented on these balconies considering their species and best orientation.

Bosco Verticale, Milan
© Stefano Boeri Architetti





Flood control

€ 60-100/m²

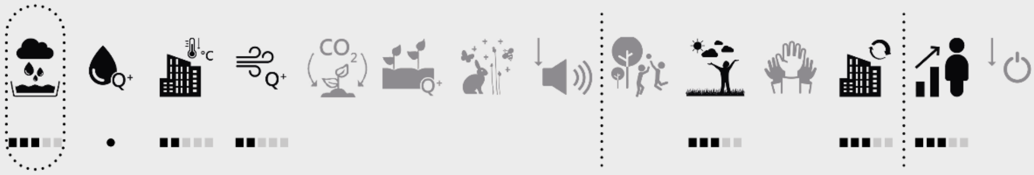
Public squares

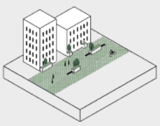
Vegetated grid pavement

Brief description

Urban areas consist of an increasing percentage of impervious surfaces and urban drainage systems are often not designed to support the increasingly heavy precipitation events. This causes an imbalance in the hydrological system where precipitation cannot be stored nor infiltrated in the soil with the risk of urban pluvial flooding. Therefore, green pavements are necessary to capture and infiltrate the excess overflow due to precipitations.

Vegetated green pavements, Antwerp © M. Kawa





Urban regeneration

-

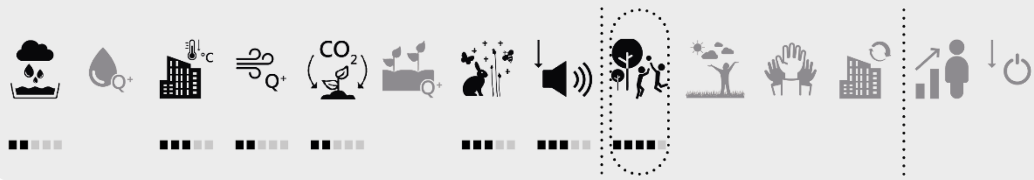
Transport linear infrastructure

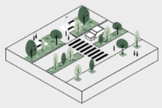
Car-free residential street

Brief description

As an important part of the transport linear infrastructure, one can define different typologies of local neighbourhood streets. These streets are the smaller streets composing the grid of a city, in contrast with the bigger avenues or boulevards. This NBS concerns a neighbourhood street from which cars are banned and which is located in a residential area. This pedestrian and bicycle friendly street uses pervious pavements and street trees, shrubs as well as deciduous hedges are implemented throughout the street.

Rijke Beukelaarstraat, Antwerp
(Groentool, n.d.)





Transport linear infrastructure

Green residential street

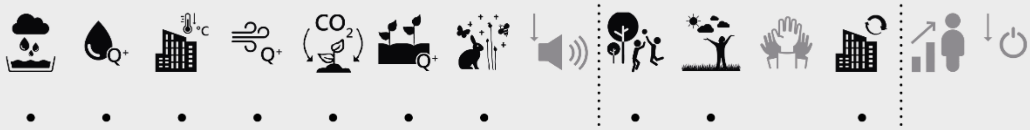
Brief description

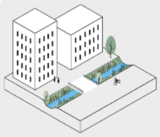
Greening streets is a key action in urban regeneration plans that creates mutually beneficial relationships between city dwellers and their environments. Including vegetation in the streetscape increases liveability and promotes well-being of residents. Green residential streets are one-way traffic streets with vegetated patches, including front lawns and street gardens.

Green residential street, Antwerp
© M. Kawa

Social justice & cohesion

-





Transport linear infrastructure

(Bio-) Swale

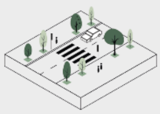
Brief description

Swales are linear topological depressions facilitating collection and infiltration of storm water runoff. The system is similar to a river valley, where excess rainwater is collected and slowly sinks into the ground. When vegetated with plants the system is called a bio-swale. Two main types can be distinguished: an infiltration swale and a buffer swale.

Bio-swale, Antwerp
© Bureau Bas Smets

Flood control

€ 10-60/m³



Transport linear infrastructure

Single tree (6-12m)

Brief description

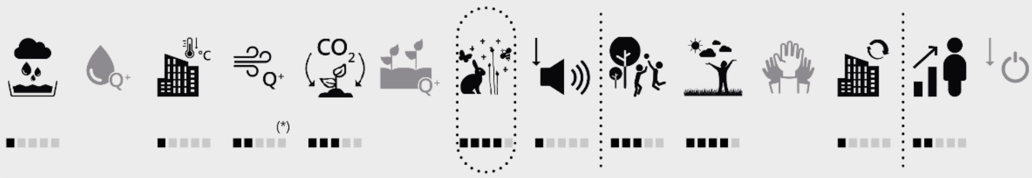
Greening streets is a key action in urban regeneration plans that creates mutually beneficial relationships between city dwellers and their environments. Including vegetation in the streetscape increases liveability and promotes well-being of residents.

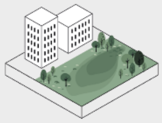
(*) When implemented in a high traffic narrow street, trees obstruct the ventilation flow, which has a negative impact on air quality.

Single tree in Flinders street, Australia © Street & Garden Studio

Heat wave impact control

€ 4-12,000 /tree





Flood control

€ 15-25/m^2

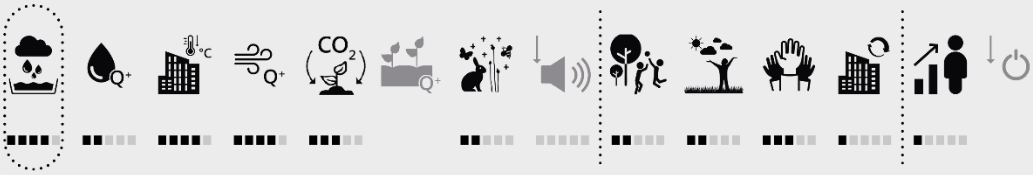
Public green spaces

Floodable plain

Brief description

Flood plains are sunken areas forming large natural basins covered with grass that can fill up with excess water runoff in case of heavy precipitation events. The rainwater is temporarily stored and gradually infiltrated in the soil.

Floodable plain in Nieuw Zuid, Antwerp © M. Kawa

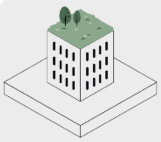


9.3.Factsheets

The factsheets are compiling all the to-be-provided characteristics defined throughout this thesis. This last level of information allows the user to make a decision whether or not to implement a specific NBS knowing all the data needed.

As for the overview sheets, this section contains the same thirteen solutions. Some consists in further development based on the factsheets developed by M. Kawa; others, concerning innovative solutions, were newly created. While developing these factsheets, specific attention has been brought on the references. As stated in Section 5.2.5, specific references are scarce in the existing evaluated catalogues; this issue required to be addressed. Therefore, the sources of the more general information, such as the general and technical descriptions, as well as the descriptive part of the financial characteristics, is outlined on the factsheet itself by the 'sources' section. In addition to that, references for the specific data, such as precise costs and the NBS performance towards a benefit, are reported on a separate sheet located at the end of the catalogue. Furthermore, all the illustrations are provided with their copyrights in the legend. This way, references are clear throughout the catalogue, and the reader has the possibility to verify certain given information if desired.

Intensive green roof



Heat wave impact control

(1)

€ 350/m²

General description

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The intensive green roof is the most advanced type of green roof supporting a broad range of species from herbs to small size trees.

The minimum substrate depth for an intensive green roof system is 20 cm but can go up to over one meter and mostly depends on the type of vegetation. Roof gardens and agriculture are equally intensive green roof systems and entail higher nutrient applications and intensive maintenance.
The elevated substrate thickness increases the overall performance of the roof system in terms of water retention, cooling, carbon sequestration and sound retention. The cooling performance of the green roof system can help address the UHI and heat stress.

The green roof performs as a rainwater buffer, allowing the substrate to saturate and store rainwater (70-150 l/m²). The vegetation absorbs a part of the water and cools the atmosphere through evapotranspiration and another part is evaporated from the soil. Additionally, the created ecosystem consisting of various species aids in improving urban biodiversity.

Financial characteristics

Construction costs
The intensive green roof costs approximately € 350/m², depending on the substrate thickness and choice of vegetation.

Maintenance description
The system requires advanced irrigation and professional maintenance. Plant selection and roof design strongly affect the amount of maintenance and irrigation required; therefore, the maintenance price varies depending on the project.

Amortisation term: Short term (3)
Green roofs get the recovery of the investment within 10 years.

Local incentives
Within Brussels, the communes of Uccle/Ukkel and Woluwe-Saint-Lambert/Sint-Lambrechts-Woluwe offer a refund up to € 500 for an intensive green roofs; and the commune of Brussels offers a refund up to € 3,500 (cf. Annex 12.4. of this thesis).

Costs of the associated grey solution (4)
In order to collect rainwater from the roof, a water tank could be installed. Their costs depends mainly on their capacity, and their aesthetics. It starts from € 50-700 for tanks of 100-750L, and can go up to € 600-1,400 for tanks of 1,000-3,000L. Naturally, the only benefit provided would be water balance.

European Parliament Wilfried Martens, Brussels
© Ecoworks

Technical description

(1) Vegetation: should be adapted to local climate conditions and species
- Intensive system: moss, succulents, herbs, tall grasses, flowers, small trees

(2) Substrate: mixture of shale, pumice, lava rock, crushed bricks, clay, and compost
- Thickness: 15 - 20 cm
- Water storing capacity: 70 - 150 l/m²

(3) Filter membrane: geotextile
(4) Drainage layer: HDPE 60 mm
(5) Protection mat with absorption
- Properties: felt fabric

(6) Root repellent waterproofing
(7) Roof structure: flat roof

Implementation requirements & notes
A structural analysis should be performed to define whether the existing roof structure could bear the additional load.

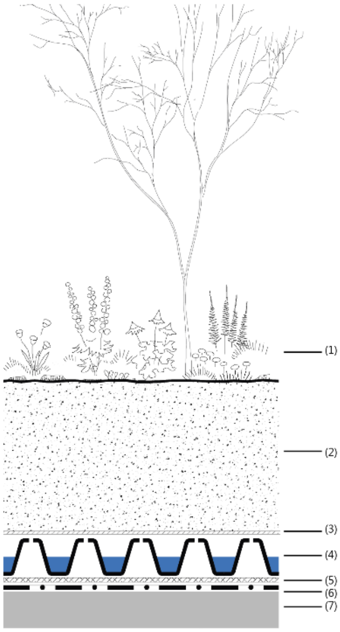
Best practice

Ecoworks, Belgium
Ecoworks is a Belgian company, which aims at integrating nature into the city by proposing swimming ponds, green roofs and green façades. Among other projects, they designed the intensive green roof on the European Parliament Wilfried Martens building.

Sources

Ecoworks - Zwemvijvers, groendaken en groengevels. (n.d.). Ecoworks. Retrieved 28 May 2020, from http://ecoworks.be/

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.



Schematic section of an intensive green roof
© M. Kawa

SEMI-INTENSIVE GREEN ROOF

Heat wave impact control

€ 250/m² (1)

(5)

(5)

(5)

(5)

(5)

(5)

(5)

(3)

(3)

(3)

(3)

GENERAL DESCRIPTION

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The semi-intensive green roof system supports a variety of vegetation ranging from succulents and herbs to tall grasses. The system is relatively low maintenance but plant selection and roof design strongly affect this aspect.

The larger substrate thickness increases the overall performance of the roof system in terms of water retention, cooling, carbon sequestration and sound retention. The cooling performance of the green roof system can help address the UHI and heat stress.

The green roof performs as a rainwater buffer, allowing the substrate to saturate and store rainwater (32-150 l/m²). The vegetation absorbs a part of the water and cools the atmosphere through evapotranspiration and another part is evaporated from the soil. Additionally, the created ecosystem consisting of various species aids in improving urban biodiversity.

TECHNICAL DESCRIPTION

(1) Vegetation: should be adapted to local climate conditions and species
- Semi- intensive system: moss, succulents, herbs and tall grasses.

(2) Substrate: mixture of shale, pumice, lava rock, crushed bricks, clay, and compost
- Thickness: 15 - 20 cm
- Water storing capacity: 40 - 150 l/m²

(3) Filter membrane: geotextile
(4) Drainage layer: HDPE 40 mm
(5) Protection mat with absorption
- Properties: felt fabric

(6) Root repellent waterproofing
(7) Roof structure: flat roof

Implementation requirements & notes
A structural analysis should be performed to define whether the existing roof structure could bear the additional load.
- Dry weight: 90 kg / m²
- Saturated weight: >150 kg / m²

FINANCIAL CHARACTERISTICS

Construction costs
The semi-intensive green roof costs approximately € 250/m², depending on the substrate thickness and choice of vegetation.

Maintenance costs and description
Maintenance varies with vegetation selection, but in general the semi-intensive green roof requires to be fertilized once a year, which comes down to a cost of € 5/m².
Additional irrigation may be needed in warm periods.

Amortisation term: Short term (3)
Green roofs get the recovery of the investment within 10 years.

Local incentives
Within Brussels, various communes offer incentive for green roofs. The commune of Brussels has a specific one for semi-intensive green roof, which amounts up to € 3,500 (cf. Annex 12.4. of this thesis).

Costs of the associated grey solution (4)
In order to collect rainwater from the roof, a water tank could be installed. Their costs depends mainly on their capacity, and their aesthetics. It starts from € 50-700 for tanks of 100-750L, and can go up to € 600-1,400 for tanks of 1,000-3,000L. Naturally, the only benefit provided would be water balance.

BEST PRACTICES

Canopy Green Roofs, Belgium
Canopy Green Roofs is a Belgian company, which offers various types of green roofs and façades in order to provide calm refugees inside the city. One of their projects is the LAAD semi-intensive green roof in Heverlee.

Ecoworks, Belgium
Ecoworks is a Belgian company, which aims at integrating nature into the city by proposing swimming ponds, green roofs and green façades. Among other projects, they designed a semi-intensive green roof in Overijse.

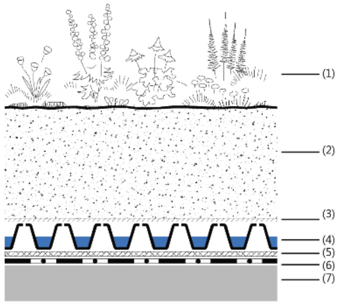
SOURCES

Canopy - Groendaken & groengevels (n.d.). Retrieved 28 May 2020, from http://canopy-greenroofs.be/home

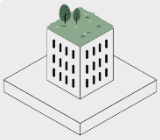
Ecoworks - Zwemvijvers, groendaken en groengevels. (n.d.). Ecoworks. Retrieved 28 May 2020, from http://ecoworks.be/

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

LAAD semi-intensive green roof, Heverlee
© Canopy Green Roofs



Schematic section of a semi-intensive green roof
© M. Kawa



Heat wave impact control

(1)

€ 75/m²

(2)

(2)

(2)

(2)

(2)

(2)

(2)

(2)

(3)

(3)

(6)

BUILDING - HORIZONTAL ELEMENT

EXTENSIVE GREEN ROOF

GENERAL DESCRIPTION

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The extensive green roof systems is relatively lightweight and usually does not entail much maintenance. It can be installed on both flat and sloped roof structures up to 45 °.

The substrate thickness between 4 and 15 cm accommodates vegetation ranging from moss to succulents and other herbaceous species. The low minimum weight of the extensive green roof (60 kg/m² in saturated state) makes it a feasible option for both new and renovated constructions.

An extensive green roof will perform as a rainwater buffer, allowing the substrate to saturate and store rainwater (32-150 l/m²). The vegetation absorbs a part of the water and another part evaporates and cools the air, potentially reducing the urban heat island effect (UHI).

Additionally, the green layer prevents the roof from heating up in summer and adds an extra layer of thermal and acoustic insulation to the building.

TECHNICAL DESCRIPTION

(1) Vegetation: should be adapted to local climate conditions and species
- Extensive system: moss, succulents and herbs.

(2) Substrate: mixture of shale, pumice, lava rock, crushed bricks, clay, and compost
- Thickness: 4 - 15 cm
- Water storing capacity: 32 - 150 l/m²

(3) Filter membrane: geotextile
(4) Drainage layer: HDPE 25 mm
(5) Protection mat with absorption properties: felt fabric
(6) Root repellent waterproofing
(7) Roof structure: flat roof or sloped up to 45°

Implementation requirements & notes

- When installed on a sloped roof structure, an additional mesh layer is required on top of the substrate to secure the system and prevent it from slipping.
- A structural analysis should be performed to define whether the existing roof structure could bear the additional load.
  - Dry weight: 60 kg / m²
  - Saturated weight: >90 kg / m²

FINANCIAL CHARACTERISTICS

Construction costs
The extensive green roof costs € 75/m².

Maintenance costs an description
Maintenance varies with vegetation selection, but in general, an extensive green roof requires to be fertilized once a year, which comes down to a cost of € 5/m².
Usually there is no need for additional irrigation.

Amortisation term: Short term (3)
Green roofs get the recovery of the investment within 10 years.

Local incentives
Within Brussels, the communes of Uccle/Ukkel and Woluwe-Saint-Lambert/Sint-Lambrechts-Woluwe offer a refund up to €500 for an extensive green roofs; and the commune of Brussels offers a refund up to € 3,500 (cf. Annex 12.4. of this thesis).

Costs of the associated grey solution (4)
In order to collect rainwater from the roof, a water tank could be installed. Their costs depends mainly on their capacity, and their aesthetics. It starts from € 50-700 for tanks of 100-750L, and can go up to € 600-1,400 for tanks of 1,000-3,000L. Naturally, the only benefit provided would be water balance.

BEST PRACTICES

Canopy Green Roofs, Belgium
Canopy Green Roofs is a Belgian company, which offers various types of green roofs and façades in order to provide calm refugees inside the city. One of their projects is the KLBS extensive green roof in Gent.

Ecoworks, Belgium
Ecoworks is a Belgian company, which aims at integrating nature into the city by proposing swimming ponds, green roofs and green façades. Among other projects, they designed a lightweight extensive green roof in Grimbergen.

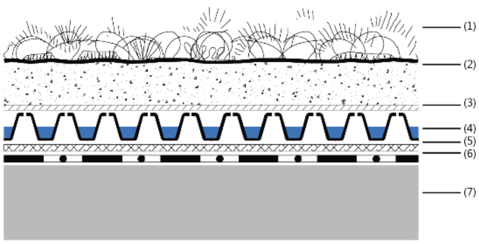
SOURCES

Canopy - Groendaken & groengevels (n.d.). Retrieved 28 May 2020, from http://canopy-greenroofs.be/home

Ecoworks - Zwemvijvers, groendaken en groengevels. (n.d.). Ecoworks. Retrieved 28 May 2020, from http://ecoworks.be/

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

Lightweight green roof, Grimbergen
© Ecoworks



Schematic section of an extensive green roof
© M. Kawa

Flood control

€ 100-800/m²[1]

Building - Horizontal element

Semi-intensive smart blue-green roof

General description

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The smart blue-green roof system is based on water storage with a capillary irrigation system. Precipitation is captured and stored in a specific layer beneath the substrate and vegetation, equipped with an integrated fibre technology for capillary irrigation. Water travels up and is evenly distributed for absorption, making that the plants have permanent access to water and nutrients.

The roofs are equipped with smart sensors and automatically controlled valves. Data collected from sensors measuring the water level in the sewer system, on the roofs and in the soil combined with accurate weather forecasts allows determining the exact amount of water to be retained or discharged when suitable. Linking a series of blue-green roofs with each other establishes a large-scale smart network for rainwater management to prevent urban pluvial flooding. The permanent water supply equally increases the green roofs' performance regarding Urban Heat Island mitigation by providing natural cooling through evaporation and evapotranspiration.

Technical description

(1) Vegetation: should be adapted to local climate conditions and species. Semi-intensive system: moss, succulents, herbs, grasses, ferns, shrubs.
(2) Substrate: mixture of shale, pumice, lava rock, crushed bricks, clay, and compost. Semi-intensive system: 8 cm. When saturated, the substrate itself can store between 32-150 l/m² of rainwater.
(3) Filter membrane with integrated fibre technology: permeable geotextile + rock wool cones (1/m²)
(4) Water storage: lightweight crate system with a height of 85 mm and capacity of 80 l/m²
(5) Root repellent waterproofing: impervious bitumen or plastic cover
(6) Roof structure: flat roof
(7) Automatic valve for smart flow control
(8) Existing drainage system

Implementation requirements & notes

- This NBS should be planned on municipal level or higher to maximize effectiveness, since data collection from public sewers and weather forecasts is involved.
- Potential for participatory planning with concerned parties and inhabitants.
- When freezing temperatures are forecasted all stored water is discharged to prevent damage.
- A structural analysis should be performed to define whether the existing roof structure could bear the additional load.
    - Dry weight: 90 kg / m²
    - Saturated weight: >170 kg / m²

Financial characteristics

Construction costs
Depending on the selection of species and substrate, the price for a semi-intensive roof system will vary between € 100-800/m². However, this price does not include the smart sensors and valves nor placement.

Maintenance description
Maintenance varies with vegetation selection. In the case of semi-intensively vegetated roofs, additional irrigation might be required. In periods of drought, tap water should be supplied to the storage layer. Additionally, fertilisation should be provided twice a year.

Costs of the associated grey solution [4]
In order to collect rainwater from the roof, a water tank could be installed. Their costs depends mainly on their capacity, and their aesthetics. It starts from € 50-700 for tanks of 100-750L, and can go up to € 600-1,400 for tanks of 1,000-3,000L. Naturally, the only benefit provided would be water balance.

Best practices

RESILIO, Amsterdam
RESILIO is a three-year project that is being developed in Amsterdam aiming to realise 10,000m² of smart green-blue roofs. Tenants are involved in the project, and as a local incentive, a municipality subsidy is available. RESILIO is the first project to connect blue-green roofs in a smart network.

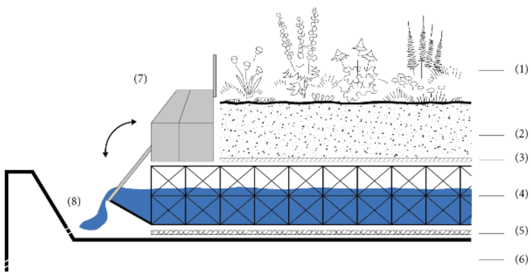
SmartRoof 2.0, Netherlands
This project aims at illustrating the potential of combining blue and green elements on rooftops to address Urban Heat Island Effect and urban runoff.

Sources

RESILIO - Het slimme daken project in Amsterdam. (n.d.). RESILIO. Retrieved 28 May 2020, from https://resilio.amsterdam/

Project Smartroof 2.0. (n.d.). Retrieved 28 May 2020, from www.//projectsmartroof.nl/

Semi-intensive smart blue-green roof, Amsterdam
© RESILIO



Schematic section of a smart blue-green roof
© Adapted by M. Kawa from RESILIO

Flood control

€ 60/m² (1)

Building - Horizontal element

Extensive smart blue-green roof

General description

Space on ground level is scarce in many metropolitan areas. Urban rooftops collectively form a large unused area with great potential for climate adaptation. The smart blue-green roof system is based on water storage with a capillary irrigation system. Precipitation is captured and stored in a specific layer beneath the substrate and vegetation, equipped with an integrated fibre technology for capillary irrigation. Water travels up and is evenly distributed for absorption, making that the plants have permanent access to water and nutrients.

The roofs are equipped with smart sensors and automatically controlled valves. Data collected from sensors measuring the water level in the sewer system, on the roofs and in the soil combined with accurate weather forecasts allows determining the exact amount of water to be retained or discharged when suitable. Linking a series of blue-green roofs with each other establishes a large-scale smart network for rainwater management to prevent urban pluvial flooding. The permanent water supply equally increases the green roofs' performance regarding Urban Heat Island mitigation by providing natural cooling through evaporation and evapotranspiration.

Technical description

(1) Vegetation: should be adapted to local climate conditions and species. Extensive system: moss and sedum.
(2) Substrate: mixture of shale, pumice, lava rock, crushed bricks, clay, and compost. Extensive system: 4 cm. When saturated, the substrate itself can store between 32-150 l/m² of rainwater.
(3) Filter membrane with integrated fibre technology: permeable geotextile + rock wool cones (1/m²)
(4) Water storage: lightweight crate system with a height of 85 mm and capacity of 80 l/m²
(5) Root repellent waterproofing: impervious bitumen or plastic cover
(6) Roof structure: flat roof
(7) Automatic valve for smart flow control
(8) Existing drainage system

Implementation requirements & notes

- This NBS should be planned on municipal level or higher to maximize effectiveness, since data collection from public sewers and weather forecasts is involved.
- Potential for participatory planning with concerned parties and inhabitants.
- When freezing temperatures are forecasted all stored water is discharged to prevent damage.
- A structural analysis should be performed to define whether the existing roof structure could bear the additional load.
    - Dry weight: 90 kg / m²
    - Saturated weight: >170 kg / m²

Financial characteristics

Construction costs

The roof system costs about € 60/m² in case of an extensive covering with substrate thickness 4 cm and Sedum vegetation. However, this price does not include the smart sensors and valves nor placement. The price will vary with the selection of species and substrate.

Maintenance description

Maintenance varies with vegetation selection. In the case of moss and sedum, no additional irrigation is required. In periods of drought, it suffices to supply the storage layer with tap water.

Costs of the associated grey solution (4)

In order to collect rainwater from the roof, a water tank could be installed. Their costs depends mainly on their capacity, and their aesthetics. It starts from € 50-700 for tanks of 100-750L, and can go up to € 600-1,400 for tanks of 1,000-3,000L. Naturally, the only benefit provided would be water balance.

Best practices

RESILIO, Amsterdam

RESILIO is a three-year project that is being developed in Amsterdam aiming to realise 10,000m² of smart green-blue roofs. Tenants are involved in the project, and as a local incentive, a municipality subsidy is available. RESILIO is the first project to connect blue-green roofs in a smart network.

SmartRoof 2.0, Netherlands

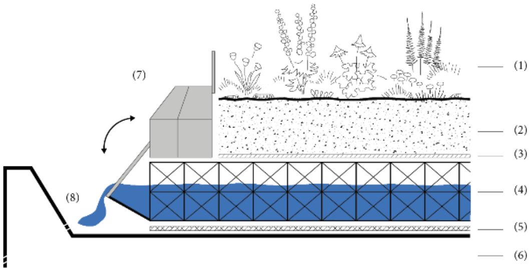
This project aims at illustrating the potential of combining blue and green elements on rooftops to address Urban Heat Island Effect and urban runoff.

Sources

RESILIO - Het slimme daken project in Amsterdam. (n.d.). RESILIO. Retrieved 28 May 2020, from https://resilio.amsterdam/

Project Smartroof 2.0. (n.d.). Retrieved 28 May 2020, from www.//projectsmartroof.nl/

Extensive smart blue-green roof, Amsterdam
© RESILIO



Schematic section of a smart blue-green roof
© Adapted by M. Kawa from RESILIO

Circular economy

-

(7)

(7)

(7)

(7)

(7)

(7)

(7)

PRODUCTIVE AQUAPONICS BUILDING

GENERAL DESCRIPTION

Three main features constitute a productive aquaponics building: a fish farm, greenhouses, and an outdoor garden. These features can be implemented on the roof of a building, either newly built or pre-existing, or on its surrounding plot. Products as vegetables, fruits, aromatic herbs and fresh fish are delivered through this NBS.

The particularity of aquaponics is the opportunity to turn a waste product into something useful thanks to an efficient water management system. First, the rainwater is harvested and supplies the fish tanks. As the fishes swim in this water, it becomes rich in nutrients from their solid waste. This nutrient rich water is then filtered through a bio-filter in order to be used to fertilise the plants from the greenhouses. In addition, a system enables to collect the water condensation coming from the evaporation of water. This water is hereafter returned to the system in complement of the harvested rainwater. In addition, the carbon dioxide rejected by the fishes is redirected to the greenhouses to help the plants with photosynthesis.

The aim of this NBS is to provide high-quality products within the urban context in order to promote short-circuit distribution.

TECHNICAL DESCRIPTION

(1) Collection of rainwater
(2) Rainwater tank
- Buffer for overflow water

(3) Fish tanks: fed by filtered rainwater
(4) Water containing fish' solid waste
(5) Bio-filter
- Converts the amonium present in the fish waste into nitrites, which are good nutrients for the plants

(6) Water rich in nutrients
(7) Water condensation collector
- Water evaporating from the plants and from the fish tanks is collected to be reinserted in the system

Implementation requirements & notes

- In the case that some of the features are to be installed on the roof of an existing building, a structural analysis should be performed to define whether the existing structure can bear the additional loads.
- Special attention should be paid to the choice of the fish species (e.g. market demand, water temperature requirements, capability to grow in tanks).
- The water parameters should be constantly monitored.

FINANCIAL CHARACTERISTICS

Local incentives
Within Brussels, various communal incentives exist concerning the installation of green roofs, which can be requested if the outdoor garden is placed on the roof, as well as the installation of a rainwater-harvesting tank (cf. Annex 12.4. of this thesis).

Costs of the associated grey solution
No grey infrastructure can be associated with the production of vegetables, fruits, herbs and fishes.

BEST PRACTICE

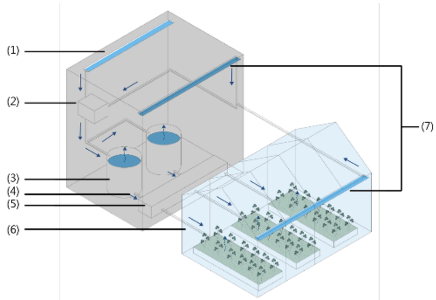
Ferme Abattoir, Brussels
Project developed by BIGH Farms and designed by Org Architects. They integrated an urban farm on an existing building. Fish farms, greenhouses and outdoor gardens occupy the rooftop of the building. An addition of a local market on the ground floor is complementing the system. The completion of this urban farm took approximately one year.

SOURCES

About - BIGH Farms. (n.d.). BIGH Farms. Retrieved 23 May 2020, from https://bigh.farm/about/.

Beckers, S. (2019). Aquaponics: A positive impact circular economy approach to feeding cities. Field Actions Science Reports. The Journal of Field Actions, Special Issue 20, 78–84.

Ferme Abattoir, Anderlecht
© BIGH-Isopix



Schematic view of the water management in aquaponics
Adapted from BIGH

Air quality

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Building - Vertical element

Vertical forest

General description

Space on ground level is scarce in urban areas. Such as towers are built with the intention to gain usable surfaces thanks to their height without occupying excessive ground surface, the same concept can be applied to greenery. This way, one can implemented considerably additional green spaces in a dense city.

The vertical forest consists in a high building covered by large green-cantilevered balconies from the façades. Various types of trees, plants and shrubs are implemented on these balconies. The species are cautiously chosen and placed according to their best orientation. As part of this NBS, a technical installation enables to monitor the needs of the plants and to manage remotely the irrigation system. This way, a greater part of the maintenance is centralised and private inhabitants or office's occupants do not need to preoccupy.

Three features compose this system: a principal network, a control group, and a drip-line. The principal network allows bringing water from the underground water storage tank to the balconies thanks to various water-lifting pumps. An intermediate fertilising device is present to add fertilisers into the water before it reaches the balconies. The control group in each plant container enables to regulate the water flow inside the container thanks to a valve and a pressure regulator. An additional filtration unit is present in the control unit. Finally, the drip-line enables a diffuse distribution of water on the surface of the substrate.

Technical description

(1) Undergroung water storage tank
(2) Principal network
(3) Control group
(4) Drip-line

Implementation requirements & notes

- The required load support for the cantilevered terraces depends on the weight of the balconies and of the plants, taking into consideration the load but also the wind effect.
- The potential falling of trees should be prevented by securing them with restraint safety systems.
- As the irrigation tubes are located on the façades, the irrigation system is discharged when freezing temperature are reached.
- A telescopic arm with a basket lift should be installed on the roof for tree maintenance.

Selection criteria of plants (non-exhaustive)

The plants and trees to integrate should:

- Be resistant to wind
- Be tolerant of pruning, and support relatively simple maintenance
- Not stimulate allergies
- Tolerate urban conditions, such as high pollution level
- Not produce any large fruit or seed (to avoid potential falling objects)
- Provide a restricted maximum canopy, as the space on balconies is limited

Moreover, the plants should be placed on the different façades according to their best orientation.

Financial characteristics

Maintenance description

As watering and fertilisation are encompassed in the automated irrigation system, the maintenance consists mainly in pruning the trees. Pruning time of a highly placed tree can take up to five times the pruning time of a ground level tree. Therefore, the estimated costs for this can be up to three to five times higher than for ground level trees.

Amortisation term

The amortisation term of a vertical forest is unknown. However, it can be taken into account that cost savings will occur due to a lowered energy consumption.

Local incentives

Within Brussels, the regional energy subsidy might be applicable to this kind of buildings. In addition, the commune of Uccle offers a local incentive concerning green walls, which is up to € 500 (cf. Annex 12.4. of this thesis).

Best practice

Bosco Verticale, Milan

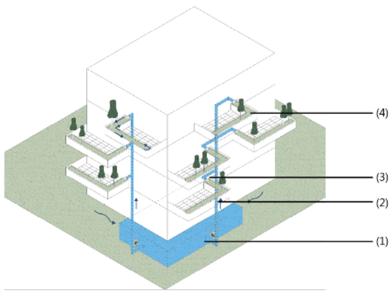
This project is the first example of a vertical forest and it was designed by Stefano Boeri Architects in Milan, Italy. They redefined the expression of green façades by providing large green-cantilevered balconies.

Sources

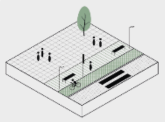
Vertical forest. (n.d.). Stefano Boeri Architetti. Retrieved 13 May 2020, from https://www.stefanoboeriarchitetti.net/en/project/vertical-forest/

Giacomello, E., & Valagussa, M. (2015). Vertical greenery: Evaluating the high-rise vegetation of the Bosco Verticale, Milan. Council on Tall Buildings and Urban Habitat.

Bosco Verticale, Milan
© Stefano Boeri Architetti



Schematic view of the irrigation system of the vertical forest



Flood control

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€ 60-100/m²

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Public squares

Vegetated grid pavement

General description

Urban areas consist of an increasing percentage of impervious surfaces and urban drainage systems are often not designed to support the increasingly heavy precipitation events. This causes an imbalance in the hydrological system where precipitation cannot be stored nor infiltrated in the soil with the risk of urban pluvial flooding.

Increasing the amount of green space and pervious surfaces in urban areas reduces surface water runoff as well as water scarcity and increases rainwater retention, infiltration and evaporation.

Green pavements exist in various forms, but usually consist of a perforated concrete base. They are an excellent solution for surfaces requiring permeability and stability. The tiles protect the soil from erosion while preserving a natural appearance. The perforations are filled with substrate with seeds, which in time will transform into a green cover.

Technical description

(1) Perforated concrete tiles filled with soil and grown with grass.
(2) Root zone consisting of stabilized sand soil
(3) Structural layer consisting of coarse grained soil, such as gravel.
(4) Existing soil

One tile measures approximately 40 cm x 60 cm and weighs almost 54 kg.

Implementation requirements & notes
These types of pavement are often selected to create paths or access to buildings for the fire brigade.

Financial characteristics

Construction costs
The initial cost lays between €60 -€100/m², depending on the type of tile and the transportation distance from the contractor.

Maintenance description
Maintenance of green pavements consists of weed control, reseeding of bare areas, and clearing of debris and accumulated sediment.

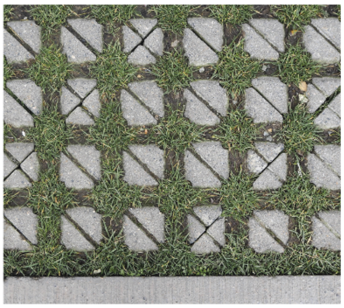
Amortisation term: Short term [9]
The period of recovery of the initial economic investment of the NBS is between 1 and 5 years.

Best practice

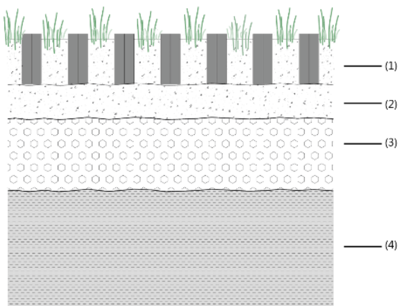
Nieuw-Zuid, Antwerp
The area of Nieuw Zuid, Antwerp is being redevelopped following the masterplan of Studio Secchi-Viganó (2012). The design, which includes environmental quality, is performed by the Bureau Bas Smets. The redevelopment of the area integrates various NBS, among which vegetated grid pavements.

Sources

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

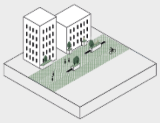


Vegetated grid pavements, Antwerp
© M. Kawa



Schematic section of vegetated grid pavements
© M. Kawa

CAR-FREE RESIDENTIAL STREET



Urban regeneration

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GENERAL DESCRIPTION

Greening streets is a key action in urban regeneration plans that creates mutually beneficial relationships between city dwellers and their environments. Including vegetation in the streetscape increases liveability and promotes well-being of residents.

As an important part of the transport linear infrastructure, one can define different typologies of local neighbourhood streets. These streets are the smaller streets composing the grid of a city, in contrast with the bigger avenues or boulevards.

The car-free residential street concerns, as its name indicates, a neighbourhood street from which cars are banned and which is located in a residential area. Residents can then enjoy a pedestrian and bicycle friendly area. In order to increase water permeability, vegetated grid pavement is used through the entire width of the street. To provide a greener and enjoyable feeling, single trees, shrubs as well as deciduous hedges are implemented throughout the street, either directly planted in pits in the streetscape, either placed in pots. In addition, climbing plants can be installed on the façades. The use of eco-urban furniture is also desired to create green resting areas. They can also be placed on each end of the street in order to indicate the beginning of a car-free residential street.

TECHNICAL DESCRIPTION

This NBS is a combination of private and public greenery. Each inhabitant of the street has the possibility to implement in front of his property green elements and furniture. However, the installation of pervious pavements throughout the street depends on public authorities. It is also the case for single trees implemented directly in pits in the streetscape.

This NBS can therefore be developed either by local authorities, either via bottom-up citizen's initiatives.

FINANCIAL CHARACTERISTICS

Construction costs
As this NBS is combining various elementary solutions, an overall price is hard to define. However, the price for a single tree lays between € 4-12,000/tree depending on the species. The implementation of vegetated grid pavements costs between € 30-90/m².

Local incentives
Within Brussels, various communal incentives concern the land permeabilization (e.g. up to € 1,000 in the commune of Brussels) or rainwater infiltrate systems (e.g. up to € 500 in the commune of Brussels and Uccle). In addition, the communes of Jette and Schaerbeek offer a free installation of a front flowerpot. Finally, Schaerbeek offers a subsidy concerning citizen's initiatives for sustainable development, which is up to € 3,000 (cf. Annex 12.4. of this thesis).

Associated grey solution
As the main aim of this NBS is to make neighbourhood streets greener, no grey solution can be associated with it.

BEST PRACTICE

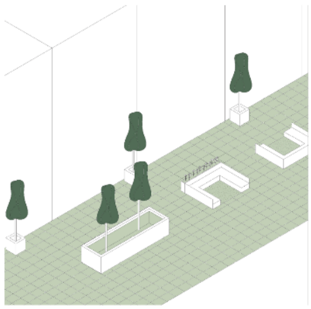
Rijke Beukelaarstraat, Antwerp
This example concerns a narrow street located in Antwerp where cars are allowed to station but pedestrians can use the whole width of the street. An attractive recreation and proximity area has been created by the integration of façade greenery, plants, shrubs and small trees.

SOURCES

Groentool - Green measures. (n.d.). Groentool of Antwerp. Retrieved 20 May 2020, from https://groentool.antwerpen.be/greenMeasures.xhtml

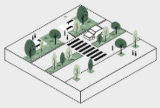
Bma. (n.d.). bma.brussels. Retrieved 11 May 2020, from //bma.brussels/fr/accueil/approche/bma.brussels. (2019, June 18). [ESPACE · PUBLIEK]—Bma. //bma.brussels/fr/2019/06/18/espace-%c2%b7-publiek/

Rijke Beukelaarstraat, Antwerp
(Groentool, n.d.)



Schematic view of a car-free residential street

Green residential street



Social justice & cohesion

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General description

Greening streets is a key action in urban regeneration plans that creates mutually beneficial relationships between city dwellers and their environments. Including vegetation in the streetscape increases liveability and promotes well-being of residents.

As an important part of the transport linear infrastructure, one can define different typologies of local neighbourhood streets. These streets are the smaller streets composing the grid of a city, in contrast with the bigger avenues or boulevards.

Green residential streets are one-way traffic streets with vegetated patches, including front lawns and street gardens. By alternating the positioning of the street gardens, they can simultaneously function as natural speed thresholds, while improving the aesthetics of a neighbourhood. The street's set-up encourages pedestrian and bicycle access, as there is no physical division between the street and the sidewalk. The streets are paved and precipitation runoff is guided along the slightly sloped street surfaces towards the middle of the road where it is drained through pipes and lead towards larger underground infiltration basins. The basins are constructed from plastic crates covered with a permeable layer (geotextile) functioning as a filter membrane that allows water to enter the crate while dirt and soil particles are filtered out. The rainwater is retained in the basin while it slowly infiltrates in the soil. The vegetated patches equally aid in managing storm water runoff, due to the soil's quality to store and infiltrate water.

Technical description

To ensure that surface runoff water is drained correctly, the street surface is sloped towards the gutter. Providing drainage in the centre of the street, prevents walkways and buildings from being flooded.

Vegetation is carefully selected based on local climate, native species and desired performance. For instance, while all plants are beneficial for cooling, some have higher evapotranspiration rates and will be more effective. The same applies for removing air pollution. Trees like the Ginko Biloba and Metasequoia Glyotostroboïdes perform well in this regard.

Financial characteristics

Maintenance description
Maintenance of green residential streets consists of keeping the street clean and managing the vegetated patches through weed control, reseeding of bare areas, and clearing of debris and accumulated sediment.

Local incentives
Within Brussels, various communal incentives concern the land permeabilization (e.g. up to € 1,000 in the commune of Brussels) or rainwater infiltrate systems (e.g. up to € 500 in the commune of Brussels and Uccle). In addition, the communes of Jette and Schaerbeek offer a free installation of a front flowerpot. Finally, Schaerbeek offers a subsidy concerning citizen's initiatives for sustainable development, which is up to € 3,000 (cf. Annex 12.4. of this thesis).

Associated grey solution
As the main aim of this NBS is to make neighbourhood streets greener, no grey solution can be associated with it.

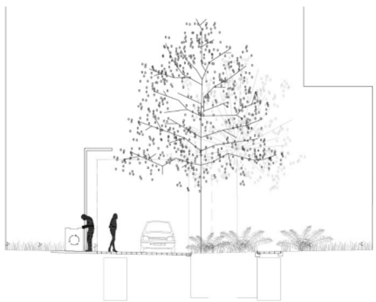
Best practice

Nieuw-Zuid, Antwerp
The area of Nieuw Zuid, Antwerp is being redevelopped following the masterplan of Studio Secchi-Viganó (2012). The design, which includes environmental quality, is performed by the Bureau Bas Smets. The redevelopment of the area integrates various NBS, among which green residential streets.

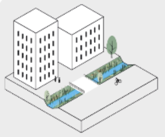
Sources

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

Green residential street, Antwerp
© M. Kawa



Schematic section of a green residential street
© Bureau Bas Smets



Flood control

(11) € 10-60/m³

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(Bio-) Swale

General description

Swales are linear topological depressions facilitating collection and infiltration of storm water runoff. The system is similar to a river valley, where excess rainwater is collected and slowly sinks into the ground. When vegetated with plants the system is called a bio-swale. Two main types can be distinguished: an infiltration swale and a buffer swale.

An infiltration swale consists of a shallow infiltration basin often combined with an underground permeable filter bed consisting of coarse-grained soil. The filter layer functions as an additional water storage and filters out pollutants, which is beneficial for soil fertility and enhances vegetation growth. Hence, it improves biodiversity due to the new ecosystem established in the swale.

In case of an impermeable soil (infiltration flowrate <1mm/h) or due to environmental issues (risk of soil or groundwater contamination) a buffer swale is chosen. The system is similar to an infiltration swale, but instead of infiltrating the rainwater runoff in the soil, it is drained through pipes underneath the swale. Optionally the pipes can be placed under a filter bed.

Technical description

The dimensioning of the required buffer volume is quite technical and requires a professional approach.

Parameters to consider

- Surface of the impervious area that is drained into the swale
- Desired infiltration surface
- Infiltration capacity of the soil
- The allowed recurring overflow period

For detailed information, please consult (Vaes & Berlamont, 2004).

The vegetation is preferably a selection of native hydrophilic species with strong cooling properties.

Implementation requirements & notes

- The groundwater level should be at least 1 m under the lowest point of the swale and the soil may not be polluted to avoid ground water contamination.
- The soil on site needs to be tested to determine the infiltration capacity in order to choose the correct type of swale.

Financial characteristics

Construction costs
The initial cost lays between € 10-60/m³, depending on the plant selection.

Maintenance costs and description (11)
Bio-swales require moderate maintenance, which costs about € 1-5/m². Maintenance of a dense and healthy vegetated cover consists of weed control, reseeding of bare areas, and clearing of debris and accumulated sediment.

Best practice

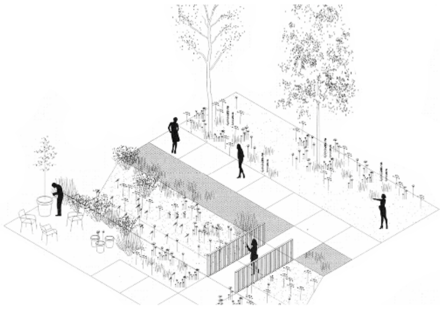
Nieuw-Zuid, Antwerp
The area of Nieuw Zuid, Antwerp is being redevelopped following the masterplan of Studio Secchi-Viganó (2012). The design, which includes environmental quality, is performed by the Bureau Bas Smets. The redevelopment of the area integrates various NBS, among which bio-swales.

Sources

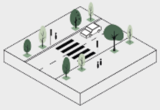
Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

Vaes, G., & Berlamont, J. (2004). Het ontwerp van bronmaat-regelen gebaseerd op continue langetermijnsimulatie. Water. (p.13). K.U. Leuven.

Bio-swale, Antwerp
© Bureau Bas Smets



Schematic view of a bio-swale
© Bureau Bas Smets



Heat wave impact control

€ 4-12,000[13] /tree

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Single tree (6-12m)

General description

Greening streets is a key action in urban regeneration plans that creates mutually beneficial relationships between city dwellers and their environments. Including vegetation in the streetscape increases liveability and promotes well-being of residents.

Street trees can remove pollutants such as fine particles (PM2.5) and carbon dioxide (CO_2) from the air. In addition, they have thermal cooling properties and can reduce the UHI-effect due to evapotranspiration.

They can equally contribute to sustainable water management as they are planted in street pits and surface water runoff can be redirected in order to infiltrate. However, street trees as the only solution for water management will probably not suffice. Combining the street trees with other NBS in a sustainable drainage system will increase the amount of water infiltrated and reduce sewer overflows.

(*) It should be noted that trees could have a negative impact on air quality when they are implemented in a high traffic narrow street, or street canyon. In this case, they obstruct ventilation flow and keep pollutants in the street.

Technical description

The implementation of street trees is relatively straightforward. The trees are planted in pits in the streetscape. It is important that the roots have sufficient space to grow.

Vegetation should be carefully selected based on local climate, native species and desired performance. For instance, while all trees are beneficial for cooling, some have higher evapotranspiration rates and will be more effective. The same applies for removing air pollution. Trees like the Ginko Biloba and Metasequoia Glyotostroboïdes perform well in this regard.

Financial characteristics

Construction costs
The species of trees affects grandly their price, which lays between € 4 and € 12,000.

Maintenance description
Maintenance of street trees consists of clearing debris and accumulated sediment.

Amortisation term: Short term [13]
The arboreal interventions get the recovery of the investment in about 5 years.

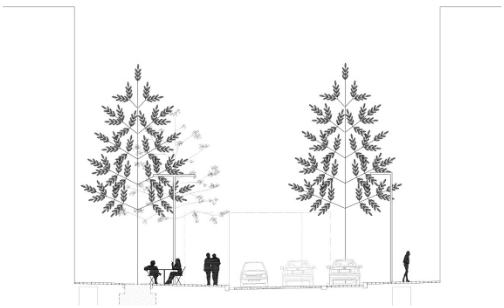
Best practice

Nieuw-Zuid, Antwerp
The area of Nieuw Zuid, Antwerp is being redevelopped following the masterplan of Studio Secchi-Viganó (2012). The design, which includes environmental quality, is performed by the Bureau Bas Smets. The redevelopment of the area integrates various NBS, among which single trees.

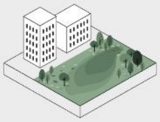
Sources

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

Single tree in Flinders street, Australia
© Street & Garden Studio



Schematic section of single trees in a street
© Bureau Bas Smets



Flood control

(15) € 15-25/m²

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PUBLIC GREEN SPACES

FLOODABLE PLAIN

GENERAL DESCRIPTION

Flood plains are sunken areas forming large natural basins covered with grass that can fill up with excess water runoff in case of heavy precipitation events. The rainwater is temporarily stored and gradually infiltrated in the soil.

The flood plains are often combined with an underground permeable filter bed consisting of coarse-grained soil. The filter functions as an additional water storage and filters out pollutants, which is beneficial for soil fertility and enhances vegetation growth.

Implementing flood plains in urban areas, for instance in a park, increases resilience and aids in preventing urban pluvial flooding.

Combining the nature-based solution with other solutions such as bio-swales and green roofs can be part of a water management plan for a whole urban area or neighbourhood.

TECHNICAL DESCRIPTION

The dimensioning of the required buffer volume is quite technical and requires a professional approach.

Parameters to consider

- Surface of the impervious area that is drained into the swale
- Desired infiltration surface
- Infiltration capacity of the soil
- The allowed recurring overflow period

For detailed information, please consult (Vaes & Berlamont, 2004).

Implementation requirements & notes

- The groundwater level should be at least 1m under the lowest point of the flood plain and the soil may not be polluted to avoid ground water contamination.
- The soil on site need to be tested to determine the infiltration capacity and whether infiltration is possible at all.

FINANCIAL CHARACTERISTICS

Construction costs
The initial cost lays between € 15-25/m².

Maintenance description
Maintenance of a dense, healthy vegetated cover consists of periodic mowing, weed control, reseeding of bare areas, and clearing of debris and accumulated sediment.

Amortisation term: Medium term [14]
Actions to be implemented related to the floodable plain will have a period of investment recovery up to 15 years.

Associated grey solution
The grey solution traditionally adopted instead of a floodable plain is a storm basin. In Brussels, storm basins above 10,000L may only be implemented by the Société Bruxelloise de Gestion de l'Eau - Brusselse Maatschappij voor Waterbeheer (SBGE-BMBW). Naturally, the only benefit provided would be water balance.

BEST PRACTICE

Nieuw-Zuid, Antwerp
The area of Nieuw Zuid, Antwerp is being redevelopped following the masterplan of Studio Secchi-Viganó (2012). The design, which includes environmental quality, is performed by the Bureau Bas Smets. The redevelopment of the area integrates various NBS, among which floodable plains.

SOURCES

Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

Vaes, G., & Berlamont, J. (2004). Het ontwerp van bronmaat-regelen gebaseerd op continue langetermijnsimulatie. Water. (p.13). K.U. Leuven.

Bassins d'orage, (2020, May 29). Bruxelles Environnement. https://environnement.brussels/thematiques/eau/leau-bruxelles/eau-de-pluie-et-inondation/bassins-dorage

Floodable plain in Nieuw Zuid, Antwerp
© M. Kawa

Schematic section of a floodable plain - Chulalongkorn University Centenary Park
© G49 Co., Ltd.

Sources concerning specific data

This sheet is compiling the sources used for specific data, such as construction costs and NBS performance towards a benefit. Unless specified otherwise, the provided source concerns the same NBS in the referred catalogue. When it is not the case, the name of the NBS used in the referred catalogue is specified.

(1) M. Kawa catalogue.
Kawa, M.-C. (2020). Urban environmental quality: Exploring and Analysing Nature-based Urban Design Solutions for Brussels. Proposal for a Common Typological Classification. Brussels Faculty of Engineering.

(2) Mean values from the Groentool & UNaLab catalogues.
Green measures | Groentool. (n.d.). Groentool of Antwerp. Retrieved 20 May 2020, from https://groentool.antwerpen.be/greenMeasures.xhtml
University of Stuttgart. (2019). Nature based Solutions - Technical Handbook. UNaLab. https://unalab.eu/documents/unalab-technical-handbook-nature-based-solutions

(3) URBAN GreenUP catalogue - NBS: Green roofs.
CAR, SGR, ACC, CFT, UOL, DEM, EGE, IZT, LEI, PMI, & SPI. (2018). URBAN GreenUP: D1.1 NBS Catalogue. URBAN GreenUP. https://www.urbangreenup.eu/insights/deliverables/d1-1---nbs-catalogue.kl

(4) Sample of the Belgian market: Brico and Bollaert
Citerne d'eau de pluie. (n.d.). Brico. Retrieved 28 May 2020, from https://www.brico.be/fr/jardin-ext%C3%A9rieur/arrosage/citernes/g418/?q=%2Ffh_type_brico%3E%7Bregenton%7D&currentPage=2&viewSize=24
Citernes à eau aériennes. (n.d.). Bollaert. Retrieved 28 May 2020, from https://www.cuve.be/citernes-a-eau-aeriennes

(5) Groentool catalogue.
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(6) UNaLab catalogue.
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(7) Beckers, S. (2019). Aquaponics: A positive impact circular economy approach to feeding cities. Field Actions Science Reports. The Journal of Field Actions, Special Issue 20, p80.

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10. Conclusion

The aim of this thesis, as part of the CO-NATURE project, was to draft a more complete and user-friendly catalogue of NBS, that can be consulted for urban design projects in Brussels. An in-depth research on existing catalogues of NBS was performed. In addition, available information about NBS already collected by CO-NATURE was consulted. Furthermore, an online survey was sent out as well. Together with the feedback of the supervisor and co-supervisor, this thesis was realised.

First of all, in order to clearly align our scope, a unique definition of urban NBS was missing. Therefore, this master thesis started by defining an exhaustive one. The drafted definition is based on the one of the EC, englobing biomimicry: " *Urban NBS are … interventions that are implemented in urban areas and that use nature and its ecosystem services to sustainably tackle societal challenges … Urban NBS provide multiple benefits to the environment, the society, the economy and health. Some solutions are inspired by processes from nature and imitate them using technical components. Others are fully copied from natural processes using only natural resources. Lastly, urban NBS can also be supported by nature which results in a combination of green and grey infrastructure."*.

Secondly, to draft a more complete catalogue, innovative solutions were included. For this, priority was given to hybrid and multi-scale NBS which are applicable to Brussels.

Thirdly, one of the main purposes of this thesis was to define a user-friendly classification of NBS. This classification should facilitate the selection of potential urban NBS for the users. However, considering the different target audiences of the catalogue as well as the growing number of available urban NBS, the conclusion was drawn that defining a classification by itself is not sufficient to facilitate the selection of NBS. Hence, a two-step approach was selected; a combination of a preliminary flexible search tool which takes into account the user's specific needs, and a paper version of the catalogue. In order to make both of them user-friendly, a persona approach was applied to indicate the user's priority specifications. The main identified criterion was the size of the user's project. Hence, this one was used to define a corresponding classification of NBS for the paper version of the catalogue. This resulted in (sub-) categories according to different urban planning elements. The advantage of the flexible search tool lies in the fact that it can be adjusted to contemporary challenges and to the personal objectives. The tool's output consists of a list of suited urban NBS, which are ranked according to their total efficiency.

Then, the user can make his final choice by consulting a user-friendly paper version of the catalogue. In this catalogue, the user will find additional information about the selected urban NBS on three different levels: datasheets, overview sheets and factsheets. In addition to the general characteristics of NBS, special focus was given to financial criteria. Herewith, two new characteristics are introduced; the costs relative to the associated grey solution, as well as a list of local incentives that exist in Brussels. Furthermore, the visual representation of the three sheets was optimised using icons, schemes and drawings.

Lastly, further enhancements of the proposed catalogue and the tool are possible. These can be investigated over the coming two years by other actors and students involved in the CO-NATURE project, which lasts until 2022. New available data about NBS in the catalogue can be added. In addition, the catalogue can continuously be completed with new urban NBS. The flexible search tool can be enhanced as well. Currently, the user can only indicate one subcategory at a time. For projects covering multiple urban planning elements, this option should thus be extended. In addition, once the demand and suitability maps of CO-NATURE have been created, they can be implemented in the tool to also take into account recorded local challenges. Finally, the tool can be translated into a web application. In addition to the given financial characteristics, the lifespan, efficacy and potential collateral savings of an NBS can be added. However, these require a more in-depth analysis.

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12. Annexes

12.1. Projects and platforms reviewed

12.1.1. CLEVER Cities

Thirty-four partners from around the world are involved in the project. It implements NBS in key districts of their front-runner cities. The project aims at driving a new kind of nature-based urban transformation for sustainable and socially inclusive cities. In order to discuss how to adapt NBS for the needs of towns and cities around the world, the front-runner[68] cities share their knowledge with fellow cities[69] (Politecnico di Milano, 2018). The catalogue is the result of collaborative ongoing work conducted with and by students of the Energy & Urban Planning Design Studio at the Politecnico di Milano and was published in September 2019 (CLEVER Cities, 2019).

12.1.2. Eklipse

The project Eklipse is funded by the European Union's Horizon 2020 programme, and is coordinated by the UK Centre of Ecology and Hydrology. This project has an aim to develop a self-sustaining support mechanism for evidence-informed decision-making affecting biodiversity and ecosystem services. This mechanism would be available for institutions, knowledge holders and stakeholders. Various project partners support the development of this mechanism (*About | Eklipse Mechanism*, n.d.). Through this project, various reports have been published, of which '*An impact evaluation framework to support planning and evaluation of NBS projects*' defines challenges to be addressed by NBS (Raymond, Berry, et al., 2017, p. 6).

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[68] Hamburg (Germany), London (United Kingdom) and Milan (Italy) (Politecnico di Milano, 2018)

[69] Belgrade (Serbia), Larissa (Greece), Madrid (Spain), Malmö (Sweden), Sfântu Gheorghe (Romania) and Quito (Ecuador) (Politecnico di Milano, 2018)

12.1.3. Groentool of Antwerp

The Groentool of Antwerp is an online platform that has been developed in collaboration with VITO NV and the University of Ghent. This tool aims at demonstrating the effects of greenery on the environment, and at suggesting various possible measures to implement greenery in the city. These measures have been classified according to ten categories, e.g., 'roof surfaces', 'open green forms' and 'lone trees'. The impact of these measures is specified according to seven defined themes: water management, heat stress, air quality, sound, biodiversity, CO_2 absorption, and recreation and proximity (*Home | Groentool*, n.d.).

12.1.4. Klimatek

The Klimatek guide was published in October 2017 and is part of the KLIMATEK programme, which is the Basque Government's scheme to support projects that boost the adaption to climate change. This project was founded to meet the objectives of the Basque Climate Change Strategy 2050, also referred to as the Klima 2050 project (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, p. 8). Twenty partners from around the world are involved in the project (*Partners | Klima 2050*, n.d.). The aim of the guide is to provide local authorities with a coherent, clear and easily replicable methodology which allows the authorities to identify and map existing NBS (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, p. 9).

12.1.5. Marie-Caroline Kawa

M. Kawa was a student of the Vrije Universiteit Brussel whose master thesis was called *Urban Environmental Quality: Exploring and Analysing Nature-Based Urban Design Solutions for Brussels. Proposal For a Common Typological Classification*. She as well was part of the CO-NATURE project.

12.1.6. Nature4Cities

The project Nature4Cities is funded by the European Union's Horizon 2020 programme. It is an online platform referencing NBS. The objectives of the project are, among others: to improve the integration of NBS in urban planning, to create an active community around the theme of NBS, and offer decision-support tools for re-naturing cities. The developed platform will provide tools to assess benefits and costs of NBS, and to manage participation processes. Three tools are already available: an NBS database, an NBS projects observatory, and an implementation models database (*Discover the project | Nature4Cities*, n.d.; *Home | Nature4Cities*, n.d.).

12.1.7. Naturvation

The Naturvation project stands for NATure-based URban innoVATION. This project is developed by fourteen European institutions, and six European cities are partners of it. The project aims at clarifying the current understanding of NBS and their potential benefits in urban areas. It also focuses on the role innovations can play in the development of NBS (*About | NATURVATION*, 2017; *NATURVATION | Home*, n.d.). In order to do so, Naturvation proposes an Urban Nature Atlas which consists of NBS examples throughout Europe. The search can either be done by location, challenge response, desired urban setting or project costs (*Urban Nature Atlas*, n.d.).

12.1.8. Oppla

Oppla stands for OPen PLAtform and is an initiative that has created an online inventory of NBS. The platform aims at promoting NBS to the public by providing various services. Recent research, tools or guidance can be retrieved through the 'marketplace'. Oppla also lists all kinds of NBS case studies which can be looked for by location, scale or type. Finally, the Oppla community facilitates the communication between members (*Natural Capital • Ecosystem Services • Nature-Based Solutions | Oppla*, n.d.).

12.1.9. ThinkNature

The project ThinkNature is funded by the European Union's Horizon 2020 programme. This project involves seventeen partners originating from eight European countries[70], with the Technical University of Crete leading it. The aims of ThinkNature are, among others: to provide continuous dialogue on NBS through its multi-stakeholder platform, to identify, communicate and promote successful NBS, as well as to foster collaboration at multiple levels (*About | ThinkNature*, n.d.). The project developed a platform in order to promote the use of NBS and to enable people to interact and exchange on this theme and its challenges (*Platform for Nature-Based Solutions | ThinkNature*, n.d.). In the framework of this project, a handbook on NBS has also been produced. The handbook is meant for gathering and promoting knowledge on NBS, including a guide to all actors involved, and is thus written in a comprehensive manner (Giorgos Somarakis et al., 2019).

12.1.10. UNaLab

The UNaLab project is contributing to the development of smarter, more inclusive, more resilient and more sustainable cities through the implementation of NBS (*Home | UNaLab*, n.d.). These NBS are demonstrated and evaluated by implementing them in three front-runner cities[71]. These actively collaborate and share their experience with seven follower cities[72] (*Home | UNaLab*, n.d.). The project's outcome will enable the development of a European NBS reference framework on benefits, cost-effectiveness, economic viability and replicability of NBS, which will guide cities in developing and implementing their own co-creative NBS (*About Us | UNaLab*, n.d.). UNaLab has developed its first draft version of a technical handbook of NBS (*Technical Handbook of Nature-Based Solutions | UNaLab*, n.d.).

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[70] Belgium, Finland, France, Greece, Italy, Netherlands, Switzerland, United Kingdom (*About | ThinkNature*, n.d.).

[71] Eindhoven (Netherlands), Tampere (Finland) and Genova (Italy) (*Home | UNaLab*, n.d.)

[72] Stavanger (Norway), Prague (Czech Republic), Castellón (Spain), Cannes (France), Başakşehir (Istanbul), Hong Kong (China) and Buenos Aires (Argentina) (*Home | UNaLab*, n.d.)

12.1.11. URBAN GreenUP

Twenty-five partners from around the world are involved in the project. In order to lower the effects of climate change, improve the air quality and the water management, and increase the sustainability of cities through NBS, the project aims at developing, applying and validating a methodology for Renaturing Urban Plans. The methodology will be demonstrated and validated by implementing NBS in three runner cities[73]. Along with this, five follower cities[74] will enhance the replication potential at European and international level (Urban GreenUP, 2019). The catalogue was published in May 2018 and acts as a central reference in the development of Renaturing Urban Plans. It presents NBS that are built in at least one of the participating cities (CAR, SGR et al., 2018).

[73] Izmir (Turkey), Liverpool (United Kingdom) and Valladolid (Spain) (*Urban GreenUP*, 2019).

[74] Chengdu (China), Ludwigsburg (Germany), Mantova (Italy), Medellin (Colombia) and Quy Nhon (Vietnam) (*Urban GreenUP*, 2019).

12.2. Categorisation in existing catalogues

CATEGORIES FOR CATALOGUES	
URBAN GreenUP[75]	
- Green route	- Smart soils
- Arboreal interventions	- Pollinator
- Carbon capture	- Vertical GI
- SUDs	- Horizontal GI
- Flood actions	- Pollutants filter
- Water treatment	- Resting areas
- Green pavements	- Urban farming
UNaLab[76]	
- Greening interventions	- Water sensitive urban design measure
- Public green space	- (River) restoration
- Vertical greening	- Measures of bioengineering
- Green roof	- Other NBS
CLEVER Cities[77]	
- Building-scale interventions	
- Public and urban spaces interventions	
- Interventions in water bodies and drainage systems	
- Interventions in transport linear infrastructures	
- Interventions in natural areas and management of rural land	
- Interventions in ecological and habitat biodiversity	
Klimatek[78]	
- Building-scale interventions	
- Interventions in the public space	
- Interventions in water bodies and drainage systems	
- Interventions in transport linear infrastructures	
- Interventions in natural areas and management of the rural land	
- Coastline/coast interventions	

[75] (*Urban GreenUP*, 2019)

[76] (University of Stuttgart, 2019)

[77] (Politecnico di Milano, 2019)

[78] (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, pp. 19–21)

M. Kawa[79]
- Building-scale measures - Green measures for public space - Measures for linear grey infrastructure - Measures for water bodies and drainage - Measures for natural urban areas

Figure 51: Categories in existing catalogues

[79] (Kawa, 2020, pp. 34–37)

12.3. Explanation of each (co-) benefit

The explanation of each benefit was defined by M. Kawa. References of these can be consulted using her master thesis.

WATER BALANCE

Water balance consists of several flows. Water entering the system through precipitation (P) is transferred into either evaporation (E), surface runoff (R) or stored in the soil or a basin (S).

$$P = E + R + S$$

Urban areas consist of an increasing percentage of impervious surfaces. Moreover, urban drainage systems are often not designed to support the increasingly intense precipitation events. This causes an imbalance in the urban hydrological system where precipitation cannot be drained stored nor infiltrated in the soil with the risk of pluvial flooding.

Increasing the amount of green space and pervious surfaces in urban areas reduces surface water runoff as well as water scarcity and increases precipitation retention, infiltration into the soil, evaporation, and evapotranspiration. Implementing NBS, such as pervious pavements or rain gardens, will allow to slow down precipitation runoff so that it can be captured, retained, drained and/ or infiltrated into the soil. Additionally, water retained by the soil and absorbed by vegetation can be released in periods of drought through evapotranspiration.

The effectiveness in terms of water balance is expressed through the retention coefficient given in litres of water retained per square meter (l/m^2). The composition of the soil and flora selection is equally important for the effectiveness.

WATER QUALITY

Clean water supply is a basic requirement for many fundamental uses that humans rely on, such as consumption, agriculture, industry, and recreation. Quality of surface and groundwater is equally important for ecosystems and biodiversity. Monitoring water quality, however, depends on many variables. In Flanders following variables are measured to determine water quality: temperature, dissolved oxygen concentrations, chemical oxygen demand, nitrogen (NH_4-N, NO_2-N, NO_3-N), phosphate, total phosphorus, chloride, conductivity, and acidity (pH).

NBS including vegetation have the potential to ameliorate water quality by filtering out pollutants, sediments, and debris. Additionally, vegetation slows down the stream flow and establishes ecosystems contributing to the water' s health.

HEAT STRESS REDUCTION

Due to the UHI effect, urbanised areas experience elevated temperatures compared to the surrounding rural zones. Typically, surface temperatures in urban areas show a difference of 15 °C in comparison with green areas on a sunny summer's day. The differences are even more noticeable at night, as the urban surfaces with a low albedo or solar reflectance absorb the sun' s energy and release it in the form of heat radiation. Darker surfaces tend to have lower solar reflectance values than light coloured surfaces. Consequently, during periods of recurring high temperatures, the UHI effect results in heat stress, which can affect a community' s environment and quality of life, as it contributes to discomfort, and other heat related complaints.

Elevated temperatures result in an augmented energy consumption for cooling and exert pressure on the power network during peak periods of demand. An increase in energy consumption is generally associated with an increase in air pollution concentrations and greenhouse gas emissions, which have a negative effect on air and water quality. Poor air and water quality can cause diseases and thus have an indirect negative effect on human health.

NBS provide an opportunity to reduce the Urban Heat Island (UHI) effect by increasing the amount of water bodies and green cool spaces and surfaces in cities. Firstly, vegetation and specifically trees, green roofs and green facades provide shade and prevent hard surfaces, such as building roofs, facades, and grey infrastructure, from absorbing solar energy and warming up. Simultaneously they create cool environments that protect humans from direct solar radiation. Secondly, cool surfaces with a high reflection coefficient have a low albedo and limit the absorption and radiation of solar energy. Finally, water bodies and green areas have cooling properties through evaporation and evapotranspiration. The effectiveness of NBS regarding heat stress abatement is expressed in surface and air temperature reduction (°C).

AIR QUALITY

Poor air quality caused by pollutants has a significant negative impact on human health. NBS relying on the creation, enhancement, or restoration of green space in urban areas can play an important role in air quality. First of all, they can aid in filtering air pollutants such as fine particles (PM2.5) and removing carbon dioxide (CO_2) from the atmosphere. Secondly, they reduce air temperature, which impedes the creation of secondary contaminants, such as ozone (O_3). Finally, they contribute to the oxygen concentration through photosynthesis and improve the atmospheric composition for humans.

CARBON SEQUASTRATION

The increasing amount of atmospheric carbon dioxide is primarily caused by the universal use of fossil fuels and has significant global health implications.

Vegetation has the ability to capture carbon dioxide (CO_2) from the atmosphere and store it as carbon, while oxygen (O_2) is released through photosynthesis. Hence, it affects the air quality positively.

SOIL QUALITY

Urbanisation and rapid industrialization negatively affect urban soil quality due to large discharges of contaminants, which in turn have negative implications on ecosystems and human health.

Similarly, to its potential for improving water quality, appropriately selected vegetation has the potential to improve soil quality by filtering out pollutants.

BIODIVERSITY

Decrease in urban biodiversity both results from and affects humans. Our survival depends on benefits from ecosystems, which in turn depend on a broad range of living organisms. Biodiversity is often used to measure how healthy a particular ecosystem is. In other words, an ecosystem occupied by a wide variety of species will translate into a high biodiversity index. Urban biodiversity is threatened by an increase in non-natural materials, such as concrete and asphalt, and a higher rate in greenhouse gas emissions. Biodiversity loss can affect human health and well-being as it results in decreased resilience to climate change and extreme weather, and reduced quality or quantity of ecosystem services.

Implementing NBS can aid in protecting and enhancing biodiversity, through improved maintenance of existing ecosystems and creation of new urban ecosystems. To illustrate, parks, cemeteries, gardens, green roofs, and vegetated facades are potential urban biodiversity hubs. Enhancing the quality of gardens by increasing the variety in species and creating green corridors connecting green spaces to establish a network can improve biodiversity.

SOUND

Noise pollution caused by increasing urbanisation, industrialization and rapid growth affects ecology, human health, and quality of life, because it distracts, disturbs, and interferes with sleep.

NBS can contribute to noise reduction in multiple ways. First of all, vegetation can be used as an acoustic barrier to block out street noise. Secondly, selecting a pavement with sound attenuating properties can aid in muting traffic noise. Finally, green roofs and facades provide an additional layer to the building structure, which aids in noise attenuation through absorption by the substrate. It is worth mentioning that different physical processes are responsible for the sound muting effect of plants: scattering, absorption and shielding. Tree trunks and branches scatter and block the sound, which is the most effective way to reduce the noise level as fewer direct soundwaves are able to traverse. Leaves however, are too frail and do not contribute to attenuation. They are inclined to vibrate with the soundwaves, which can conceal the original sound. Coniferous trees with closely spaced needles, however, display a higher sound absorption. Green shielding is only effective for noise reduction with a dense layer of vegetation. The noise can also be attenuated indirectly, through absorption by unpaved soil and through reduced wind speed. Hence, sound attenuation depends on a few NBS related variables: density, height, surface of the vegetation and appropriate selection of plants. Noise reduction can be monitored by measuring the difference in sound level (dB) before and after the implementation of the NBS.

RECREATION AND PROXIMITY

Studies have shown that accessibility to qualitative green space positively affects human well-being, as it provides many benefits including social cohesion, recreation, and environmental education. Many citizens however have limited access to green space due to limited or non-existing availability of green infrastructure in their proximity. Implementing NBS can increase the amount and improve the distribution of accessible green space in the urban tissue.

HEALTH & WELL-BEING OF INHABITANTS

Many of the abovementioned benefits have significant impacts on human health and well-being. NBS can contribute to a broad spectrum of positive psychological and physiological benefits through providing opportunities for physical activity, relaxation, and stress relief and through the provision of ecosystem services, such as heat stress reduction and decrease in air pollution. In other words, NBS can contribute to improving overall human health and well-being.

PARTICIPATORY PLANNING AND GOVERNANCE

Involving citizens in planning, management and monitoring of projects allows them to become committed in their neighbourhood and promotes general awareness. Through monitoring inhabitants can easily contribute to data collection from implemented NBS.

URBAN REGENERATION

Urban regeneration refers to improvement in the economic, physical, social, and environmental conditions of an urban area that has experienced negative change and is considered non-resilient. NBS supporting the implementation and optimisation of green, blue, and grey infrastructure can contribute to urban regeneration and sustainable growth.

When implementing NBS it is crucial to consider the correlations between urban regeneration, urban planning and development, urban design and aesthetical value, urban ecology and sustainable energy and water use. For instance, well managed landscapes generally have a lower crime rate and enhance social capital. However, it should be noted that urban regeneration comes with a potential risk of issues concerning gentrification and social justice. For instance, housing prices often rise with urban regeneration which can result in social division.

IMPROVING LOCAL EMPLOYMENT

The implementation of NBS, on one hand, creates new economic opportunities for "Green businesses" and on the other hand, generates "Green-Collar Jobs" that can range from low-skill positions to high-skill jobs and enhance local employment.

LOWERING ENERGY CONSUMPTION

Elevated temperatures and heat stress result in an augmented energy consumption for cooling and an increase in air pollution concentrations and greenhouse gas emissions, negatively affecting air and water quality which has negative health implications.

NBS such as (blue-)green roofs and vegetated facades reduce energy consumption in buildings, as they perform as an additional insulating layer. Performance depends strongly on the set-up of the system and varies with substrate thickness and vegetation type.

12.4. Local incentives

This annex concerns local incentives for Brussels. The following list holds local incentives which can be related to the use of NBS. However, as local incentives are continuously altered, it is advised to verify on the regional and the communal websites which incentives are still valid.

LOCAL INCENTIVES RELATED TO THE USE OF NBS	
Regional – Brussels-Capital Region[80]	
Housing renovation subsidy	Concerns the renovation of various aspects of a building over more than 30 years old - e.g. the permeabilization of the soil intra-islands can be subsidised up to €1,000/housing unit
Energy subsidy	Concerns various improvements related to energy consumption - e.g. roof insulation can be subsidised up to €40/m² of roof, depending on income category
Communal – Anderlecht[81]	
Only regional subsidies	
– Auderghem/ Oudergem[82]	
Only regional subsidies	
– Berchem-Sainte-Agathe/ Sint-Agatha-Berchem[83]	
Complementary energy subsidy	
Composting bin	Refund of 50% of purchase price (up to €50)
Rainwater harvesting tank	Refund of €250/tank per household (up to 25% of investment)

[80] More regional incentives can be found on the homegrade.brussels website (*Primes | Premies*, n.d.; *Primes 2020*, 2020)

[81] (*Primes et Soutien | Anderlecht*, n.d.)

[82] (*Urbanisme | Auderghem*, n.d.)

[83] (*Primes | Berchem-Sainte-Agathe*, n.d.)

– Brussels[84]	
Composting bin	Refund of 75% of purchase price (up to €50)
Rainwater harvesting barrel	Refund of 75% of purchase price (up to €100/barrel per household)
Rainwater harvesting tank	Refund of €1,000/tank (up to 100% of purchase price)
Extensive green roofs	Refund of €20/m² (up to €3,500)
Semi-intensive green roofs	Refund of €25/m² (up to €3,500)
Intensive green roofs	Refund of €30/m² (up to €3,500)
Rainwater infiltration system[85]	Refund of 75% of construction costs (up to €500)
Land permeabilization	Refund of 75% of construction costs (up to €1,000)
– Etterbeek[86]	
Composting bin	Refund of 50% of purchase price (up to €50)
– Evere[87]	
Only regional subsidies	
– Forest/Vorst[88]	
Only regional subsidies	
– Ganshoren[89]	
Only regional subsidies	
– Ixelles/Elsene[90]	
Complementary energy subsidy	Refund of 10% of the regional subsidy (up to €200/household)
Complementary renovation subsidy	Refund of up to €800/renovated housing
Rainwater harvesting system	Refund of 10% of construction costs (up to €200)

[84] (*Primes vertes | Bruxelles.be*, n.d.)

[85] e.g. valley, ditch, infiltration trench with draining material, dry basin, wet basin

[86] (*Les primes | Administration communale - Etterbeek*, n.d.)

[87] (*Urbanisme & Environnement | Evere*, n.d.)

[88] (*Primes | Forest*, n.d.)

[89] (*Urbanisme | Ganshoren*, n.d.)

[90] (*Logement | Ixelles*, n.d.)

– Jette[91]	
Roof insulation	Refund of €10/m² (up to €250)
Rainwater tank	Refund of €250/installation
Composting bin	Refund of 50% of purchase price (up to €50)
Front flowerpot	Installation by the commune (plant purchase and maintenance at the expense of the requester)
– Koekelberg[92]	
Only regional subsidies	
– Molenbeek-Saint-Jean/ Sint-Jans-Molenbeek[93]	
Only regional subsidies	
– Saint-Gilles/ Sint-Gillis[94]	
Composting bin	Refund of 50% of purchase price (up to €50)
Rainwater tank	Refund of 50% of purchase price (up to €100)
– Saint-Josse-ten-Noode/ Sint-Joost-ten-Node[95]	
Complementary energy subsidy	Refund up to 25% of the regional subsidy
Complementary renovation subsidy	Refund up to 25% of the regional subsidy
– Schaerbeek[96]	
Subsidy for citizen's initiatives for sustainable development[97]	Refund up to €3,000 (for a citizen's group or an association)
Front façade planting	Installation by the commune
Front garden landscaping/ permeabilization of the front area	Refund up to 50% of the construction costs
Composting bin	Refund of 75% of purchase price (up to €75)

[91] (*Les Primes | Jette*, n.d.; *Primes Communales | Jette*, n.d.)

[92] (*Primes | Koekelberg*, n.d.)

[93] (*Les Primes | Molenbeek*, n.d.)

[94] (*Primes | Saint-Gilles*, n.d.)

[95] (*Urbanisme & Environnement | SJTN*, n.d.)

[96] (*Primes | Schaerbeek*, n.d.; *Primes environnementales | Schaerbeek*, n.d.)

[97] e.g. shared vegetable garden, common repair workshop, collective compost hub

– Uccle/ Ukkel[98]	
Natural pond	Refund of 50% of the construction costs (up to €150)
Rainwater tank	Refund up to €500
Extensive green roof/wall	Refund of €200 for the first 10m² and 10€/additional m² (up to €500)
Intensive green roof/wall	Refund of€ 200 for the first 10m² and 15€/additional m² (up to €500)
Rainwater infiltration system	Refund of €200 for the first 25m² and 4€/additional m² (up to €500)
– Watermael-Boitsfort/ Watermaal-Bosvoorde[99]	
Only regional subsidies	
– Woluwe-Saint-Lambert/ Sint-Lambrechts-Woluwe[100]	
Composting bin	Refund of 50% of purchase price (up to €50)
Extensive green roof	Refund of €200 for the first 10m² and €10/additional m² (up to €500)
Intensive green roof	Refund of €200 for the first 10m² and €15/additional m² (up to €500)
Rainwater tank	Refund of 20% of construction costs (up to €500)
Non-return valve on the sewage connection (against flooding)	Refund of 50% of construction costs (up to €200)
– Woluwe-Saint-Pierre/ Sint-Pieters-Woluwe[101]	
Only regional subsidies	

Figure 52: Local incentives related to the use of NBS

[98] (*Les Primes Environnementales Communales | Commune d' Uccle*, n.d.; *Primes et Logement | Commune d' Uccle*, n.d.)

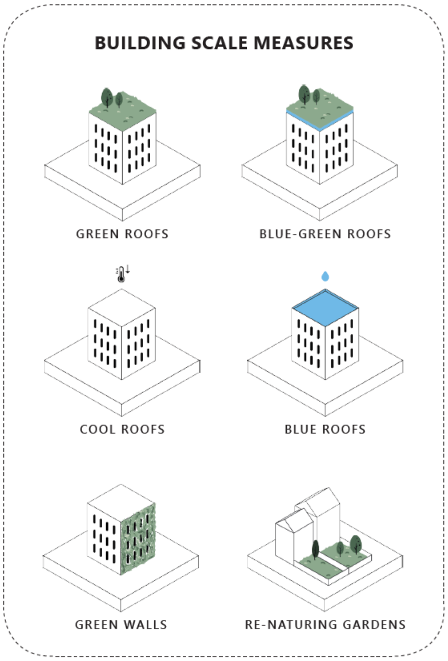
[99] (*Service Environnement | Watermael-Boitsfort - Watermaal-Bosvoorde*, n.d.)

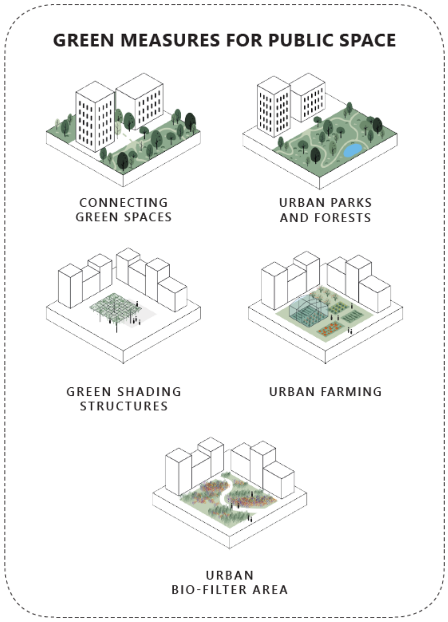
[100] (*Primes vertes octroyées par la commune | Woluwe-Saint-Lambert*, n.d.)

[101] (*Primes Energie et Rénovation | Woluwe Saint Pierre*, n.d.)

12.5. Schemes for the types of NBS

This annex references all the schemes developed by M. Kawa in relation to the types of NBS. [102]





[102] (Kawa, 2020, pp. 34–37)

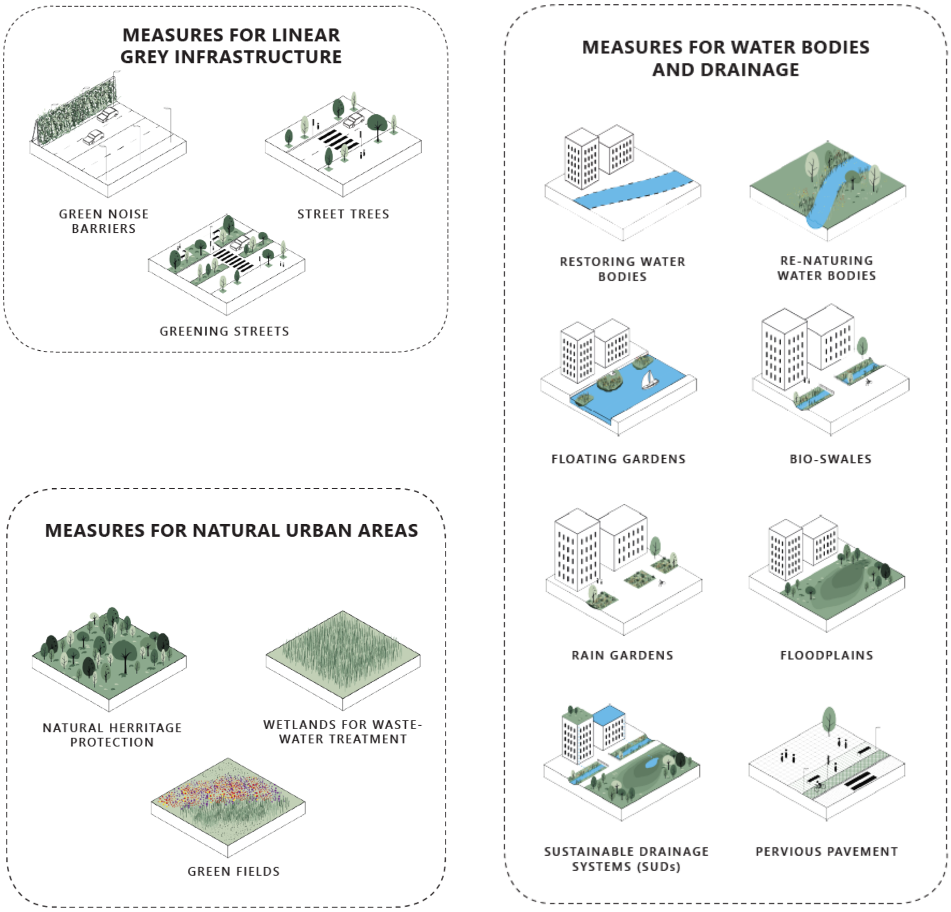


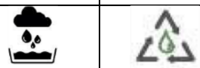
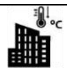
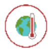
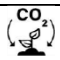
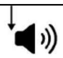
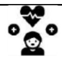
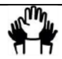
Figure 53: Schemes for NBS types (Kawa, 2020)

12.6. Online survey to define benefits' icons

An online survey concerning the representation of the benefits was performed using Google Forms. Each question concerned one benefit and was presented as multiple choice. The respondent had to choose one icon per question that he or she considered as the most representative in relation to the name of the benefit. The survey was spread by the means of social networks and 75 answers were collected. This annex illustrates all the icons that were used for the survey content. In addition, the complete results of the survey are outlined through pie charts with the percentage of answers, followed by a brief discussion.

12.6.1. Online survey content

Table 12: Used icons for the survey

	Benefits	M. Kawa[103]	Klimatek[104]	Naturvation[105]	URBAN GreenUP[106]	Eklipse [107]	IUCN [108]
Environmental	Water balance						
	Water quality						
	Heat stress reduction						
	Air quality						
	Carbon sequestration						
	Soil quality						
	Biodiversity						
	Sound						
Social	Recreation & proximity						
	Health & well-being						
	Participation						
	Urban regeneration					(*)	
Economic	Local employment						
	Lowering energy consumption						

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103 (Kawa, 2020, p. 41)

104 (*Nature-Based Solutions for Local Climate Adaptation in the Basque Country*, 2017, p. 23)

105 (*Urban Nature Atlas*, n.d.)

106 (*Challenges | URBAN GreenUP*, n.d.)

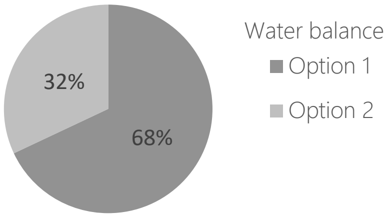
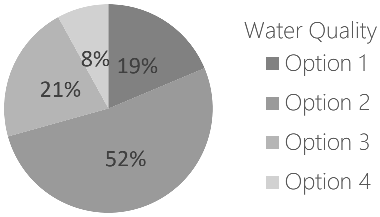
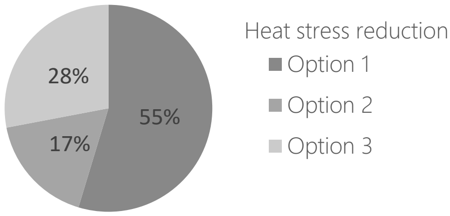
107 (Raymond, Berry, et al., 2017, p. 6)

108 (*Nature-Based Solutions to Address Global Societal Challenges*, 2016, pp. 12–15)

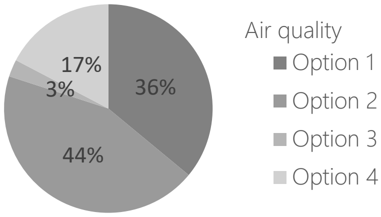
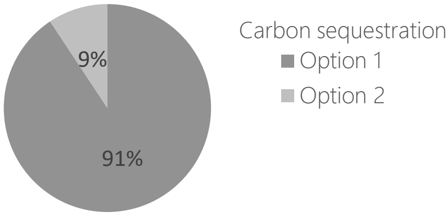
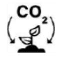
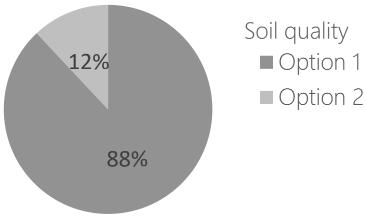
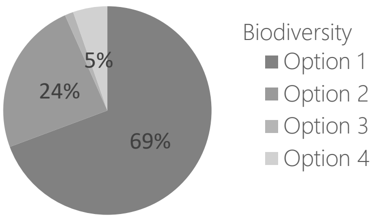
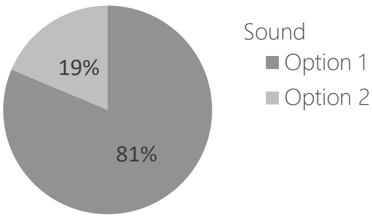
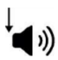
(*) not included in the survey; too similar to another icon which could bias the results.

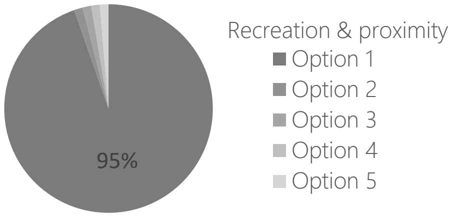
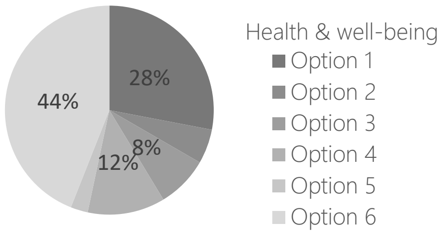
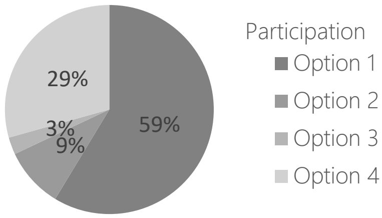
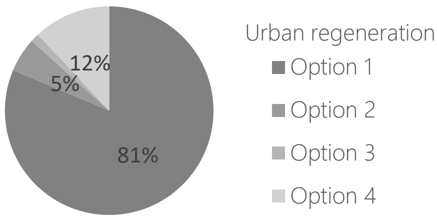
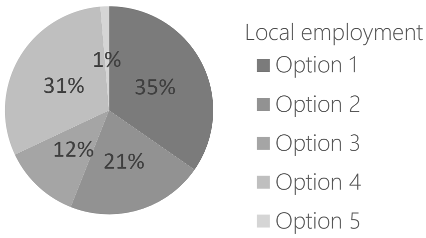
12.6.2. Online survey's results

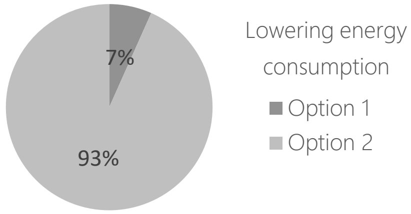
Table 13: Results of the survey

<table>
<tr><td colspan="2">Benefits</td><td>Results [109]</td><td>Chosen icon</td></tr>
<tr><td rowspan="3">Environmental</td><td>Water balance</td><td>
</td><td></td></tr>
<tr><td>Water quality</td><td>
</td><td>
</td></tr>
<tr><td>Heat stress reduction</td><td>
</td><td>
</td></tr>
</table>

[109] The number of the options corresponds to the presented order of the icons in the previous table.

	Air quality		
	Carbon sequestration		
	Soil quality		
	Biodiversity		
	Sound		

<table>
<tr><td rowspan="4">Social</td><td>Recreation & proximity</td><td>
</td><td></td></tr>
<tr><td>Health & well-being</td><td>
</td><td></td></tr>
<tr><td>Participation</td><td>
</td><td></td></tr>
<tr><td>Urban regeneration</td><td>
</td><td></td></tr>
<tr><td>Economic</td><td>Local employment</td><td>
</td><td></td></tr>
</table>

	Lowering energy consumption		

12.6.3. Discussion

The results of the survey are illustrating the answers collected by 75 respondents. It was chosen to spread this survey through social media to people who are not specifically related to the subject. This way, it can be made sure that the icons are understandable by anyone, which will provide a user-friendly catalogue.

For several benefits, a clear majority for a specific icon can be noticed. For instance, carbon sequestration, soil quality, sound, and lowering energy consumption show a majority over 80%. This mainly happens when only two icons were part of the question. It can therefore be assumed that the percentages are more scattered when a large amount of choice is possible. This can, in some cases, induce similar results for various icons. As an example, local employment concludes in 35% for Option 1 and 31% for Option 4, which respectively corresponds to 26 and 23 answers over 75. Therefore, in order to have more probative results, the survey might be rethought to include only two possible choices per benefit. This may be achieved by taking in consideration the two best icons for each benefit and redoing the survey.

Moreover, even though it was specified in the survey not to take it into account, respondents may have been influenced by the colours of the icons or the cohesiveness between each question. In order to avoid that, the icons could have been redrawn before the survey in order to provide a similar layout for each of them.

ABSTRACT

As a result of both climate change and demographic growth, cities are currently facing major environmental, social, and economic challenges. Urban nature-based solutions are increasingly seen as ideal methods to deal with these issues. These have the ability to mitigate the effects of extreme climate events as well as to improve the liveability of the city. In order to promote the use and to increase the understanding of urban NBS, a user-friendly catalogue allowing an efficient search for, and choice of, suited NBS is needed.

One exhaustive definition of urban NBS will be drafted in this master thesis. In addition, a comparative analysis of existing documents about urban NBS will be performed in order to indicate contemporary issues. The target audience of the to-be-drafted catalogue is researched to fully answer to the users' needs. A user-friendly paper version of the catalogue, as well as a digitalised flexible search tool, will be delivered. For this reason, the structure, content, and representation of the proposed catalogue are defined in depth. Finally, to provide the user with a more complete catalogue of NBS, innovative solutions which are specifically interesting for Brussels are included as well.