EXPLORING OPPORTUNITIES FOR REWILDING THE BUILT ENVIRONMENT THROUGH NATURE-INCLUSIVE DESIGN

CASE STUDY BOERHAAVEWIJK, POST-WAR RESIDENTIAL NEIGHBOURHOOD IN HAARLEM, THE NETHERLANDS

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ABSTRACT

With the worldwide biodiversity decline and cities that should adapt to climate change, rewilding the built environment to restore biodiversity and increase the degree of natural areas is necessary. Yet, there is currently no established overview of potential rewilding strategies for urban environments. This study explores various opportunities for rewilding the built environment through nature-inclusive design and presents a toolbox that architects and urban planners can implement in the design process to create opportunities for biodiversity and make cities greener and more resilient. Furthermore, the suggested framework can be used to create strategies on the larger scale. Rewilding strategies, however, are highly dependent on the characteristics of a specific environment and thorough site research is necessary to come up with suitable strategies. The typical Dutch post-war neighbourhood Boerhaavewijk in Haarlem is taken as a case study to demonstrate the application of these strategies.

KEYWORDS

Rewilding, Biodiversity, Nature-Inclusive Design, Urban Ecology, Ecosystems, Patch-Corridor-Matrix, Species, Boerhaavewijk, Haarlem

I. INTRODUCTION

"[…] over the years, we lost our balance. We moved from being a part of nature to being apart from nature." (Attenborough & Hughes, 2020, p. 125). This is evident from our planet's biodiversity—one of the signs of an ecosystem's health and resilience (Vink & Vollaard, 2017)—which has been facing a loss for over 50 years and continues to decrease today (WWF & ZSL, 2022; IPBES, 2019). Climate change is harming biodiversity worldwide, not least in urban environments, which are facing rising temperatures, air pollution and water scarcity, among others (IPCC, 2018). Additionally, urban landscapes increasingly need to cope with extreme weather conditions including floods, heat waves, and cyclones (Ebi et al., 2021). This calls for measures to restore biodiversity worldwide, particularly in cities, which account for sixty to eighty percent of global greenhouse gas emissions. We are facing a future in which we need to accommodate more people, provide a higher quality of life, and mitigate the consequences of climate change (Lehmann, 2021). Instead of decreasing the surface of natural areas across the world, the degree of natural areas needs to strongly increase to stabilise biodiversity, and with it our planet (Attenborough & Hughes, 2020). Urban regreening initiatives enable 'repairing' and restoring some of the harm done to ecosystems while boosting urban resilience. Attenborough (2020) states "[…] the rewilding of the world will suck enormous amounts of carbon from the air and lock it away in the expanding wilderness […] this nature-based solution would be the ultimate win-win—carbon storage and biodiversity gain all in one" (p. 136). Lehmann (2021) confirms

that rewilding provides significant opportunities to increase biodiversity, develop self-sustaining ecosystems, and mitigate climate change.

The term ‘rewilding’ is mainly used regarding the reintroduction of species of wildlife—flora and fauna that have been displaced or eradicated from the area. The concept of rewilding within natural areas is often applied through ‘restoration by letting go’, allowing nature to take the driving seat (Tree & Schlosser, 2019), and green spaces to develop without human intervention (Phillips, 2022). It serves as a form of large-scale biological and ecological restoration to regain functional and resilient ecosystems (Noss, 1992; Noss & Cooperrider, 1994). The term is now widely used, although its meaning has become varied with wider use. It retains its original meaning while also being used to describe restoration in general, recovery of Pleistocene species, and urban greenways (Pettorelli et al., 2019). There is ‘ecological rewilding’ relating to biophysical nature, rewilding of water, land and wildlife. And on the other hand ‘human rewilding’, which relates mainly to personal, social or cultural dimensions, such as urban rewilding. Human rewilding is not about reinforcing the strict separation between humans and nature, but about interweaving those spheres, especially giving space to natural processes in the context of the current, all-controlling, human dominance on Earth (Arts et al., 2022).

Bringing nature into people’s lives has a positive impact on human health and well-being, as concluded by Nieuwenhuijsen et al. (2022), Kondo et al. (2018), Konijnendijk (2022), and Marselle et al. (2021). According to Lehmann (2021), “Contact to nature is essential for human existence, urban well-being, and good quality of life” (p. 1). All green spaces within urban areas, whether large or small, contribute to reducing stress and mental illness. Unfortunately, a lot of cities worldwide do not provide inhabitants with green spaces or access to it (Lehmann, 2021). Rewilding urban areas is thus required to foster or establish people’s connection to wild environments, and vice versa, it provides a wide range of advantages for nature, including decreasing biodiversity loss and recovering damaged ecosystems (Lehmann, 2021). Even on smaller scale, rewilding is valuable, because “no tract of land is too small for the wilderness idea” (Leopold, 1942, p. 24). Rewilding strategies that include good urban design and planning can make a profound positive contribution to solving the problems related to climate change and societal challenges (Lehmann, 2021).

1.1 Objective

This paper focusses on exploring opportunities for rewilding the built environment to create more biodiversity in urban areas by presenting rewilding strategies through practical examples and literature study. To demonstrate the application of these strategies, the residential neighbourhood Boerhaavewijk in Haarlem, the Netherlands, is taken as a case study.

The research question of this paper is: *How to rewild the built environment through nature-inclusive design in a residential neighbourhood?*

This question can be answered using the following sub-questions:

- *How can the concept of rewilding be applied in the built environment?*
- *What are the requirements for a nature-inclusive design to be an ecological connection between the built zone and its surrounding landscape?*
- *How can rewilding through nature-inclusive design create opportunities for biodiversity in a residential neighbourhood in the Netherlands, with Boerhaavewijk as a case study?*
- *What are the specific species and their requirements in Boerhaavewijk?*

1.2 Case Study

In Schalkwijk, the urban fringe of the city of Haarlem, Boerhaavewijk is a typical 1960s reconstruction neighbourhood, characterised by a spacious layout, long sightlines, and wide distances. The district has a strongly inward-looking character with clear boundaries and the building blocks create separate areas within the neighbourhood (Gemeente Bestuur Haarlem, 2018). Boerhaavewijk rests on a peat meadow area and reclaimed land makes up the natural reserve that borders the district's eastern edge. The Poelpolder to the east is an example of a typical Dutch polder on the outskirts of the city. It establishes a distinct barrier between the city and the surrounding landscape and separates rural from urban. Neighbourhoods often show a lack of green connectivity, such as park connectors or green corridors, both internally and with the surrounding region. They also tend to have an excessively paved surface, as does Boerhaavewijk, which is counterproductive for nature development. The existing green in neighbourhoods tends to be primarily artificial landscaping, such as lawns, sports fields, and private gardens. This typical Dutch post-war neighbourhood Boerhaavewijk, which is due for renovation and offers ample opportunities to incorporate urban rewilding, is taken as a case study to demonstrate the application of this paper's rewilding strategies.

1.3 Paper outline

In part 2 'Strategies to Rewild the Built Environment', several strategies are examined with the use of practical examples. It shows the possibilities of rewilding on different scales and in different contexts. For a larger scale strategy, Kowarik's (2018) framework is put forward in which urban wilderness is seen as a social-ecological system. The 'Four Natures Approach'(Kowarik, 2018) and the '3-30-300 rule' are suggested to use within this framework.

In part 3 'Rewilding Strategy for Boerhaavewijk', this paper's strategies are applied to this residential neighbourhood in Haarlem, the Netherlands. Starting with a historical analysis of the area, followed by a list of the specific species and their requirements to come up with a suitable rewilding strategy by using Kowarik's (2018) framework and the practical examples from the toolbox from part 2.

II. STRATEGIES TO REWILD THE URBAN ENVIRONMENT

As Attenborough describes, all countries are developing countries; the poorer countries have the challenge to improve their living standards in unprecedented ways while achieving a sustainable footprint, and the wealthy countries have to maintain their high quality of life while drastically decreasing their environmental footprint. Restoring nature thus becomes a practical policy option for governments (Attenborough & Hughes, 2020). There are many different rewilding strategies which can be applied in many different ways and on many different scales in a city or neighbourhood. Which ones are suitable depends on the characteristics of each individual environment. Nonetheless, Arts et al. (2022) describe two general preconditions for rewilding to be possible in urban areas: the built environment needs to maintain the societal functions it fulfils for its residents. Secondly, the residents of the area need to accept nature into their society and daily lives. Both conditions are necessary for biotic and antibiotic processes to enhance each other. Yet, rewilding does not need to be implemented directly on a large scale. Local applications at garden-, building-, district- and park-level can already greatly enhance biodiversity (Arts et al., 2022). However, according to Maller et al. (2019), research on greening cities is still in its early stages, and the literature is unclear on how rewilding strategies are handled to increase city resilience. In this part, various strategies at these different scales and in diverse environments are outlined using examples from practice. These are all recent urban rewilding projects which are categorised to, eventually, form a toolbox which architects and urban planners can use in the design process to create nature-inclusive designs in the urban environment.

2.1 Ecological sculptures & elements

Starting at the smaller scale, this section shows that it is possible to give nature a helping hand through elements or sculptures that stimulate natural processes. For example, the application of amber-coloured, bat-friendly lighting is less disruptive to bats (Vink & Vollaard, 2017). Providing bats with a place to stay is an often integrated element in the façades of buildings, for example through the ceramic bat boxes in the masonry to a joint design by Dick van Hoff and Koninklijke Tichelaar. In Boekelo in the Netherlands, bats were given compensation in the form of a bat tower, because bat roosts were removed during the renovation of a motorway. This tower serves as a breeding and wintering ground for the common pipistrelle, as well as a summer and wintering ground for the serotine bat and the endangered brown long-eared bat. Throughout the whole tower, the bat has been considered: the plinth has a rough texture to provide a hold for bats to crawl in from below, cavities are provided in the roof, and inside, the gypsum walls have openings of 2 to 3 centimetres. Another Dutch design is a 'bat bridge' situated on the route of different bat species. The varied stays were designed with the behaviour and needs of bats in mind (Vink & Vollaard, 2017).

Similarly for birds, nesting can be stimulated in building façades, as done in the WNF building in Zeist where nesting spaces are built into the façade. For example, the common swift originates from rocky areas and sees buildings as rock formations. Centuries ago, people started to live in a form of symbioses with the common swift, providing them with openings to fly into buildings, while the birds catch insects which are irritating to humans (Vink & Vollaard, 2017).

Insects are also increasingly considered in designs. The sculptural 'buzzbench' in Amstelveen is designed for wild bees and other insects. In Rotterdam the 3-kilometre-long 'beeline' connects the northern part of the city with the natural environment, and includes insect hotels and new management of the roadsides of riverbanks. Next to strengthening the ecological network, the route has an educational function as well. The Sky Hive in Maastricht lifts bees up into the sky and can be a suitable solution to avoid potential clashes between humans and bees. Insect hotels can be found in several city parks in London, which are beautiful sculptures made for numerous insects. The 'crinkle crankle wall' built-in Distripark Eemhaven in Rotterdam, functions as a noise barrier and offers shelter to wind- and temperature-sensitive species. Plants can grow on it and animals can shelter between the rocks (Vink & Vollaard, 2017).

Elevated paths, for example in Natur Park Südgelände, are a way to reduce human interference with nature, allowing natural processes to occur, an 'ideal setting for rewilding' (Owens & Wolch, 2019). In the Shangri-La Botanical Gardens and Nature Centre in Orange, Texas, buildings are placed above the ground on a helical pier base to reduce habitat incursion (Jodidio, 2012). And in Amsterdam in the Circular Breeding Ground de Ceuvel, there is a diversity of plants beneath the jetty and between the built units, resulting in a biotope for insects, birds, and small mammals (Vink & Vollaard, 2017).

Elements to support the local biodiversity can also be made for plants, such as the Flower Archway in the Botanical Garden in Culiacán, Mexico. The plants that cover this architectural structure engulf it, making it almost impossible to discern the distinction between the 'built' shape and nature. Though the construction is similar to garden trellises, the growing greenery makes it appear to be an organic element of the garden itself (Jodidio, 2012). The so-called 'Supertrees' in Singapore support over 158,000 plants and offer comparable functions to living trees, such as heat absorption, shade, and rainwater filtering (Harris, 2021).

Hence, there is a myriad of possibilities to support and enhance biodiversity with sculptures and elements, and in many cities around the globe, these are increasingly being applied. However, given the smaller scale of such measures, they should ideally form part of an integrated, larger-scale strategy for a green urban environment, so their impact can be maximized.

2.2 Green buildings

The trend of ‘green roofs’ and ‘green façades’ is becoming increasingly popular around the world and is offering an exciting new way of promoting biodiversity in cities (Liberalesso et al., 2020). The Environmental Education Centre in Hoorn, the Netherlands, is not just a building offering educational meaning, but serves as space for nature itself, as 85% is covered with vegetated soil (Jodidio, 2008). This unusual combination of nature and building is increasingly emerging around the world. Examples of so-called ‘green roofs’ include the sloped green roofs of the Holocaust Museum Los Angeles, where a variety of types of grass are used to establish and encourage biodiversity (Lamoth, 2018), the Hypar Pavilion Lawn in New York which is oriented away from the noise of the city to generate bucolic urbanism (Jodidio, 2008), and the Library of Delft University of Technology, which also has a sloped lawn roof accessible to people. However, the extent to which they promote biodiversity depends on the type of vegetation—yet another simple ‘grass paving’ has far fewer natural benefits than diverse vegetation. Implemented correctly, however, green roofs may serve as significant oases for plants and animals, especially birds and insects. Scientists are currently testing a wet variant of the green roof, known as a polder roof, on the top of the N100 building, the Dutch Institute of Ecology, in Wageningen. Most green roofs have a thin layer of sedum vegetation, which can withstand dry periods but are less effective in collecting water. The ‘blue-green roof’ of the N100 building includes space for grasses and bigger plants, as well as underneath water storage (Vink & Vollaard, 2017).

Alongside green roofs, green façades are being developed as well. The Bosco Verticale in Milan was the first high-rise residential building to feature elevated nature. The aim is to contribute to reforestation and naturalization in the city and to be an example of sustainable housing (Well & Ludwig, 2020). However, it appeared that this form of sustainable housing was only accessible to the rich, due to the high cost of an apartment within the building and the monthly costs to maintain the greenery, about 1500 euros per apartment (Vink & Vollaard, 2017). But the architect of the Bosco Verticale, Stefano Boeri, has proven with the Trudo Tower in Eindhoven that vertical green is also feasible for social housing. The buildings are experienced as a ‘green escape in urban daily life’, hence bringing nature into urban areas is a valuable aspect of this typology (Visser, 2019). Moreover, Visser (2019) argues that vertical forests have a significant influence on how people see the urban environment and may develop into meaningful green places where people can meet, reinforcing a sense of belonging. This building typology contributes to a greener and more biodiverse city, not only due to its lush appearance from the abundance of plants and trees but also because it draws in a wide variety of fauna (Boeri, 2017). Furthermore, such vertical forests are conceived as metropolitan landmarks as they are vibrant, eye-catching buildings, which can raise awareness of the need for nature in cities. As nature slowly but surely takes over as the greenery grows on the balconies, a vertical forest may ultimately have a green multiplier effect on the adjacent area. Currently, however, the Bosco Verticale and the Trudo Tower remain somewhat lone green islands. It would be more valuable if multiple such green high-rises in an area could form connections, both on an ecological and societal level, contributing to creating a green corridor in the urban environment. More examples include the Hedge Building in Rostock and the M6B2 Tower of Biodiversity in Paris, where local biodiversity is stimulated by actively using the wind along the high roof and façades to disseminate the seeds of the plants throughout the city (Jodidio, 2008; Vink & Vollaard, 2017).

Green buildings are not necessarily dependent on the availability of soil, as the Caixaforum Vertical Garden in Madrid shows that vegetation can prevail as long as it receives a proper mix of water with dissolved minerals. This also provides a way to mitigate damages to the building’s walls by roots (Jodidio, 2008). The Caixaforum Vertical Garden also interacts with the botanical garden across the street, contributing to a green corridor. Similarly, the Mercator Sportplaza in Amsterdam is completely covered in plants, forming a green link with the highly vegetated Rembrandtpark. Both on the roof and the façade, more than fifty trees, shrubs, and plants receive optimal amounts of water through a sophisticated watering system (Vink & Vollaard, 2017).

Another example of such a high-tech vertical garden with an integrated water system is the Oasis of Aboukir in Paris. The outer layer of the wall is meant to resemble moss, by working as a sponge. Again, nutrient-rich water is delivered to the plants via a network of pipelines, making optimal uses of gravity to regulate the flow down. A gutter at the bottom of the wall gathers excess water for reuse. Those vertical green walls without soil do, however, depend on technology. While they do depend on more sophisticated technology, these soil-free strategies offer another alternative to green buildings (Vink & Vollaard, 2017).

In summary, green buildings are increasingly emerging around the world, and are showing promising potential for rewilding urban environments: they create appealing green environments, increase biodiversity, provide shelter for animals, like birds and insects, and serve as heat-absorbing areas (Vink & Vollaard, 2017).

2.3 Gardens & parks

On a slightly larger scale within urban context, strategies for city gardens and parks are set out here. Starting with water, since water aids in the cooling of urban environments, hence enhancing the ecological coherence of so-called 'green and blue' networks provides opportunities (Vink & Vollaard, 2017). Urban water bodies in combination with waterside vegetation are increasingly used in city parks, such as the Summer Garden in Beijing and the English Garden in Munich, to create natural corridors in cities (Breuste, 2020). Parks within cities are considered pleasant and contribute to cooling the urban heat. They can even be created in areas with little free space, as shown in Chicago's Millennium Park, which covers a parking garage. Although it is clearly an urban garden, the artificial characteristics are not obvious, and the convivial atmosphere provides little indication that it was built on top of a parking garage (Jodidio, 2008). An urban garden may also be a smaller element, but still with a significant contribution, as 'the Garden that climbs the stairs' in Bilbao. This dynamic and colourful urban space comes across as a landscape taking over architecture and public space and its fragrant flowers are attracting both insects and strolling visitors (Jodidio, 2008).

Parks and gardens may also be elevated, as seen at the High Line park in New York, which was built atop an old elevated railway, where nature has reclaimed an important element of a former vibrant piece of urban infrastructure (Jodidio, 2008). Spaces like these that are no longer in use, can be put to good use as new urban gardens. The architect Palleroni demonstrates this with the Zhong-Xiao Boulevard in Taipei, where he created ecologically oriented projects which are weaved into an existing urban context. He transformed previously abandoned and unused urban areas into functional, environmentally valuable gardens (Jodidio, 2008). Collective gardens and green spaces often work very well too, bringing local residents together, like in Eden Bio in Paris. The aim is to create new, strong ecosystems and at the same time, provide meeting places for residents which strengthens the identity of the neighbourhood (Vink & Vollaard, 2017).

As Breuste (2020) states: "Wildlife gardens are a model for the reintegration of nature […] This notion is becoming increasingly attractive as an individual and personal countermeasure against denaturation" (p. 34). Individuals can provide a home for many wild plants and animals in their own gardens by allowing natural processes to take place and reducing maintenance. The gardener is given a sense of accomplishment in contributing to nature and a healthy environment (Breuste, 2020). In Arnhem, there is a so-called Rode-lijsttuin (Red List City Garden) concerning a list of endangered plant and animal species. Individuals and smaller projects can contribute to opportunities for biodiversity and protecting these species when designing for them. For example, they fill the edges of the garden with vegetation that prefers shadier conditions, while the terrace follows the sun's path so the owner can sit in the sun during the whole day. With this type of nature management, where both nature and people are considered, individual residents can contribute on small scales in their own gardens (Vink & Vollaard, 2017).

In the Netherlands, residential gardens are often separated from each other by fences. The 'Buurjongens' Groenschutting' (Boy next door's Green Fence) is a new design for fences which tackles both the social divide and the environmental issue. The modular design offers 'windows' to communicate with neighbours, flower and plant containers, insect hotels, feeding tables for birds and numerous nesting boxes. It also includes a trellis for climbing plants and smaller land-based animals, like hedgehogs, can pass through small spaces between fence and ground (Vink & Vollaard, 2017).

All together can be said that parks and urban gardens can provide pleasant, cooling environments, while also aiding in the reintegration of nature. Urban parks, both large and small, can be created in areas with little space, like on top of parking garages and unused elevated railway lines. Designers are weaving ecologically-oriented projects into existing urban contexts and collective gardens are bringing local residents together. Additionally, individuals can contribute to opportunities for biodiversity in their own gardens.

2.4 Ecological connections

Extending green spaces throughout the built environment as well as improving access to green areas, is anticipated to have a significant positive impact on a variety of factors, including human health, ecosystem services, and ecosystem restoration (Lehmann, 2021). While extending, creating green corridors connecting these green spaces is vital for forming urban landscapes. Natural connections between landscapes are often severed by human activities due to urbanisation, e.g. through the construction of motorways. Environmentalists and conservation biologists have urged for the preservation of those natural connections and believe that landscape connectedness improves population viability for many species (Beier & Noos, 2008). However, connections between nature within the city or neighbourhood is even so crucial to give biodiversity the best opportunities (Breuste, 2020). In their research on the connectivity of habitat corridors, Beier and Noos (2008) found that well-designed research frequently supports the corridors' effectiveness as a conservation measure. Almost all research they found on corridors suggests that animals in nature benefit from or use them and at least no study has yet shown that ecological corridors have a negative impact. Furthermore, larger gene pools are needed to prevent inbreeding within species in order to have a healthy and varied biodiversity. This results in the need for a larger habitat and thus, connections to other habitats if expansion is not possible (Vink & Vollaard, 2017).

The 'patch-corridor-matrix' model is often used to understand a landscape by reducing its complexity. A distinction is made between three elements. Patches are regions of homogeneous ecological units which visually distinct from their surroundings. Corridors are thin, linear strips of land which on both sides differ from the matrix. The function of a corridor is determined by the context and form, e.g. a barrier, a filter or a habitat conduit. A matrix is the most widespread and linked landscape element type existing, playing a prominent role in landscape functioning and surrounding patches. This method often used within landscape ecology, is based on the centrality of an organism. The model simplifies the landscape from the perspective of a specific species, with patches representing favourable habitats connected by corridors within an unfavourable matrix setting (Antrop, 2021). This matrix is unfavourable to this particular species but does serve other species. Conservation initiatives frequently advocate the use of corridors to facilitate dispersion among fragmented populations. The corridors themselves can, however, not only determine the extent to which this tactic improves an organism's connectivity, but also the composition of the matrix. That is why the research of Baum et al. (2004) suggests that in

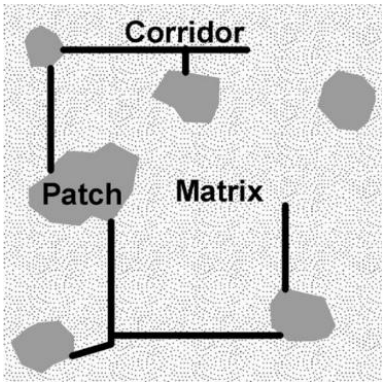

Figure 1: Patch-Corridor-Matrix landscape model (Hedblom, 2008)

strategies to enhance dispersal between fragmented populations, the matrix should be addressed alongside corridors since it is an integral component of landscapes.

Ecological connections are being applied in cities, such as Singapore's Nature Ways which form over 90 miles of green corridors providing structures for biodiversity and connecting green spaces. These corridors cater to the needs of different species and at different heights by replicating the layers of the ecosystem with canopy, emergent, shrub, and understory layers (Harris, 2021). Another way to reach different levels of an ecosystem is by the repetition of 'vertical forests'. If multiple (high-rise) buildings in an environment are covered with greenery, together they can add value to ecological connectivity in that area. One 'vertical forest', such as the Bosco Verticale in Milan, is a bit of a lost island that will not contribute much to creating connections for biodiversity (section 2.2).

As mentioned above, urban development causes limitations in ecological connections. Fauna passages are therefore a solution to connect separate areas, provide species with larger habitats and prevent roadkill. The fauna passage of the Haagse Bos in the Netherlands is an excellent example of the creation of an ecological connection for small mammals such as the pine marten and the red squirrel. They can now cross the motorway to the adjacent natural area, thanks to the bridge equipped with wires attached to surrounding trees (Vink & Vollaard, 2017). Even in the air, techniques are provided for animals to cross safely, as has been done with the artificial tree as an 'ultrasonic beacon' in the middle of a motorway in Friesland, the Netherlands. Several bat species fly safely across the road along the rows of trees and this beacon. This principle of hop-over for bats is possible because of the higher vegetation that provides the right shelter for a safe crossing (Vink & Vollaard, 2017).

Ecoducts, the enlarged version of fauna passages, are suitable solutions to make the crossing for wildlife possible. In Groningen, the Netherlands' first urban wildlife crossing comprises a four-metre-wide bicycle and pedestrian path separated by an apple rose hedge from a fauna passage of 3.5 metres wide. A planting substrate and stumps were placed in this section of the bridge to offer cover for wildlife such as foxes, hares, hedgehogs, and deer. Information on the usage of the wildlife crossing is given through a webcam and an interactive panel (Vink & Vollaard, 2017). Besides preventing crossing animals from being hit by a car, ecoducts also contribute to a more natural environment since it mimics the habitat of local ecosystems. By creating green corridors in this way, the safety of the animals should be taken into account, as well as data about the local climate. Ecoducts consist of earth and undergrowth from the area, and small or medium-sized trees can be added. They can be found worldwide, adapted to the local situation. Australia, for example, has renovated existing tunnels that crossed motorways to make suitable ecoducts for koalas. Near Sacramento, a 15-centimeter-wide mini-tunnel allows frogs to go to the swamp by passing under the road. In Alberta, one of the largest ecoducts in the world was constructed for the local wildlife to cross the Trans-Canada Highway and over 150,000 crossings of bear, elk, deer, rabbit and other smaller animals were logged between 1996 and 2016. Reindeer was an important aspect of the construction of several 'reinducts' in Sweden, and so were monkeys the biggest victims of road kills in Brazil where they now have exclusive footbridges for monkeys, and so on, there are plenty more examples of the use of ecoducts around the world (Ecoduct: The green bridge that saves lives and beautifies the world's roads, n.d.). In the Netherlands, ecoducts are part of the Ecological Main Structure, aiming to improve biodiversity. With less than ten percent of land area consisting of nature, the Netherlands had the lowest percentage of natural falcons in the world in the 1980s, and this acreage was only decreasing (Tweel & Boom, 2021). This Ecological Main Structure (Ecologische Hoofdsturctuur, EHS) is the result of development since 1990 because of the disappearance of nature and biodiversity (Ecologische Hoofdstructuur, n.d.). It is a national network of nature reserves, big and small, and the connection between the areas allows flora and fauna to spread. Not only ecoducts over motorways but also tunnels under roads are part of this structure (Ecologische Hoofdstructuur, n.d.). Within this EHS map, nature

has priority in the designated areas to protect flora and fauna from dying out in isolated areas and to prevent nature areas from losing their value (Natuurnetwerk Nederland (ehs), n.d.).

When connecting green spaces, there will be an ecological gradient with a transition between different biotopes. There will be a transition when connecting nature and the built environment; an urban-rural environment gradient. This gradient can be smoothened with rewilding strategies to connect certain areas (McDonnell & Pickett, 1990; McDonnell et al., 1993).

Hence, the creation or expansion of green spaces in urban areas can have a number of positive impacts on human health, ecosystem services and restoration. Connecting these green spaces with green corridors is seen as important for forming a successful urban landscape, as it can help to prevent the severance of natural connections caused by urbanisation and provide a larger habitat for biodiversity.

2.5 Human aspects: dialogue, appreciation, and education

An important aspect of any rewilding project is an integral approach to the design process, which includes all stakeholders (e.g. designers, ecologists, local community, etc.). In his research on the integration of ecological understanding in the design process, Felson (2013) highlights the importance of interdisciplinary discussions between ecologists and designers. Successful collaboration between them requires an open and inclusive platform for input, shared ownership and managed dialogue towards integration. Equally essential are analyses of the site conditions, land use history and patterns, and to have site visits and, meeting with stakeholders during the design process (Felson, 2013). Another important human aspect as part of a rewilding strategy is to increase appreciation for urban wilderness. As an example, these concepts are applied in the German cities of Dessau-Roßlau, Hannover, and Frankfurt am Main, all of which participate in the German project “Städte Wagen Wildnis” (Cities Dare Wilderness). Active dialogues with residents and experts on ideas and experiences create new opportunities to allow natural processes into diverse urban green areas. Furthermore, much attention is paid to creating an appreciation for nature among the city residents. The aim is to improve species and habitat diversity as well as the quality of life for the inhabitants by “bringing people and nature together”. This is done through educational and informative events, and the processes that take place on a piece of urban green space are well documented and shown to visitors. In Hannover, for example, all areas of the project are thoroughly documented to increase public interest and appreciation. Since Frankfurt is growing rapidly, communicating the intrinsic values of the precious urban islands of natural succession is the goal. This is done through an educational programme with presentations and workshops to generate lasting interest and appreciation for urban wilderness (Welcome to “Städte wagen Wildnis”! Urban Wilderness, n.d.).

Education is a widely used strategy to generate interest and knowledge about nature and urban wilderness among residents and visitors. Often, this is done through information boards that teach visitors about the flora and fauna in a certain area, for example in Natur Park Südgelände in Germany. This park is even accessible for the blind since it is provided with audio descriptions to guide visitors through the park. To make the visit even more fun, visitors can enjoy a range of artwork along the two routes (Owens & Wolch, 2019; History and origins of the Natur Park Südgelände, n.d.). The municipality of Eindhoven, the Netherlands, has started a ‘Pool adoption programme’ to raise awareness among children about their green environment. Children learn about nature while also taking part in the conservation and management of the pools, which are home to many species of insects, birds, mammals, and amphibians (Vink & Vollaard, 2017). As a final example, in Washington D.C., a master plan for the Sidwell Friends Middle School has been developed that strongly emphasises environmental responsibility. The building itself is highly sustainable because multiple elements and techniques are integrated to reduce electricity consumption and the need for artificial cooling. Grey water is collected via the vegetated roof and

rooftop planters teach the students both about plants and environmental issues and how to handle them (Jodidio, 2008).

Hence, dialogue, appreciation, and education are three strategies that can be implemented to include local communities in rewilding designs and processes. At the same time, they create awareness among the people and teach them about biodiversity and natural environments. Altogether, there are multiple strategies to rewild the built environment, ranging from small to bigger scale and from individuals to political management. All of the strategies should preferably be part of a large-scale strategy for a green urban environment.

All of the above categories consisting of examples of recent urban rewilding projects form a toolbox for architects and urban planners to use in the design process, see figure 2. Designers can use this toolbox to find inspiration for rewilding on different scales and in different contexts within the urban environment. This can be implemented in an early stage of the design process to create nature-inclusive designs where the architect not only designs for humans but also fulfils an ecological role and thus also designs for nature.

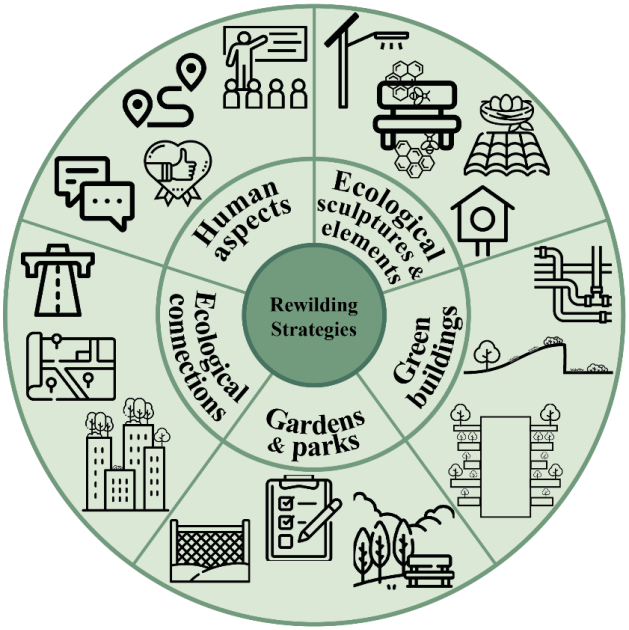

Figure 2: Toolbox of nature-inclusive designs in urban environment (drawn by author)

2.6 Larger-scale strategy

To develop a rewilding strategy on a larger scale, such as a neighbourhood, this paper uses Kowarik's (2018) framework on urban wilderness, which is seen as a social-ecological system. The social and ecological dimensions of wilderness are connected and linked to planning approaches, creating challenges when linking the dimensions (figure 3). In this integrated approach, the ecological dimension requires identifying the natural elements in an area that can meet the potential for wilderness, which makes it the supply side. The demand side concerns the social dimension which needs to be

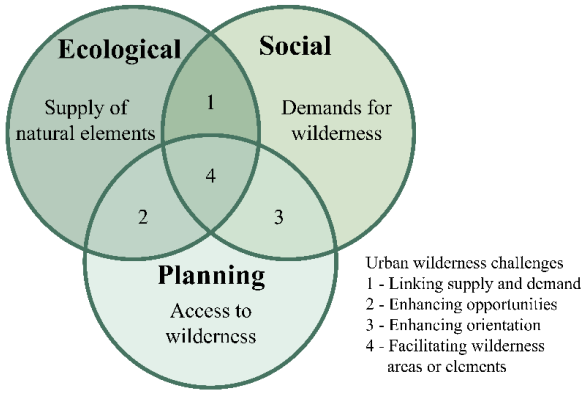

Figure 3: Urban Wilderness as a social-ecological system: three overlapping dimensions and related challenges (Kowarik, 2018) (drawn by author)

understood, possibly done through a social science approach to identify the preferences of urban wilderness, and hence the underlying values of residents. Finally, access to urban wilderness should be offered through the planning dimension. Government approaches can build on insights from the first two aspects.

2.6.1 Ecological

Identifying the supply of natural elements in an area that can meet the potential for wilderness can be done through the 'Four Natures Approach' (Kowarik, 2018). Within this approach, nature is divided into four types of nature determined by the degree of anthropogenic impact the landscape has experienced (Breuste, 2020), as shown in figure 2. The first, Nature 1, are historical ecosystems; remnants of pristine landscapes. Nature 2 consists of hybrid ecosystems; patches of agrarian landscapes or forestry land use such as fields, managed grasslands, and cultivated forests. Nature 3 also consists of hybrid ecosystems in the sense of designed urban green spaces, such as parks and gardens. And lastly, Nature 4 are new urban ecosystems; fallow land, plots, and mounds that may arise after a break in ecosystem development, for example, due to construction activities.

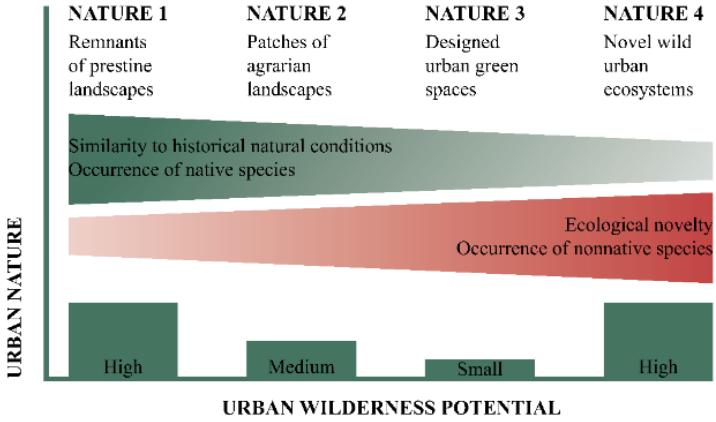

Figure 4: 'Four Natures Approach' (Kowarik, 2018)

According to Breuste (2020), all four natures may contribute to the urban nature experience in a green city and an urban landscape can be formed through interconnected nature between surrounding cities. As mentioned in the previous section on ecological connections, it is important to create green corridors on a larger scale, between cities to form urban landscapes, but equally important are connections between the different types of nature within the city or neighbourhood.

2.6.2 Social

To define the demands for urban wilderness in a specific area, a social science approach is advised (Kowarik, 2018). Since a social science approach, research on human behaviour, is too broad for the scope of this project, this paper recommends the use of the new '3-30-300 rule' (figure 5) which is already used by dozens of other scientific papers (Nieuwenhuijsen et al., 2022). It is a rule of thumb for urban forestry and urban greening that ensures that every residence has a minimum amount of nature around it, assuming this corresponds to the residents' preferences for urban wilderness. The first element of this '3-30-300 rule' stands for the minimum number of trees that should be visible from every house; everyone should be able to see at least three trees of a decent seize from their home. The next element of the rule concerns the tree canopy cover: every neighbourhood should have a tree canopy cover of at least 30 per cent. The last element has to do with the distance to a park or green space: everyone should be able to be in a public green

Figure 5: '3-30-300 rule' (Konijnendijk, 2021)

space within a 300-metre walk from their home (Konijnendijk, 2021). In research from Nieuwenhuijsen et al. (2022), Konijnendijk (2022), and Marselle et al. (2021) it becomes clear that nature has a positive impact on human health and well-being and that surrogate measures of the '3-30-300 rule' are associated with improved mental health indicators.

2.6.3 Planning

In the planning dimension of the framework, mental and physical access to wilderness is discussed and can be provided through governance approaches based on insides from the ecological and social aspects of the framework. According to Kowarik (2018), there are three key, interwoven paths to assure chances for wilderness interactions in urban areas. First of all by the conservation of existing wilderness, secondly by fostering the development of wilderness in culturally shaped areas, and lastly by providing access to existing and new wilderness areas. Access to wilderness can be increased both by improving people's orientation towards wilderness; mental access, and by creating possibilities for encountering urban wilderness; physical access.

Improving the orientation of people towards wilderness can be done through information and environmental education (Kowarik, 2018). There is a lot of potential for environmental education in urban wilderness areas (Knapp et al., 2016). In addition, it is essential to provide knowledge of the historical, social, and biological roles of wilderness areas (Rupprecht et al., 2015). For example, forest research done by Gundersen et al. (2017) found that people disliked dead wood, however, offering information about its ecological role of it resulted in more positive valuations. Furthermore, close contact with local communities and stakeholders is critical for wilderness-related planning procedures (Rall & Haase, 2011).

Creating possibilities for encountering urban wilderness can be done in several ways. Design elements, tools, and strategies to provide urban wilderness at different scales and in diverse environments are outlined using examples from practice in the previous sections and the categorisation of these examples led to the toolbox of nature-inclusive designs in urban environments (figure 2).

The best approach for a specific area is entirely dependent on the location and its circumstances. For instance, rewilding strategies have been successfully proposed to facilitate the development of new wilderness areas in abandoned rural landscapes throughout Europe (Navarro & Pereira, 2012; Corlett, 2016). In urban areas, on the other hand, rewilding strategies can also be considered, as demonstrated in the previous sections on rewilding strategies.

2.6.4 Urban wilderness challenges

Four urban wilderness challenges are related to the three overlapping dimensions of Kowarik's (2018) framework (figure 2). These challenges should be addressed to arrive at an appropriate rewilding strategy for a certain area. The first challenge can be found between the ecological and social dimension: the supply of natural elements and the demands for wilderness should be linked. Secondly, opportunities should be enhanced between the supply of natural elements, the ecological aspect, and access to wilderness, the planning aspect. The third challenge is to enhance the orientation when the social and planning aspects are linked. And the last challenge is to link all of them and to facilitate wilderness areas or elements within the area.

To answer the sub-question *How can the concept of rewilding be applied in the built environment?* it can be concluded that both on the larger and the smaller scale in the urban environment, rewilding strategies can be applied. From private gardens where residents can implement strategies specific to local biodiversity by e.g., taking the Red List into account, up to city parks where people can enjoy nature without disturbing it by e.g., the use of elevated paths. The dozens of examples of nature-inclusive designs on and to buildings show how people and

nature can live together. But in addition to architectural designs that must take nature into account, people's attitude towards nature is also crucial. Providing education and creating awareness and appreciation is essential in order to create a balance between humans and nature and to restore nature within the built environment. If people give nature space to let its processes take place, then nature can flourish, and biodiversity will recover.

For a nature-inclusive design to function as an ecological connection between the built zone and its surrounding landscape, it is important to identify the types of nature that will be connected. It is recommended to use a method to identify the types of nature such as the 'Four Natures Approach' (Kowarik, 2018). Thus, to answer the sub-question *What are the requirements for a nature-inclusive design to be an ecological connection between the built zone and its surrounding landscape?*, those requirements depend on, among other things, the characteristics of the area, the types of nature, the local biodiversity, and the requirements of the species.

III. REWILDING STRATEGY FOR BOERHAAVEWIJK

The application of the strategies to a residential neighbourhood is shown through the theoretical application to Boerhaavewijk. Starting with a brief analysis of the historical natural landscape of the neighbourhood, followed by information on the specific species and their requirements in Boerhaavewijk. This data is essential to come to a rewilding strategy for this specific area.

3.1 Historical landscape

It is imperative that an area is thoroughly investigated before rewilding the place. One of the first aspects that should be looked at carefully is the historical landscape (Felson, 2013). Around 2750 BC, Boerhaavewijk was located entirely on peatland, like most of the Netherlands. From 800 AD onwards, a lake was created which, together with the peatland, was ploughed over by man to become reclaimed land. From 1850, the lake that existed next to the area which is now called Boerhaavewijk, became a drained polder and over a century later, in 1968, the residential area was built. Paleogeographic maps for this historical analysis of the Netherlands can be found in appendix 1, and an overall historical analysis zoomed in on Boerhaavewijk in appendix 2. Today's Poelpolder is a remnant of how nature was before the construction of the district began. There is little untouched nature left in the Netherlands. Actually, almost all seminatural landscapes in Central Europe are the result of centuries-old conventional agriculture, hydrological, and silvicultural management regimes. Those regimes have led to high biodiversity ecosystems and numerous rare or endangered species. Several of these diverse and species-rich ecosystems are in jeopardy as a consequence of land-use changes linked with agricultural intensification, urban growth, and human influences (Diemer et al., 2003).

3.2 Species & their requirements in Boerhaavewijk

When rewilding through nature-inclusive designs, it is essential to have knowledge of the species and their requirements in a certain area. This part answers the sub-question *What are the specific species and their requirements in Boerhaavewijk?* so the designer can implement strategies specifically for these species to help increase biodiversity in the urban environment. Research from Delft University of Technology on a design strategy for a nature-inclusive building has listed the current biodiversity and their requirements in Schalkwijk, Haarlem (Buiter, 2021). Since Boerhaavewijk is located within this district, this list is applicable to this project. Another research from this university on nature-inclusive design and urban biodiversity has come up with several architectural interventions for flora and fauna (Wildenberg, 2021). The interventions from this study possible for local biodiversity in Boerhaavewijk are also implemented in this section (appendix 3).

It emerges that interventions can be made in the façades of buildings for different fauna. For the shrew mouse, longhorn beetles, natterjack toad, ermine, martens, mason bees, house sparrow,

serotine bat, and the swift, cavities in façades are optimal interventions to meet their needs (the exact knowledge of these design elements can be found in appendix 3*)*. For insects, loose stones or the installation of perforated bricks can be used to build a refuge in façades in the same manner as insect hotels would (Wildenberg, 2021). Other elements in the façade and on roofs are the nesting stones for birds and bat boxes for bats (section 2.2). For sand bees, south-oriented sand paths are required, elements such as the 'buzzbench' (section 2.1) could be designed and is a fine way to bring nature and people together in the built environment. The 'Buurjongens' groenschutting' could well be applied between the private terraced houses in the neighbourhood for hedgehogs and shrew mouses to crawl under to another garden, and to provide food for house sparrows and swifts (section 2.3). Vegetated roofs for the underground biodiversity consisting of microfauna (fungi, bacteria, and nematodes), mesofauna (mites and springtails), and macrofauna (worms, millipedes, spiders, and insects), can provide these animals with a stable habitat. It is recommended to create natural roofs since those provide more opportunities for diverse vegetation than a brown or sedum roof. This does demand a thick layer of soil for the vegetation to grow in and frequent maintenance is needed, so the building's structure should be of sufficient strength. In this way it could become a green-blue roof where water storage is possible. In addition, green façades and balconies with planters for butterflies, birds and insects could be applied in the neighbourhood (Wildenberg, 2021). Green roofs also meet the needs of the dragonfly and the small newt (Buiter, 2021).

3.3 Applying rewilding strategies to Boerhaavewijk

The urban wilderness framework (Kowarik, 2018) is theoretically applied to Boerhaavewijk to lead the most suitable rewilding strategies to facilitate wilderness areas and elements.

3.3.1 Ecological

To identify the supply of natural elements in Boerhaavewijk that can meet the potential for wilderness, as required for the ecological aspect of Kowarik's framework, the 'Four Natures Approach' (Kowarik, 2018) is applied (figure 6). In Boerhaavewijk, but actually, in the whole of the Netherlands, Nature 1, the historical ecosystem, is no longer present. Every bit of nature in the Netherlands is touched by humans, nothing is unaltered because it is never completely without human influences. The polder, the natural area of Boerhaavewijk, is not pristine; it consists of patches of agricultural land and therefore belongs to Nature 2. Almost all nature within the residential area in Boerhaavewijk are loose patches and consist of designed urban green spaces, Nature 3, as are the allotments in the north-east of the area. Nature 4 can be found in the northwest of Boerhaavewijk; a piece of novel wild urban ecosystems. Since new buildings will be constructed in this area in the near future, it is not seen as a potential for this project. Figure 6 clearly shows that Boerhaavewijk has a strict furthering. While inside the residential area itself, Nature 3 can be found in loose patches scattered throughout the neighbourhood. Those natural elements, the patches of designed urban green spaces, can meet the potential for wilderness and these two types of nature, Nature 2 and Nature 3, can be linked by green corridors.

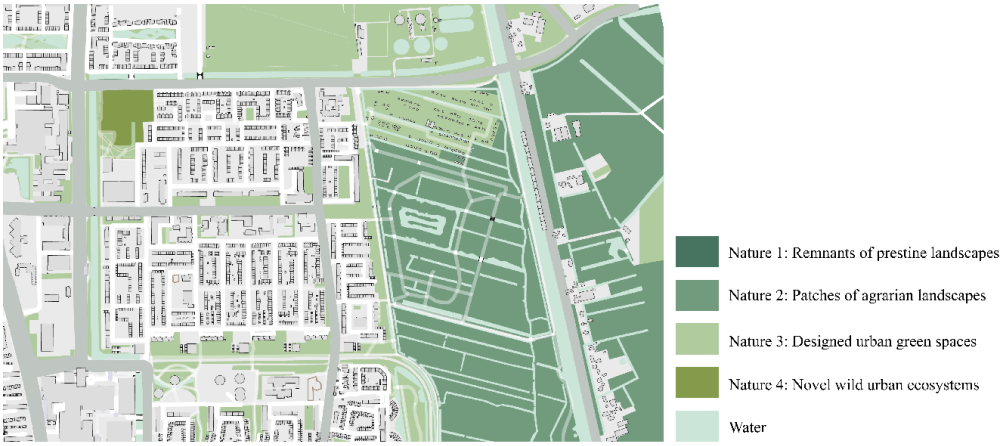

Figure 6: 'Four Natures Approach' (Kowarik, 2018) applied to Boerhaavewijk (drawn by author)

Green corridors can be formed by connecting the highest buildings in the neighbourhood. A connection on a higher level is formed when the buildings apply green façades and green roofs which meet the requirements of the local biodiversity. A schematic representation of this patch-corridor-matrix model is shown in figure 7 below. The non-schematic map of the application of this model can be found in appendix 4 and this schematic drawing is a result of it. The patches are the buildings and together they form potential corridors within the matrix which is the built area of Boerhaavewijk.

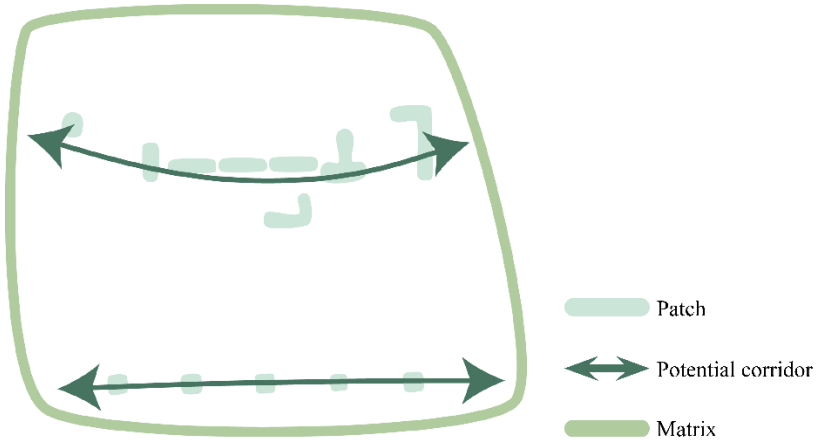

Figure 7: Schematic representation of the patch-corridor-matrix model applied to Boerhaavewijk (drawn by author)

3.3.2 Social

The '3-30-300 rule' is applied to define the demands for urban wilderness in Boerhaavewijk. Five buildings spread around the neighbourhood are taken as case studies (figure 8). Remarkably is that the rowhouse in the north of the neighbourhood does not have any trees around it, as for more houses in this area. One of the other buildings, a residential flat, offers only enough trees for some of the apartments, but not from every side trees can be seen. The other three buildings do meet the rule to have at least three trees around the buildings.

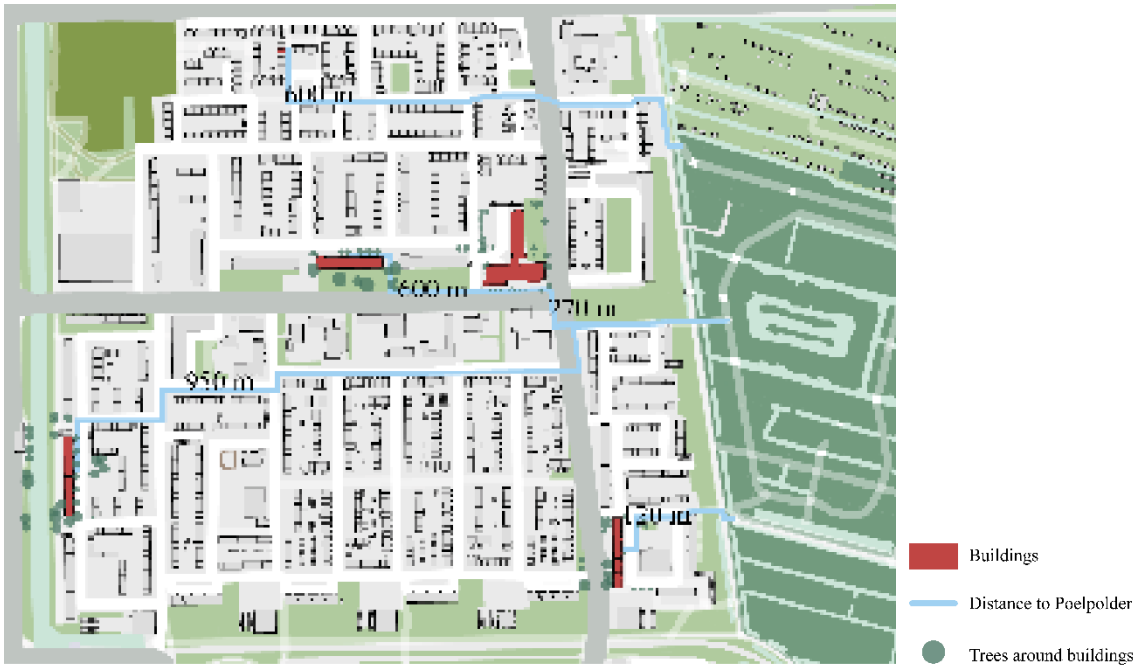

Figure 8: '3-30-300 rule' (Konijnendijk, 2021) applied to Boerhaavewijk (drawn by author)

In terms of the percentage of tree canopy cover, this is 21,7% for Boerhaavewijk, appendix 5 shows a map of the tree canopy cover. This does not meet the which says to have at least 30% tree canopy, so there is a potential for the neighbourhood to add more trees.

Regarding the distance to a public green space, this may provoke some discussion on the definition, for example, the size of it. If the polder on the east side of the neighbourhood is taken as the only representative public green space, then only a third of the neighbourhood is located at a 300-metre distance from this green space (appendix 6A). But if the lawns within the neighbourhood, which are considered to be designed urban green spaces, Nature 3, are also considered public green space, then almost all the buildings in the neighbourhood have access to a green space within 300 metres (appendix 6B). These are very simply landscaped grass fields and not of spectacular size, therefore there is potential to make these fields more pleasant and natural public green spaces.

All in all, there is a demand for more trees in Boerhaavewijk, as, firstly, not every house has enough or any trees around it, and secondly, the tree canopy cover does not meet the requirement of 30%. Whether every house complies with the 300-metre rule is a somewhat subjective matter since it could be argued that the lawns do not meet the qualities of a public green area or a park. In that case, these lawns could be more feral to give them a more natural effect.

3.3.3 Planning

The mental and physical access to wilderness can be generated by creating curiosity and providing people with information. There could be several information boards at certain points, among others on the outer edges of the polder so people are drawn into that area. But also in the middle and on the west side of the neighbourhood, there should be signs indicating that there is a nature reserve to the east. One or more walking and jogging routes could be created in this natural area, equipped with a quiz or a podcast providing more information about the ecology of the area. Not only educational elements through these routes with information, but teaching children about the local ecology will also increase involvement with nature from a young age. Schools can implement programmes to help maintain the Poelpolder and to take part in conservation and management, as instituted by the municipality of Eindhoven, described in section 2.1.

Currently, children do not seem to play in the Poelpolder area because there can be no parental supervision and there are no playing elements for children. If, for example, a public centre or a place for children to play and for parents to recreate is established, parents can keep an eye on their playing children. The possibility of having for instance a cup of coffee in this natural area will also make the place a more attractive destination. The local foundations could be involved in this project and more cohesion within the neighbourhood is created.

3.3.4 Urban wilderness challenges

The four challenges accompanying the implementation of this rewilding strategy (Kowarik, 2018) are (figure 3): linking supply and demand, enhancing opportunities, enhancing orientation, and facilitating wilderness areas or elements. Tackling those four challenges will answer the sub-question *How can rewilding through nature-inclusive design create opportunities for biodiversity in a residential neighbourhood in the Netherlands, with Boerhaavewijk as a case study?*

In Boerhaavewijk, the first challenge between the ecological and the social aspect can be tackled by allowing the existing green areas (figure 6) within the built environment to become more natural, creating more natural spots inside the neighbourhood and simultaneously, connecting them to the natural environment of the Poelpolder. In addition, there will be no discussion about whether these green spaces are sufficient once they look more natural and, with the plantation of more trees as well, the area will comply with the '3-30-300 rule'.

Secondly, opportunities should be enhanced between the ecological aspect; the supply of natural elements, and the planning aspect; access to wilderness. It can be concluded that providing visitors with information about the ecological situation generates more interest, awareness, and respect among people recreating in nature (Rupprecht et al., 2015; Gundersen et al., 2017). Opportunities can also be found when access to wilderness is formalised by e.g. creating pathways and official entrances, which improves the attractiveness of natural areas (Unt & Bell, 2014). To create close contact with local communities and stakeholders (Rall & Haase, 2011), it is advisable to involve the various foundations in Boerhaavewijk as their network with local residents is large. Building for instance a community centre can bring people together, creates more appreciation for nature, and maintaining the natural area can be done by the local community.

To enhance the orientation when the social and planning aspects are linked, challenge 3, information could be provided through information boards along routes in the natural area. Environmental education could be taught at schools, as Boerhaavewijk has nine properties with an educational function including primary schools where children could be taught about local nature.

Linking all of these challenges is necessary to arrive at a sound (design) strategy to enable wilderness areas or elements in Boerhaavewijk. This paper's toolbox can provide the architect with examples and ideas for nature-inclusive designs, both on the larger scale of the neighbourhood as well as on the smaller scale of the building level.

IV. CONCLUSION

This paper explored opportunities for rewilding the built environment through nature-inclusive design. The rewilding strategies put forward were developed from practical examples and literature study. Boerhaavewijk in Haarlem, the Netherlands, was taken as a case study to demonstrate the application of these strategies.

Specific rewilding strategies addressed in this paper have shown their opportunities for increasing biodiversity and thus rewilding the built environment through practical examples. This paper has summarised and categorised these examples to provide designers with a toolbox to use for implementing rewilding strategies early in the design process. Ecological sculptures and elements

can be designed very specifically for a species to meet their needs, such as nesting boxes for birds and sculptural insect hotels. The greening of buildings can also be applied to high-rise buildings, providing balconies with planters as on the Bosco Verticale. It is possible to use technical innovations which create valuable green roofs and façades with sophisticated water systems. Gardens and parks can contribute to rewilding on a small scale, in residents' own gardens, with the help of the Red List City garden, providing a list of endangered species to design for, and the Buurjongens' Groenschutting responding to many species. On a large scale, urban parks can be created even when it seems there is no space for them: on top of a parking garage or unused railways. By forming ecological connections, for example through fauna passages and ecoducts, habitats are expanded, species can spread, and the city becomes more climate adaptive. Human aspects also contribute to rewilding. Not only by facilitating education and information on ecosystems but also through design interventions on a small scale, such as (elevated) routes provided with artworks.

It is suggested to use a framework to come to a suitable rewilding strategy for a certain area, such as Kowarik's (2018) framework where the ecological, social, and planning dimensions are linked. To identify the supply of natural elements to meet the ecological dimension, the 'Four Natures Approach' can be used. Within this approach, nature is divided into four groups: historical ecosystems, two types of hybrid ecosystems, and new urban ecosystems. Mapping and connecting these types of nature contributes to a greener, more resilient environment. To define the demands for urban wilderness for the social dimension, this paper recommends using the '3-30-300 rule': at least three trees around each house, 30% tree canopy cover in the area, and 300 metres to the nearest park or natural area. To foresee the last aspect of the framework, the planning dimension, approaches should be based on insides from the ecological and social aspects to provide access to wilderness. Improving people's orientation toward wilderness and creating possibilities for encountering urban wilderness is necessary to facilitate mental and physical access to wilderness. The developed toolbox can be used to obtain examples of rewilding elements and strategies to create access to wilderness in the built environment. For every situation, it is important to do thorough site research, including historical and site analyses, as well as site visits and meetings with stakeholders early in the process. Interdisciplinary discussion between ecologists and designers can lead to successful collaboration. Furthermore, providing information and education are strongly suggested elements.

Altogether, many strategies can be applied to rewild the built environment and Boerhaavewijk was taken as an example. What can be taken from this case study to give recommendations on wilderness areas and elements, is that first of all, this neighbourhood consists of a lot of designed urban green spaces, Nature 3, within the built area which could be connected to the polder to the east which is categorized as Nature 2: patches of agrarian landscapes. Connections could appear by creating green corridors. A suggestion is to make patches of the highest buildings in the neighbourhood by equipping the buildings with green façades and roofs, so together they will form corridors. The neighbourhood should also get more trees planted, not only to provide for these green corridors but also to meet the '3-30-300 rule', as the current tree canopy cover is too low. Additionally, it is strongly recommended to map the specific species of an area to meet their needs and to design for them.

In conclusion, rewilding strategies are very site-specific and depend on the characteristics of an environment. Strategies can be applied on both the larger and smaller scale and thorough site analyses and research on the ecosystems are strongly advised to come up with the most suitable rewilding strategy for a specific area in the built environment. Using Kowarik's (2018) framework will lead to a rewilding strategy and this paper's toolbox will help architects and urban planners to implement rewilding strategies early in the design process, to create opportunities for biodiversity and make cities greener and more resilient.

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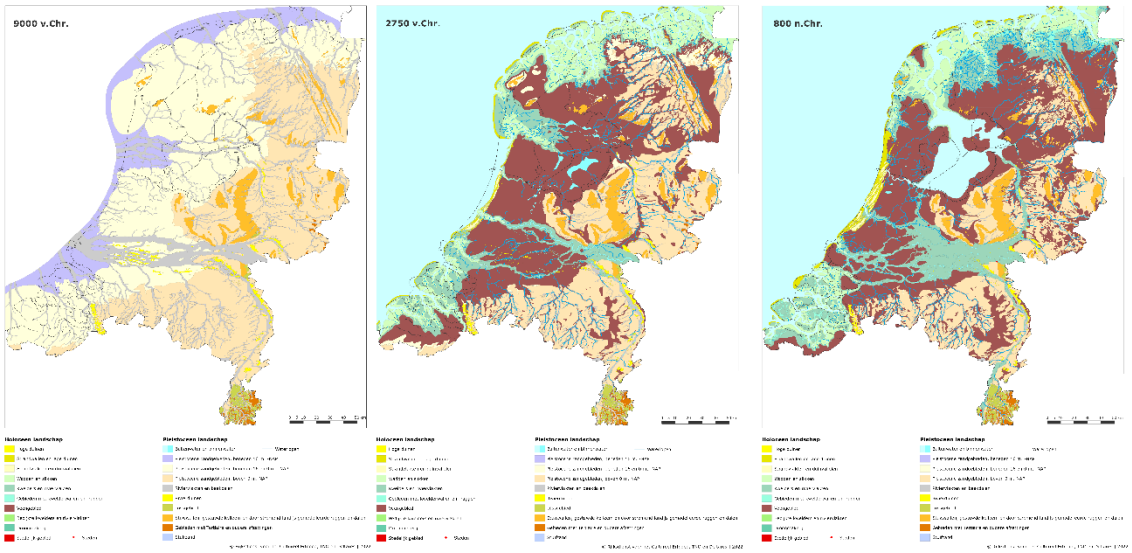
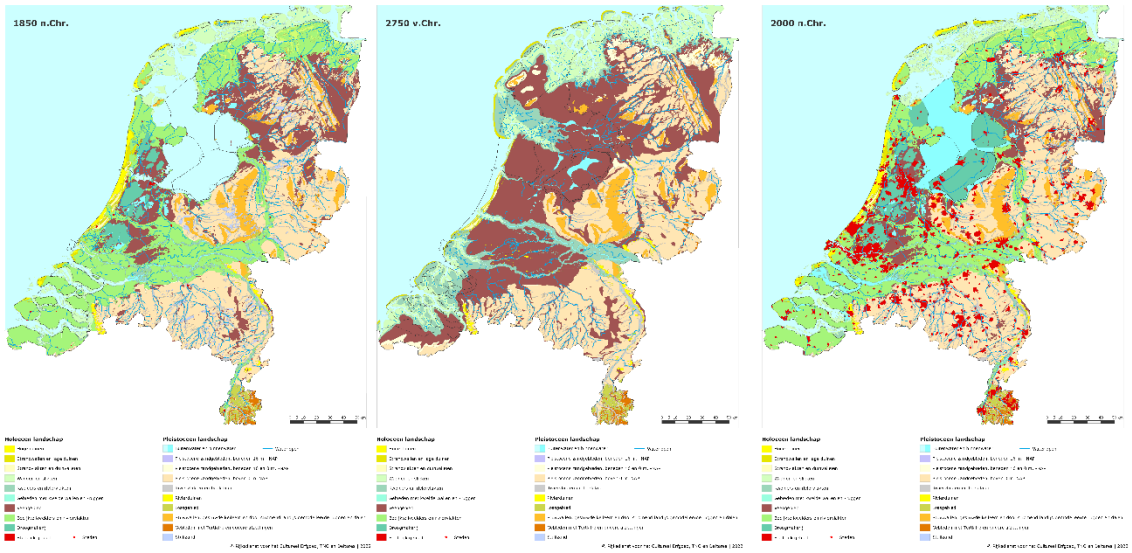
FIGURES

APPENDIX 1.

Historical analysis of the Netherlands through paleogeographic maps (Paleogeographical maps, 2022)



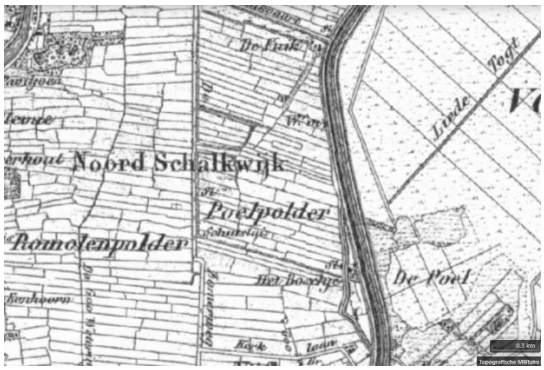


APPENDIX 2.

Overall historical analysis zoomed in on Boerhaavewijk (Historical maps Boerhaavewijk, n.d.)

1815 Haarlemmermeer

1815 Boerhaavewijk

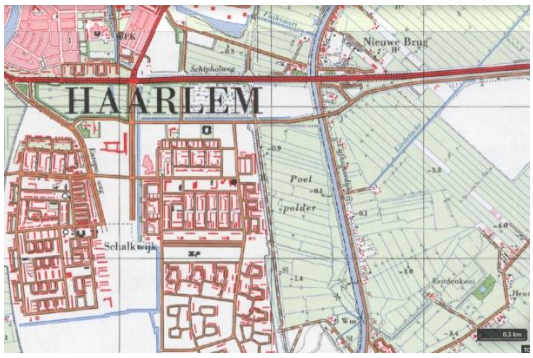


1850

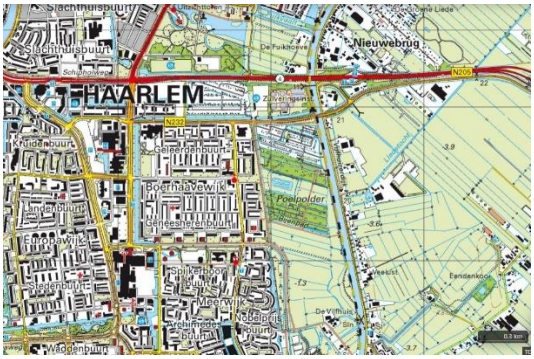
1900

1950

1968



1969



2021

APPENDIX 3.

Species in Boerhaavewijk (Buiter, 2021; Wildenberg, 2021).

Species	Habitat info	Feeding	Water	Design elements	Comments
Dragon-flies	Often found near water sources, preferably stationary water. Also like high and warm spaces.	Flying insects such as mosquitoes, flies, hoverflies and butterflies.	Near water sources.	Undeep permanent water, green-brown roofing.	Like all insects, they are dependent on the sun for warmth.
Small Newt	Undeep water sources, preferably stationary water with nearby vegetation or cairns.	Water fleas, small snails, worms and varied insects.	Undeep water sources.	Undeep permanent water, green-brown roofing.	
Sand Bees	Nests are dug undergound on sand surfaces.	Pollen and nectar from Butterfly bushes.	Not needed.	Sand paths. South oriented.	Sand paths needed.
Hedge-hogs	Nests are well hidden made of leaves, moss or other material that is often located under (blackberry) bushes or fagots.	Beetles, caterpillars, earthworms, earwigs and snails.	Puddles that form after rain or undeep permanent water.	Hiding cavities on ground level.	Hedgehogs are nocturnal.
Shrew Mouse	Sheltered places such as piles of branches or nests of dry grass and leaves. In gardens, they also often use compost heaps or man-made material.	Hunts insects, spiders, larvae, woodlice, snails, worms, moths, mosquitoes and cockroaches, as well as lizards, young mice and carrion.	Puddles that form after rain or undeep permanent water.	Small cavities in façade, reachable through climbing or walking.	Vulnerable to hard sounds. Mainly nocturnal but also active during the day.
Common Toad	Small scale varied landscape with access to deep water.	Ants, beetles and larvae.	Deep water.	Access to water.	
Longhorn Beetles	Often found in (dead) wood. Nesting height: <1 metre.	Tree sap, nectar and pollen.	Not needed.	Small holes in wood on façade south oriented.	Ability to create housing for other insects by digging holes in wood.
Natterjack Toad	Puddles that form after rain or undeep permanent water and sand paths. Other possibilities are openings in rocklike surfaces. Nesting height: <1 metre.	Flies, ants, beetles and spiders.	Puddles that form after rain or undeep permanent water.	Openings in stone façade.	Natterjack toads are mainly nocturnal. Hibernation in piles of leaves.
Ermine	A burrow, usually an old mole den or rabbit hole and usually moves along	Small mammals, birds and bird eggs.	Puddles that form after rain	Cavities in façade resembling rabbit holes.	

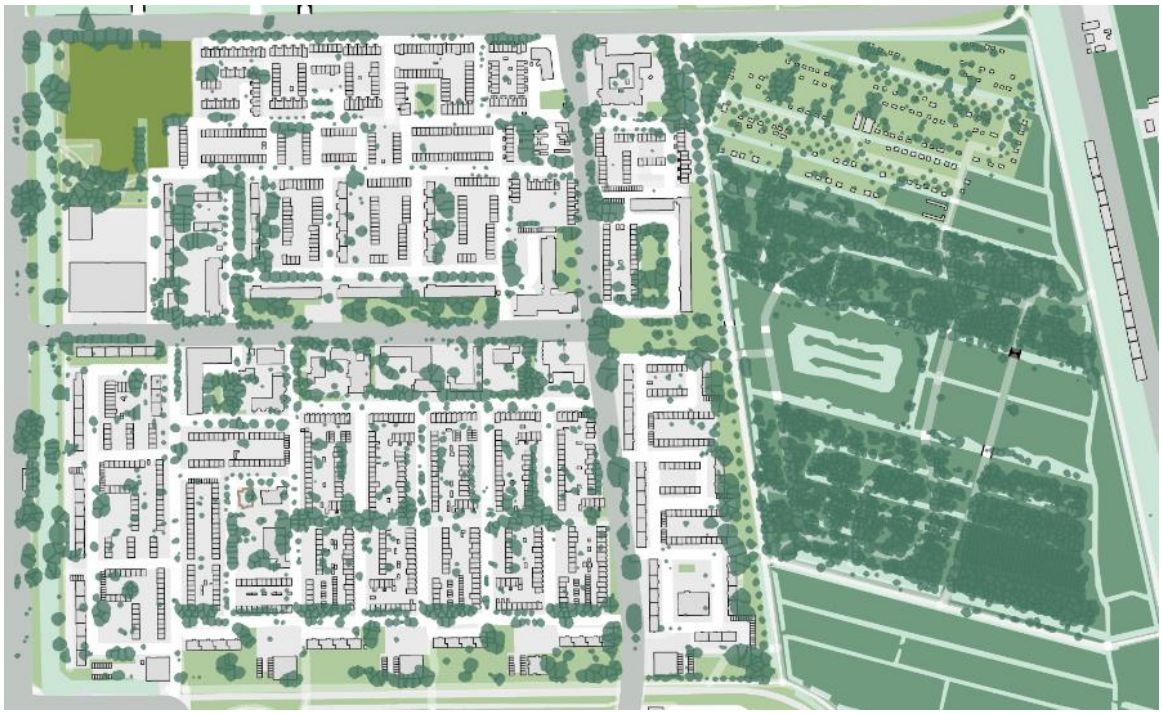
	linear elements that provide cover such as hedges, walls, bank lines, etc. Nesting height: <1 metre.		or undeep permanent water.		
Martens	Warm and dry spaces with soft materials. Nesting height: <1 metre.	Small mammals, birds, fruit, insects and fish.	Puddles that form after rain or undeep permanent water.	Warm and dry cavities in façade.	
Mason Bees	Nests are created in small holes in wood, reed or stone. Nesting height: <5 metre.	Pollen and nectar.	Not needed.	Small holes in façade, preferably brick or wood, south oriented.	Make use of artificially created holes.
House Sparrow	Nests are often made under roof tiles, in holes and cracks in buildings and in sparrow boxes. Often nest in colonies. Nesting height: 1-10 metre.	Seeds, grains, insects, flower buds, bread, berries, peanuts and fat balls. In the breeding season mainly insects.	Puddles that form after rain or undeep permanent water.	Holes and cracks in façade. East oriented. Small bird that needs a lot of green in its surroundings. It thrives in messy, human environments, like older sub-urban neighbourhoods with a combination of open and more dense green patches. A complete habitat - food, shelter, nesting space - should be created on a small surface (providing just nesting places is not sufficient).	Picky birds that only come to areas where there are bushes, sand paths and grass. They nest in spring and summer, in colonies. Very social; most nests are in close proximity of another.
Serotine Bat	Dependent on buildings for nests; cavity walls, behind the paneling, under roof moldings and roof tiles or under the lead around the chimney. Nesting height: 5-10 metre.	Big night butterflies, beetles and mosquitoes.	For hydration they skip over water surfaces while flying.	Cavities in façade, west oriented.	Notorious for using bat boxes. During mating season colonies are between 10 - 150 individuals.
Swift	Nests often build under gutters, behind a downspout, dormer window, roof tile, or in a hole in the wall and also in nest stones. Often swifts tend to nest in colonies. They also live in nesting boxes. Nesting height: 5-15 metre.	Flying insects such as mosquitoes, flies, hoverflies and butterflies.	For hydration they skip over water surfaces while flying.	Nest stones, rough façade, no reflective surfaces, nooks and crannies. East oriented. Dependent on crevices to nest in to survive. Providing a place for nesting is most important.	No reflective surfaces & no smooth surfaces around their nesting height. The built environment is like a mountainous landscape for the common swift: a rocky environment with crevices to nest in. They live in the air, except when breeding.

APPENDIX 4.

Patch-Corridor-Matrix model applied on Boerhaavewijk, with potential corridors formed by connections between the highest buildings of the neighbourhood (drawn by author).

APPENDIX 5.

Tree canopy cover in Boerhaavewijk is 21.7% (Cobra Groeninzicht & Voets, 2022) (drawn by author)



APPENDIX 6A.

‘3-30-300 rule’: 300 metres to Poelpolder (drawn by author).

APPENDIX 6B.

‘3-30-300 rule’: 300 metres to urban green spaces (drawn by author).