

MASTER

Towards green densification

Urban Green Infrastructure to enhance both urban ecological resilience and human well-being in a densifying Eindhoven

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TOWARDS GREEN DENSIFICATION

Master thesis | Merijn van der Does

Towards Green Densification

Urban Green Infrastructure to enhance both urban ecological resilience and human well-being in a densifying Eindhoven

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Urban Green Infrastructure to enhance both urban ecological resilience and human well-being in a densifying Eindhoven

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Merijn van der Does

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part I

literature

Abstract

Cities are shifting away from expanding and towards densifying, driven by the recognition that urban expansion is linked to a range of severe environmental and social issues. Eindhoven, a city in the Netherlands, exemplifies this trend, actively pursuing significant densification to realize 35.000+ new dwellings within the existing urban fabric before 2040. While densification brings many advantages, such as increased economic productivity and diverse social opportunities, its adverse impacts on urban ecological resilience and human well-being are tremendous. Collaboratively, people and nature can achieve a mutually beneficial potential through Urban Green Infrastructure (UGI). This study focuses on leveraging UGI to enhance both urban ecological resilience and human well-being in a densifying context. However, evidence-based guidance for implementing UGI in such scenarios is currently lacking.

This research aims at identifying UGI interventions and their impact on human well-being and urban ecological resilience. Employing a theoretical framework, systematic literature review, handbook review, and critical policy review, six main strategies were identified with corresponding UGI interventions for their application in densifying urban contexts. These UGI interventions were assessed on their benefit to human well-being and urban ecological resilience, and policy recommendations were derived from the findings. The study's results are presented into a policy and design guide, providing evidence-based practical examples for urban designers, planners, and decision makers in Eindhoven and beyond.

The study prioritizes the potential of UGI to enhance both human well-being and urban ecological resilience, enhances the understanding of UGI's role in densifying environments and provides a framework for integrating UGI into urban planning, design, and decision-making practices.

Keywords

urban green infrastructure (UGI), urban densification, urban ecological resilience, human well-being



Figure 1 Green street 't College (van der Smitte, 2020)

1. Introduction

The global trend of urbanization is significantly impacting the distribution of the world's population. In 2021, the share of the global population residing in urban areas was estimated at 56% (UN-Habitat, 2022), as illustrated in Figure 2. Projections indicate that by 2050, this share is expected to rise to 68%, leading to an additional 2.2 billion urban residents (Pereira & Baró, 2022; UN-Habitat, 2022).

In recent years, there has been a notable shift from urban expansion and urban sprawl to urban densification (Artmann et al., 2019). This shift is driven by the recognition that urban expansion is linked to a range of severe environmental and social issues, including increased congestion, social segregation (Ahlfeldt & Pietrostefani, 2017; Lemoine-Rodríguez et al., 2020), as well as global biodiversity decline and losses of crucial ecosystem services (Stuiver, 2022).

In contrast, compact cities or dense urban areas offer numerous advantages, including increased economic productivity (Ahlfeldt & Pietrostefani, 2017), a wide range of diverse social opportunities (Lemoine-Rodríguez et al., 2020), enhanced efficiency of public services (Ahlfeldt & Pietrostefani, 2017). Furthermore, these dense cities have a reduced pressure on the landscape and a lowered ecological footprint (Gleeson & Wada, 2013; Newman, 2006) compared to sprawled cities. However, it is important to acknowledge that the global trend of urbanization also brings about negative consequences, including severe global environmental decline and threatened human well-being in urban settings.

It is well established that urbanization is a major driver of many climate-related issues (Stuiver, 2022). These negative effects can be seen in critical areas such as problems with water regulation, declining biodiversity and reducing carbon sequestration (Chung et al., 2021; Stuiver, 2022; Vink et al., 2022). Alarming statistics presented by the World Wide Fund for Nature (WWF, 2022) indicate a global biodiversity decline of 69% in species over the past 50 years (Figure 3), emphasizing the need for a turning point. Focusing specifically on the biodiversity status in the Netherlands, findings of the 'Convention on Biological Diversity' (Sanders et al., 2019) show that the awareness of biodiversity has increased, however the status of local biodiversity continues to decline.

Share of the urban population worldwide

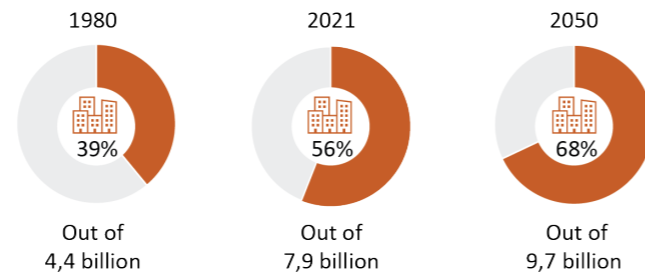


Figure 2 Share of the urban population worldwide (UN-Habitat, 2022)

Global biodiversity decline

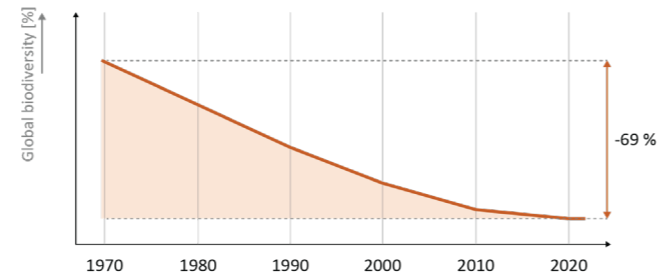


Figure 3 Global biodiversity decline, based on (WWF, 2022)

Threshold of two hours spent in nature for good health

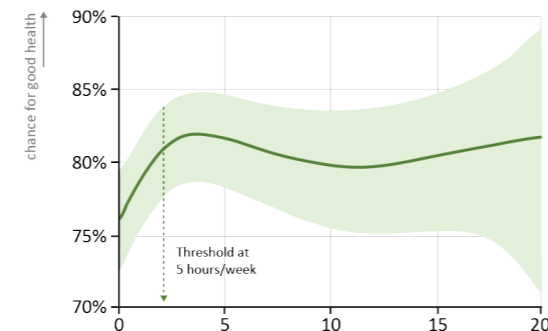


Figure 4 Two hours of nature per week for good health (IVN Natuur Educatie, 2020)

It remains a highly debated question if urban densification can serve as solution for the threatened ecology (Ahlfeldt & Pietrostefani, 2017). As sprawled cities and degraded agricultural lands make the countryside less suitable for plant and animal species, urban environments are becoming increasingly vital for their survival (Vink et al., 2022). Despite global greening trends, the urbanization process continues to reduce urban green infrastructure (UGI) (Pereira & Baró, 2022).

Controversies also exist for the impact of urban densification on human well-being. For instance, the promotion of walk- and cyclability (Gemeente Eindhoven, 2020a) that dense cities bring positively impact well-being. However, negative effects of urban densification on mental well-being have been widely observed, including lowered senses of community, social withdrawal, stress and anxiety (Ahlfeldt & Pietrostefani, 2017; Lai et al., 2021). Furthermore, physical health is negatively impacted by factors like air pollution, high temperatures, and increased traffic accidents (Ahlfeldt & Pietrostefani, 2017; Sukhdev et al., 2013).

With the acceleration of these urban problems, recognition grows for the importance of UGI to maintain human well-being (Chen et al., 2021). A research points out that spending a minimum of two hours per week in nature influences chances for good human health positively (Figure 3) (IVN Natuur Educatie, 2020). However, as pointed out by Wicki et al. (2021), planning for dense cities often involves the reduction of UGI, which negatively influences the supply of ecosystem services (ES) and, consequently, well-being.

Focusing on the urban context, Hansen et al. (2017) address that UGI has been recognized as a powerful tool to address a broad range of urban challenges, including enhancing (urban) biodiversity and improving overall human well-being. To put this in practice, people must take responsibility to not only execute out of human perspective, but also take responsibility to provide for nature, as nature relies on humans to articulate its value (Stuiver, 2022). As cities are a product of past of human practices, people possess the power to transform it again (Hardcastle et al., 2005). However, the development of UGI is complex and diverse, given the dynamic densifying and urban landscape (Vink et al., 2022). Achieving the potential of UGI to address both global

“How can urban green infrastructure enhance both urban ecological resilience and human well-being in a densifying Eindhoven?”

trends of threatened human well-being and environmental decline introduces additional complexities. To effectively integrate UGI in dense urban contexts, evidence-based practical examples are urgently needed (Mommers et al., 2021; RIVM, 2021).

The Municipality of Eindhoven has proposed an urban densification vision, focusing on adding over 35.000 additional dwellings within the existing urban fabric before 2040 (Gemeente Eindhoven, 2020c). The vision also includes plans to provide an additional 8m² of green space per added dwelling, with a particular emphasis on large green and blue structures (Gemeente Eindhoven, 2017). Besides, the municipality has announced 10 million euros will be devoted to greening the inner-city of Eindhoven (Studio040, 2023). However, so far the vision lacks specific guidance on how to implement UGI within the areas designated for densification.

The aim of this research is to investigate what spatial and non-spatial UGI interventions can enhance both human well-being and urban ecological resilience in a densifying context (Figure 5). For this, UGI interventions will be identified and scored based on their effect on both human well-being and urban ecological resilience. Furthermore, it aims to critically identify if these UGI interventions are currently incorporated into policy. Finally, this research will provide practical examples of UGI interventions supporting both human well-being and urban ecological resilience within designated densification areas in Eindhoven. For this the main research question will be answered: **‘How can Urban Green Infrastructure (UGI) enhance both human well-being and urban ecological resilience in a densifying Eindhoven?’**

To answer the main research question, sub questions are formulated. Table 1 presents the sub questions with their corresponding methods, results and the information the results are based on.

The relevance of this research lies in its potential to inform the urban designing, planning and policy making processes. By investigating the potential of UGI interventions to enhance both human well-being and urban ecological resilience, it offers valuable insights for urban designers, planners and decision makers in Eindhoven and other cities. Furthermore, the provision of practical examples specific for implementing UGI into densifying urban contexts, supports evidence-based practices and contributes to improving overall human well-being and urban ecological resilience in urban contexts.

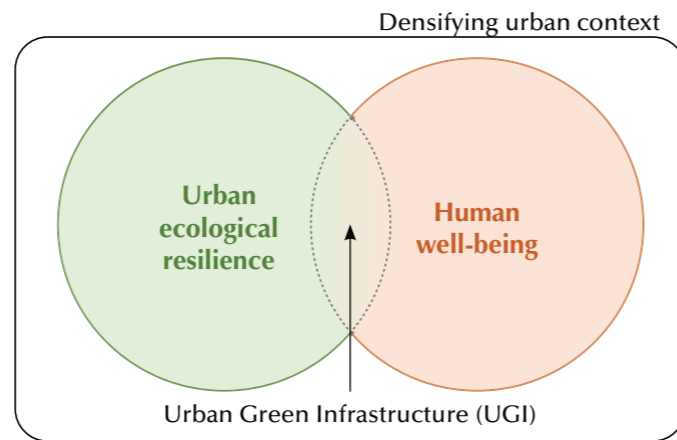














Figure 5 Research focus area

In section 2: 'Theoretical Framework' more insight is given the key concepts and the way they interact: urban densification, UGI, urban ecological resilience and human well-being. Section 3: 'Methodology' shows the methodology of the paper consisting of a systematic literature review, handbook review, critical policy review, and the creation of a design guide. Followingly, section 4: 'Results' will follow the same order as the methodology and present the results of the research. Finally, section 5: 'Conclusion and Discussion' will provide an overall critical reflection of the research process as well as limitations and recommendations for further research.

Table 1 Overview of research questions and corresponding methods and results

Sub questions	Methods	Results
What spatial and non-spatial UGI interventions exist?	<ul style="list-style-type: none">  Systematic literature review  Handbook review 	<ul style="list-style-type: none"> • Inventarisation of spatial and non-spatial UGI interventions based on data from the literature and handbook review
What UGI interventions are suitable for densifying areas?	<ul style="list-style-type: none">  Systematic literature review  Handbook review 	<ul style="list-style-type: none"> • Overview of what UGI interventions are suitable for densifying areas based on data from the literature and handbook review
How can main strategies for the implementation of these UGI interventions be formulated?	<ul style="list-style-type: none">  Systematic literature review  Handbook review 	<ul style="list-style-type: none"> • Overview of six main strategies for the implementation of UGI in densifying areas based on data from the literature and handbook review
How do these UGI interventions influence human well-being and urban ecological resilience?	<ul style="list-style-type: none">  Systematic literature review  Handbook review 	<ul style="list-style-type: none"> • Relation matrices per strategy showing the relation between UGI interventions and the key themes based on data from the literature and handbook review
How do the UGI interventions score on their contribution to human well-being and urban ecological resilience?	<ul style="list-style-type: none">  Systematic literature review  Handbook review 	<ul style="list-style-type: none"> • Scoring system for the influence of UGI interventions on human well-being and urban ecological resilience based on data from the literature and handbook review
To what extent are the strategies and UGI interventions incorporated in policy?	<ul style="list-style-type: none">  Critical policy review 	<ul style="list-style-type: none"> • Overview of inclusion in current policy • Recommendations for future policy • Based on policy documents at different scale levels (global, national, municipal)
How can the strategies and UGI interventions be presented as evidence-based practical examples?	<ul style="list-style-type: none">  Design guide creation 	<ul style="list-style-type: none"> • The 'Urban Green Guide' for the implementation of UGI in densifying contexts • Based on the combined research from literature, handbooks and policy documents

2. Theoretical framework

In this section, the key concepts that form the foundation of this thesis are described and their interrelationships are explained. The key concepts are urban densification, UGI, human well-being and urban ecological resilience. Table 2 shows a clear overview of the definitions used for these key concepts in this thesis.

2.1 Urban Green Infrastructure and urban densification

Research by Madureira & Monteiro (2021) shows that compact city development is characterized by high-density and mixed land uses, along with efficient public transportation. They point out that pursuit of both this and urban greening objectives often creates a significant conflict, known as the ‘compact city paradox’ (Figure 6). This dilemma revolves around the challenge of simultaneously achieving urban densification and greening. In this thesis, urban densification is defined as the process of increasing the ratio of housing units or people per unit of land area (Bibri, 2020) to accommodate a growing population (Madureira & Monteiro, 2021). Currently, the challenge lies in the absence of comprehensive approaches for the practical implementation of both dense and green cities (Madureira & Monteiro, 2021).

However, Lehmann (2021) suggests that density and urban green can co-exist through strategies simultaneously increasing urban density

while expanding green spaces and integrating innovative approaches to UGI. In this thesis, urban green infrastructure is defined as a network of green spaces, blue spaces and other natural features within urban areas (UK Houses of Parliament, 2013) operating at various spatial scales (du Toit et al., 2018). Moreover, the UGI network is subdivided into scale levels presented in Table 3, as based on ‘Urban Green Infrastructure Planning: A Guide for Practitioners’ (Hansen et al., 2017).



Figure 6 Urban densification, UGI and the Compact City Paradox

Table 2 The key concepts and corresponding definitions

Key concepts	Definition
Urban Green Infrastructure (UGI)	A network of green spaces, blue spaces and other natural features within urban areas (UK Houses of Parliament, 2013) operating at various spatial scales (du Toit et al., 2018).
Urban densification	The process of increasing the ratio of housing units or people per unit of land area (Bibri, 2020) to accommodate a growing population (Madureira & Monteiro, 2021).
Human well-being	A subjective indicator of one’s quality of life (Daams & Veneri, 2017). Influenced by health, social development and belonging (Moore et al., 2017)
Urban ecological resilience	The ability of urban (eco)systems to absorb disturbances and to reorganize themselves in order to retain the same function, structure, identity and feedback systems (Vink et al., 2022) Building on biodiversity, connectivity (Peterson et al., 1998) and (a)biotic fitness (Stuiver, 2022; Vink et al., 2022).

Table 3 UGI network scales, as based on (Hansen et al., 2017)

UGI network scale	Elaboration
Region hub (RH)	Large natural area connected to the region
Region corridor (RC)	RH – RH connector
City site (CS)	City level green space, e.g. park
City corridor (CC)	RH – CS or CS – CS connector
Neighbourhood steppingstones (NS)	Neighbourhood level greenery
Street corridor (SC)	Street level greenery
Site steppingstones (SS)	Site level greenery, e.g. integrated in building envelope

2.2 Urban Green Infrastructure and human well-being

UGI is increasingly recognized as the principal provider of ecosystem services (ES) supporting well-being of urban populations (Madureira & Monteiro, 2021). The concept of biophilia supports this notion by emphasizing the innate connection people have with nature, and the significant benefits that can be derived from the increased presence of UGI (Beatley & Newman, 2013; Russo & Cirella, 2017). Biophilic planning does not only contribute to human well-being, but also contributes to a healthier environment by mitigating the urban heat island effect (Reeve et al., 2015).

Daams & Veneri (2017) define human well-being as a subjective indicator of one’s quality of life. Moore et al. (2017) broke down the concept of human well-being into factors with a strong relation with urban densification and UGI (Figure 7). Within this thesis, these factors have been categorized into three main pillars. These are described in Figure 8.

UGI maximizes the provision of ecosystem services that benefit human well-being (Madureira & Monteiro, 2021). However, it is important to acknowledge that ecosystems can also provide negative effects on human well-being (Von Döhren & Haase, 2015), especially in densely populated areas (Madureira & Monteiro, 2021). Ecosystem

Services (ES) encompass the direct and indirect benefits people derive from ecosystems, including provisioning, regulating, supporting, and cultural services (Sukhdev et al., 2013). On the other hand, Ecosystem Disservices (EDS) refer to ecosystem functions that have harmful effects on human well-being, such as nuisances, biological hazards, and geographical hazards (Von Döhren & Haase, 2015).

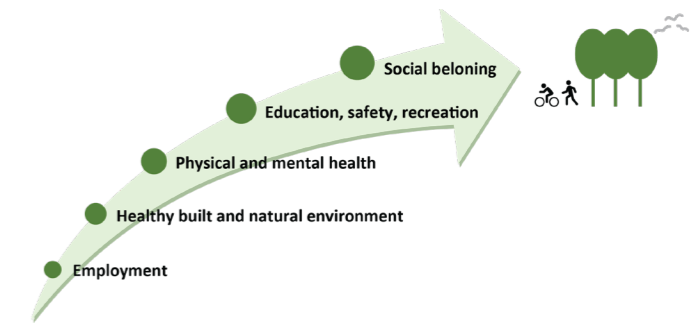


Figure 7 Principles determining human well-being according to the 'International Ecocity Standards' (Moore et al., 2017)

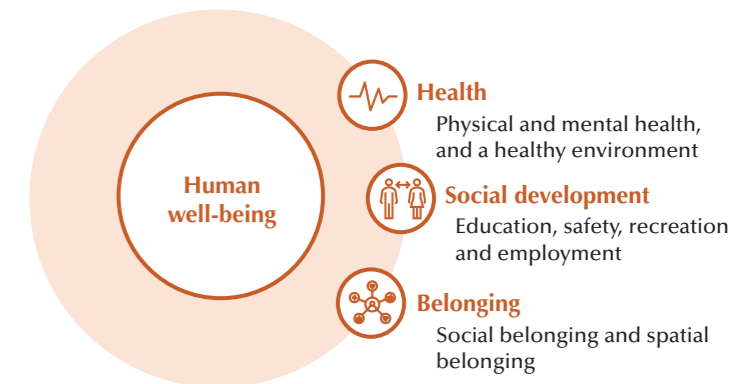


Figure 8 Pillars for human well-being

2.3 Urban Green Infrastructure and urban ecological resilience

Peterson et al. (1998) emphasize that ecosystems should be understood as interconnected and self-organizing entities consisting of processes and structures at various scales Figure 9. Ecological resilience is created when these ecosystems interact between the different scales. This highlights the importance of UGI networks on different scales.

Vink et al. (2022) define urban ecological resilience as follows: the ability of urban (eco)systems to absorb disturbances and to reorganize themselves in order to retain the same function, structure, identity and feedback systems. By integrating UGI into urban planning and design, cities can enhance their capacity to withstand and adapt to environmental changes, ensuring the continuity of vital ecosystem functions.

To further define, biodiversity, connectivity and (a)biotic fitness serve as its main pillars for achieving urban ecological resilience through implementing UGI (Figure 10). Firstly, biodiversity plays a critical role in urban ecological resilience as species interactions shape the interconnections between the different scales. Losses of these species cause disruption, increasing the risk of collapse. Diversity, richness and complexity contribute making ecosystems more resilient for disturbances (Vink et al., 2022). Secondly, connectivity is essential for promoting interaction and movement of species across ecosystem scales (Peterson et al., 1998). UGI planning for connectivity enables support and protection of vital processes, functions and benefits that individual green spaces cannot provide alone (Hansen et al., 2017).

Lastly, ecological systems can be subdivided into two aspects: biotic factors ('all that lives', such as animals and plants) and abiotic factors ('all that doesn't live', such as water and soil) (Stuiver, 2022). UGI can only start to exist when the right conditions for natural processes in urban environments are in place (Vink et al., 2022), starting with the fitness of these biotic and abiotic elements.

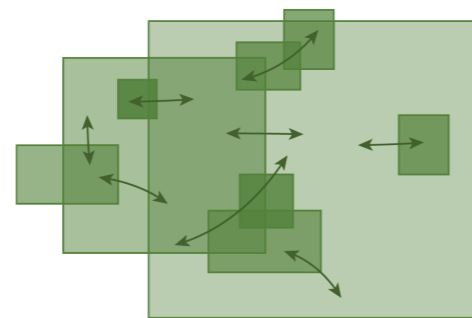


Figure 9 Interconnected ecosystems operating at various scale levels

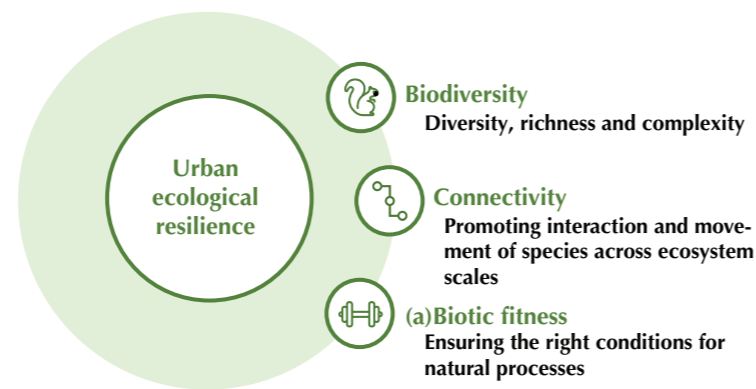


Figure 10 Pillars for urban ecological resilience

2.4 Conceptual framework

Figure 11 highlights the interrelationships among the key concepts of this thesis. Urban densification is shown to have both positive and negative effects on human well-being, while it has a negative impact on urban ecological resilience. The effect of UGI on urban ecological resilience is positive. While, through ES and EDS, UGI can have both positive and negative effects on human well-being. This research aims to examine what UGIs have positive effects on both human well-being and urban ecological resilience in a densifying context. By exploring these relationships, the study seeks to contribute to a comprehensive understanding of how UGI can enhance the resilience of urban ecosystems and promote the well-being of urban residents in a densifying context.

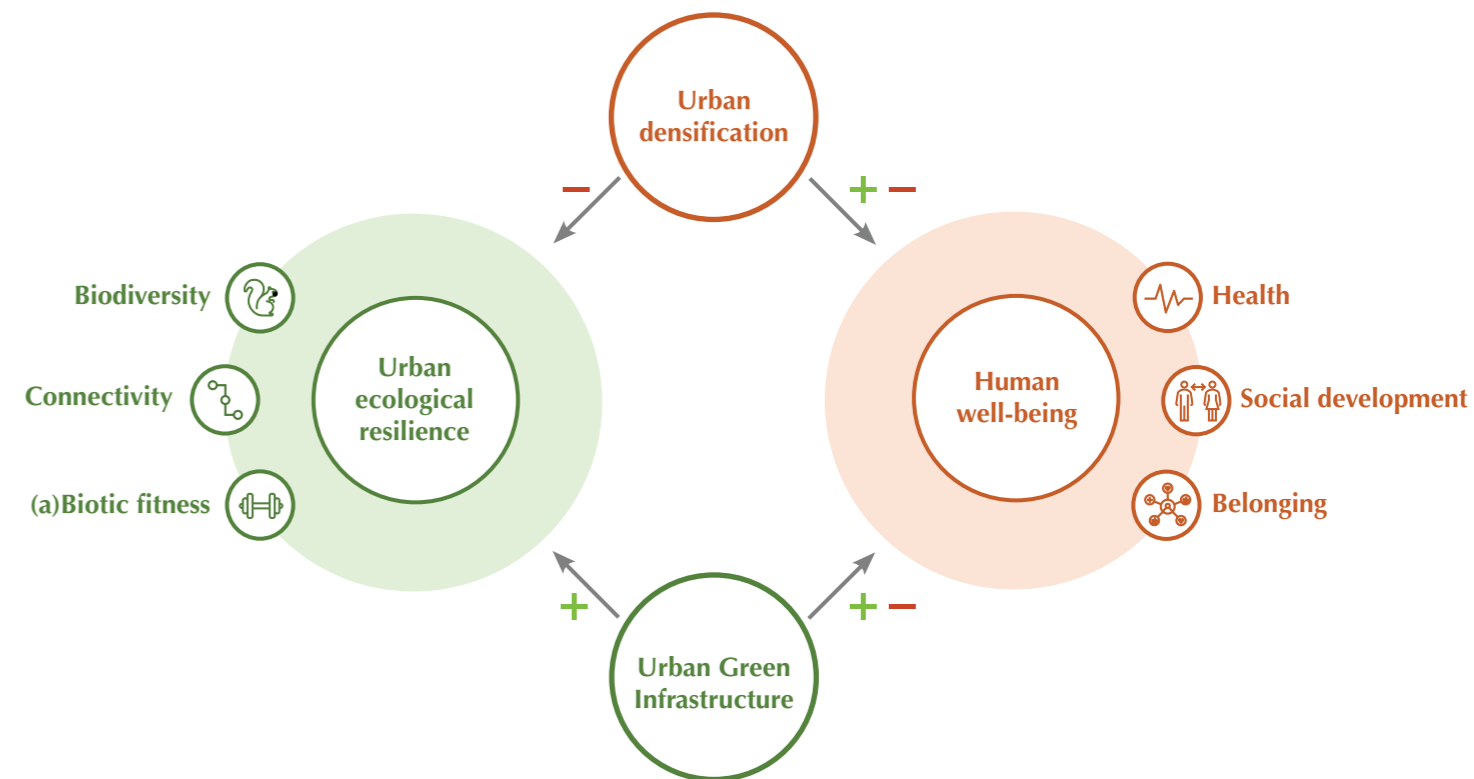


Figure 11 Conceptual model of the relationships between the key concepts

3. Methods

Figure 12 illustrates the framework of this thesis, comprising of three distinct stages: Research, City Strategy and Neighbourhood Design. Within this methodology, the focus lies on the 'Research'-section. The systematic literature and handbook review provide the basis for identifying six strategies for enhancing human well-being and urban ecological resilience in a densifying city through spatial and non-spatial UGI interventions. A critical policy review evaluates the alignment of existing policies with the key concepts and strategies, from which policy recommendations follow. The findings (strategies, UGI interventions, and policy recommendations) have been bundled in a policy and design guide offering evidence-based practical examples. Finally, a critical reflection is done to review the overall research process and to give suggestions for further research.

3.1 Systematic literature review

Firstly, a systematic literature review has been conducted to find existing interventions of UGI. The research papers are used to create a scientific basis for the evaluation of the influence of these UGI interventions on both human well-being and urban ecological resilience in a densifying context. This systematic literature review consisted of three different phases: data collection, data selection and data reviewing. These phases will be further elaborated in the Results section.

3.2 Handbook review

Subsequently, a handbook review was conducted to validate and enrich the knowledge obtained from the systematic literature review. The handbooks provided established practical relevance on the key themes of this thesis. This review consisted of two main phases: data collection and selection, and handbook reviewing. These phases will be further elaborated in the Results section.

3.3 Critical policy review

The objective of this review is to evaluate the alignment between the research and existing policy documents. For this, policy documents functioning at different scale levels are researched to find out to what extent they align with the six strategies.

3.4 Policy and Design guide book

To make the results of this research applicable in practice, a design and policy guide was developed. This guide serves as valuable resource for

urban designers and planners. The design and policy guide presents data to provide a comprehensive understanding of the information presented. The guide offers clear guidance on incorporating UGI within a densifying context, whilst focusing on enhancing human well-being and urban ecological resilience. By consulting this guide, practitioners can gain insights and actionable recommendations for implementing UGI effectively.

3.5 Spatial mapping analysis: city scale

Within this section, two different city-scale analyses have been carried out. One (1) to find the current state of human well-being and urban ecological resilience per neighbourhood and one (2) for city-wide structures. These analyses are conducted using the pillars for human well-being and urban ecological resilience as a framework. Together they function as a basis for the city strategy. (1) QGIS is used for the mapping analysis per neighbourhood using varying data sources. From this, two conclusion maps are created illustrating the state of neighbourhoods regarding the key themes. This analysis is used as a basis to find the intervention neighbourhood for the neighbourhood design phase. (2) This analysis has brought the state of city-wide structures regarding human well-being and urban ecological resilience.

3.6 City Strategy

A strategy for Eindhoven is created based on the following key themes: urban densification, human well-being and urban ecological resilience. The strategy aims at applying the six strategies of applying UGI into densifying cities.

3.7 Neighbourhood analysis

For the intervention neighbourhood 'Muschberg, Geestenberg' an analysis is conducted to determine neighbourhood characteristics and the state of human well-being and urban ecological resilience based on their pillars. Concepts are presented for the key themes and a masterplan framework is created aiming at the application of UGI interventions on the neighbourhood scale.

3.8 Neighbourhood design

Based on the neighbourhood analysis, a concept is created for the redevelopment of Sectie-C. The six strategies and UGI interventions form the basis for this redevelopment.

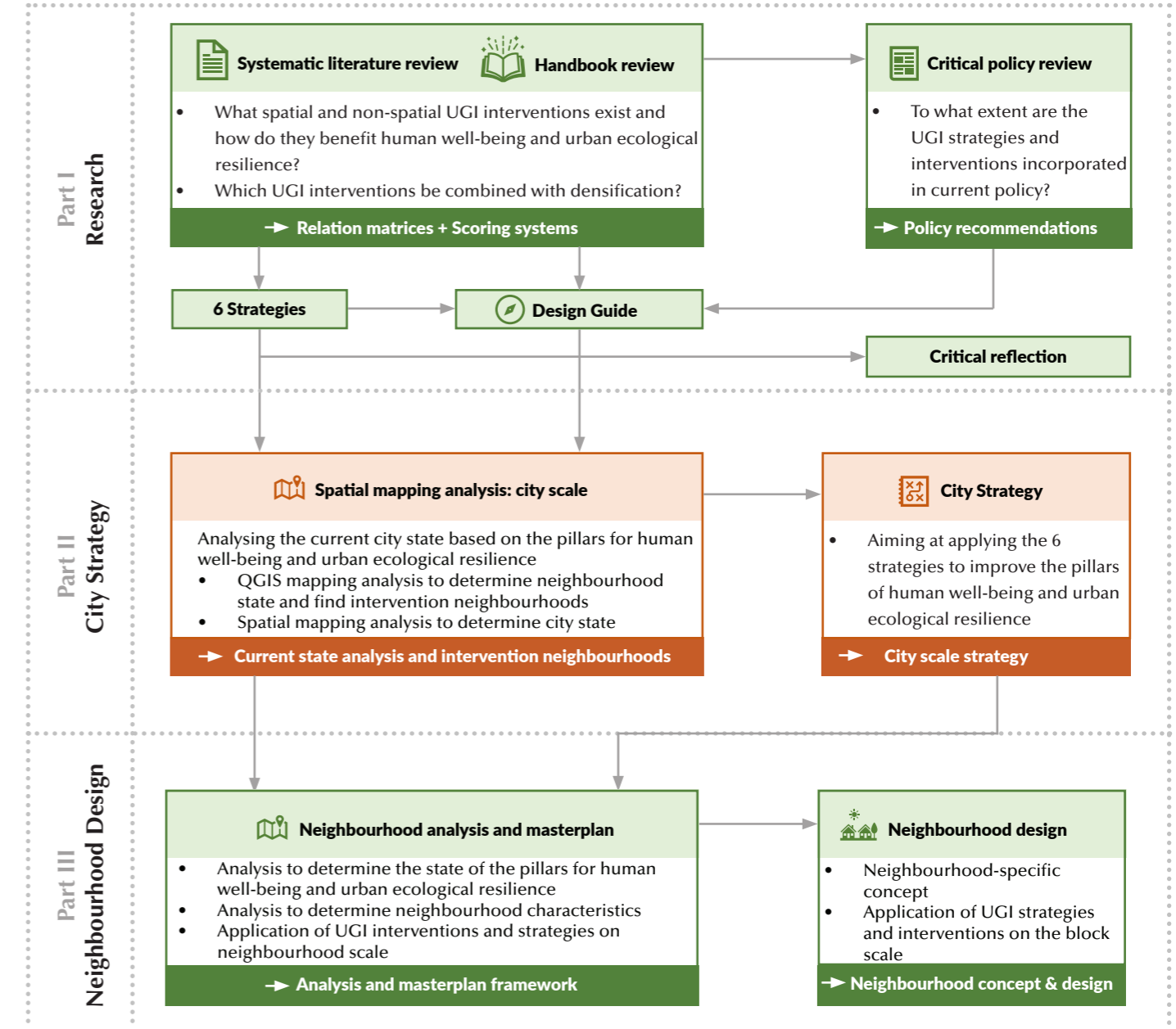


Figure 12 Schematic structure of thesis

4. Results

This chapter describes the data collection and selection, the data review and the results of the systematic literature and handbook review, and the critical policy review.

4.1 Systematic literature and handbook review

Together, a systematic literature review and a handbook review aim at answering the following research questions:

- 1 What spatial and non-spatial UGI interventions exist?
- 2 What UGI interventions are suitable for densifying areas?
- 3 How can strategies for the implementation of these UGI interventions be formulated?
- 4 How do these UGI interventions influence human well-being and urban ecological resilience?

The academic papers and handbooks and serve as a scientific basis for identifying the UGI interventions, evaluating their suitability for densifying areas, and evaluating their influence on both human well-being and urban ecological resilience in a densifying context. Additionally, the handbook review validates and enriches the

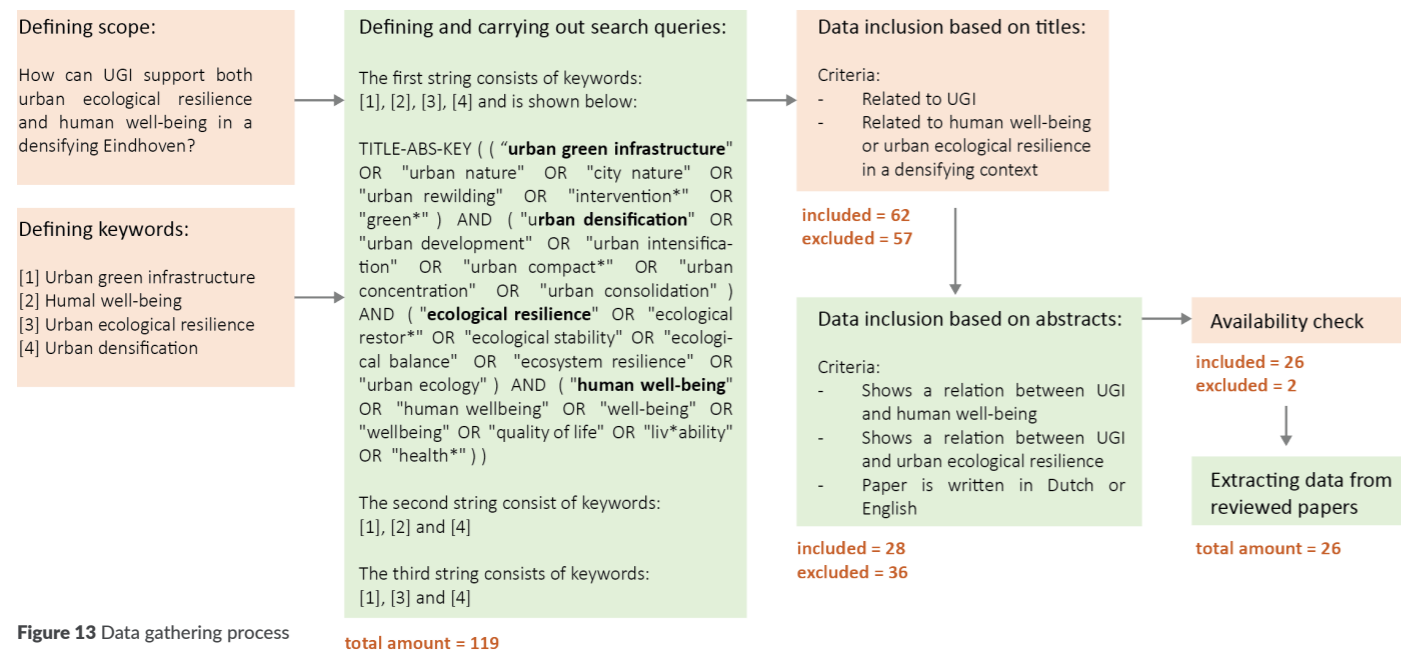


Figure 13 Data gathering process

knowledge obtained from the systematic literature review and brings structure to the UGI interventions by helping identify main strategies.

4.1.2 Data collection and selection systematic literature review

An overview of the process of data collection and selection is visualized in Figures 13 and 14. To collect data, firstly the scope of the literature research was determined by setting the research question and the keywords: urban green infrastructure, human well-being, urban ecological resilience, and urban densification. A search-query was formed using all four keywords and tested in the search engine

Table 4 Inclusion (I) and exclusion criteria (E)

In-/ exclusion criteria titles	<ul style="list-style-type: none"> • Does it relate to UGI? (I) • Does it relate to a densifying context? (I)
In-/ exclusion criteria abstracts	<ul style="list-style-type: none"> • Does it relate to human well-being? (I) • Does it relate to urban ecological resilience? (I) • Does it relate to UGI or urban densification? (I) • Is it written in Dutch or English? (E)

Scopus in April, 2023 (Table 5). The research query with all keywords, generated 38 papers as a result. However, after applying inclusion and exclusion criteria (Table 4), only five relevant papers remained.

Because of the limited amount of relevant papers found, two additional queries have been used for a larger scientific basis (Table 5). One search query encompassed the keywords urban green infrastructure, human well-being and urban densification and generated 44 results. After applying in- and exclusion criteria, eleven papers were included. Finally, the third search query was created using the keywords urban green infrastructure, urban ecological resilience and urban densification, and generated 37 results. After applying the in- and exclusion criteria for this search, ten papers remained. Altogether, the three search queries formed a scientific basis of 26 relevant papers. Appendix A.1 shows an overview of the 26 papers reviewed in this section. In the tables in the results section, these papers will be referenced through their corresponding DID-number.

Table 5 Overview of search queries

Search query 1	TITLE-ABS-KEY (("urban green infrastructure" OR "urban nature" OR "city nature" OR "urban rewilding" OR "intervention*" OR "green*") AND ("urban densification" OR "urban development" OR "urban intensification" OR "urban compact*" OR "urban concentration" OR "urban consolidation") AND ("ecological resilience" OR "ecological restor*" OR "ecological stability" OR "ecological balance" OR "ecosystem resilience" OR "urban ecology") AND ("human well-being" OR "human wellbeing" OR "well-being" OR "wellbeing" OR "quality of life" OR "liv*ability" OR "health*"))
Search query 2	TITLE-ABS-KEY (("urban green infrastructure" OR "UGI" "urban nature" OR "city nature" OR "urban green space" OR "greening" OR "compact urban green") AND ("urban densification" OR "urban intensification" OR "compact urban space" OR "compact city" OR "urban concentration" OR "urban consolidation" OR "urban infill") AND ("ecological resilience" OR "resilience" OR "ecological stability" OR "ecological balance" OR "ecosystem resilience" OR "urban ecology" OR "urban ecosystems" OR "urban biodiversity"))
Search query 3	TITLE-ABS-KEY (("urban green infrastructure" OR "UGI" "urban nature" OR "city nature" OR "urban green space" OR "greening" OR "compact urban green" OR "ecosystem services") AND ("urban densification" OR "urban intensification" OR "compact urban space" OR "compact city" OR "urban concentration" OR "urban consolidation" OR "urban infill") AND ("human well*being" OR "quality of life" OR "liv*ability" OR "health"))
Access	Open
Language	English
Database	Scopus, April 2023

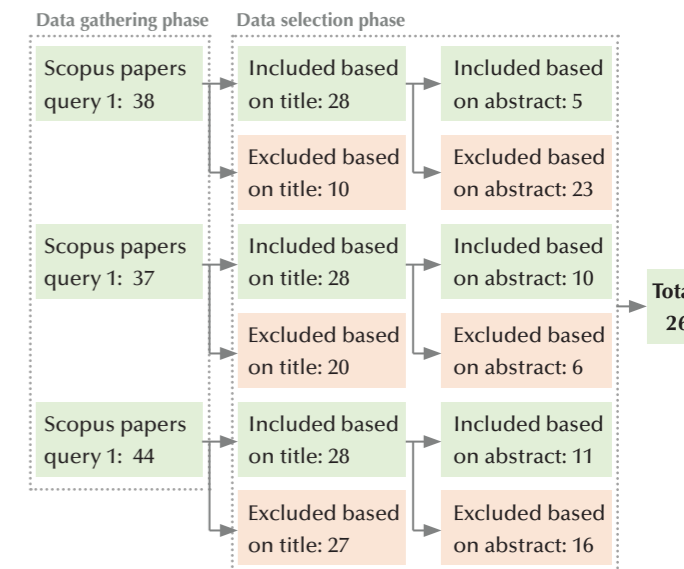


Figure 14 Inclusion and exclusion results of the search queries

4.1.4 Data collection and selection handbook review

Firstly the scope and key research themes are defined: UGI, human well-being, urban ecological resilience, and urban densification. An internet search is done to find relevant handbooks to the key themes and the scale of implementation (municipal/ city scale). This is complemented by handbooks referenced in literature researched in the systematic literature review, when relevant for the key themes. Together, this provided 7 handbooks which can be found in Appendix A.2. In the tables in the results section, these handbooks will be referenced through their corresponding DID-number.

4.2 Identifying and filtering UGI interventions

Finally, data has been extracted from the selected papers. This data is used to identify different UGI interventions that are evaluated on their benefit to both urban ecological resilience and human well-being in a densifying context. In the results section, the results from this data reviewing section and the handbook review are combined. The reviewing of handbooks has brought additional structure to the collected UGI interventions found in the systematic literature review by helping to identify six main strategies for achieving human well-being and urban ecological resilience. These results are presented together with the results from the systematic literature review.

4.2.1 Identifying UGI interventions

The selected academic papers and handbooks are examined to identify both spatial and non-spatial UGI interventions. These interventions

Urban Ecological Resilience

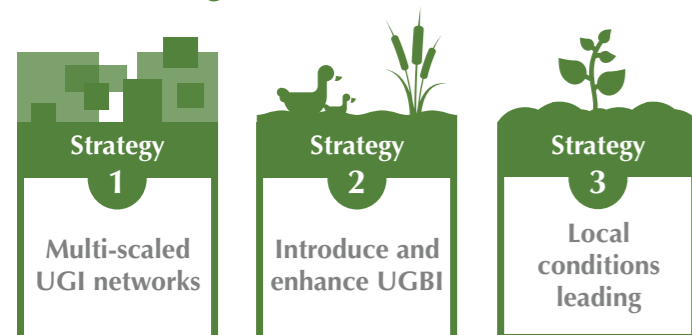


Figure 15 Six strategies for UGI implementation in densifying areas

are organized in a comprehensive table, capturing relationships between UGI interventions and the pillars supporting human well-being and urban ecological resilience. The result is an overview of data-based relationships between UGI interventions and key themes. Initially, the inventory yielded around 400 spatial and non-spatial UGI interventions. After grouping and filtering, 220 relevant interventions remained for further analysis.

4.2.3 Suitability for densifying areas

Subsequently, the UGI interventions underwent filtering based on their suitability for densifying areas. This has been done based on the following criteria for UGI in densifying cities:

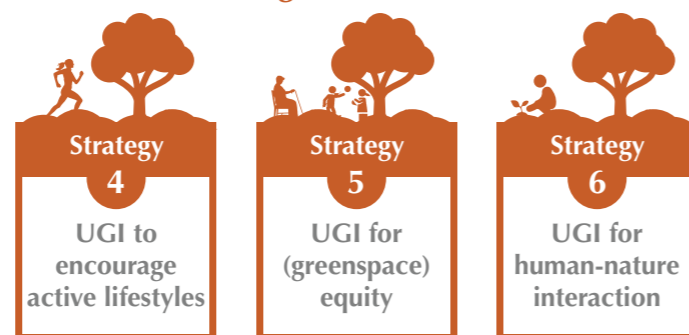
1. If the UGI interventions aim at enhancing existing UGI (Amaya-Espinel et al., 2019)
2. If the UGI interventions prioritize quality UGI over quantity (Artmann et al., 2019)
3. If the UGI interventions aligns with standards for “Compact Urban Green Space”, where UGI fits within small open spaces or maintains a limited ground-level footprint (de Roode, 2021)

After applying these criteria, the list of UGI interventions reduced from 220 to 120 relevant UGI interventions for densifying areas.

4.2.4 Strategies for UGI implementation

Six main strategies were identified, encompassing a range of Urban Green Infrastructure (UGI) interventions applicable to densifying contexts (Figure 12). Strategies 1-3 primarily focus on enhancing urban ecological resilience, while strategies 4-6 emphasize improving human

Human well-being



well-being. In the context of densifying cities, it is crucial to (1) design multi-scaled UGI networks, (2) introduce and enhance Urban Green Blue Infrastructure (UGBI), (3) prioritize local conditions in UGI design, (4) design UGI to encourage active lifestyles and physical activity, (5) design UGI to promote environmental justice and greenspace equity, and (6) design UGI to facilitate human-nature contact and interaction.

4.2.5 Relation matrices

To process the results found in the systematic literature review and handbook review, relation matrices have been created for each strategy, resulting in six total. These matrices can be found in Appendix B and describe the relationship (positive, neutral or negative) between the UGI interventions, and the pillars for human well-being and urban ecological resilience. Furthermore, the data on which the nature of the relationship is based is included in the matrices. The structure of the matrices is further elaborated in Appendix B.1.

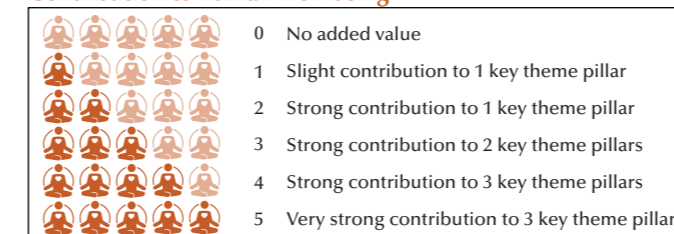
4.3 Data review

This section provides a structured presentation of the findings derived from the systematic literature and handbook review. The strategies and their corresponding UGI interventions are presented in Main Strategy

Tables 1-6 for a clear overview. The tables provide the categorized UGI interventions for which a scoring system for human well-being and urban ecological well-being is applied. This scoring system shows their benefit to the key themes human well-being and urban ecological resilience. Tables including the data gathered in the literature and policy reviews can be found in Appendix B.

The scoring is done based on the scheme presented in (Figure 16). With this scheme, the benefit for the key themes is found. For the purpose of this research, it is assumed that all main pillars for both key concepts are equally important for achieving human well-being and urban ecological resilience. For each strategy, one UGI intervention that has a very strong contribution to the pillars of both human well-being and urban ecological resilience is highlighted and clarified. Besides, one UGI intervention that scores low for either both or one of the key themes is elaborated. Additional outcomes might be explained if necessary. The UGI interventions with a very strong contribution to both key themes can be considered the most effective interventions, based on the literature and handbooks.

Contribution to human well-being



Contribution to urban ecological resilience

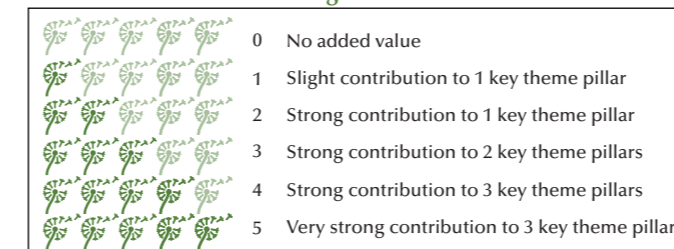


Figure 16 Six strategies for UGI implementation in densifying areas

4.3.1 Main Strategy 1: Multi-scaled UGI networks

Strategy 1 Multi-scaled UGI networks

Reviewing the data shows that ten papers and all seven handbooks emphasize the significance of a multi-scale network of UGI in densifying urban contexts, as indicated in Table 6. Implementing a networked series of UGI facilitates the reconnection of fragmented urban ecological landscapes (Kirk et al., 2021), benefitting both human walkability (Vich et al., 2019) and promoting connectivity for other species (Hansen et al., 2017; Kenniscentrum sport & bewegen, 2021). Moreover, this strategy not only promotes movement, but also mitigates environmental risks (Hansen et al., 2017). As interconnected green spaces demonstrate superior ecological functions compared to isolated ones (Rostang et al., 2021), networked series of UGI at various scale levels enhances local biodiversity (Kenniscentrum sport & bewegen, 2021). Finally, it facilitates abiotic flows such as water and air (Hansen et al., 2017), contributing to fresher air within the urban fabric.

All UGI interventions related to this strategy, can be found in Main strategy Table 1. For this strategy, fifteen UGI interventions have a very strong contribution to the pillars of both human well-being and urban ecological resilience. An example of this is ‘Designing and greening of roofscapes into green- (Gemeente Amsterdam, 2019; Madureira & Monteiro, 2021; Singh et al., 2020; Tillie et al., 2018), brown- (Gemeente Amsterdam, 2019) or water roofs (Gemeente Amsterdam, 2019; Natural England, 2023), sky gardens and roof gardens’ (Gemeente Amsterdam, 2019; Kirk et al., 2021). Implementing these roofscape designs, enhances human well-being by offering climate mitigation benefits, capturing fine particles (Tillie et al., 2018), water buffering and reducing urban heat islands (UHI) (Gemeente Amsterdam, 2019). Vegetated roofs appear more effective than surface vegetation for reducing UHI in dense urban contexts (Madureira & Monteiro, 2021). Moreover, these roofscapes can provide a safe and accessible green space, particularly beneficial for vulnerable groups (Stewart, 2020). Furthermore, they contribute to urban ecological resilience by functioning as additional stepping stones in the UGI network, improving connectivity and expanding species habitat for birds, bees, bats and other insects (Gemeente Amsterdam, 2019).

Within this strategy, only one UGI measure and intervention one UGI intervention that scores high for human well-being and low for urban ecological resilience, namely ‘Maximizing street furniture and amenities in UGI (e.g. benches, water fountains, bike parking, street lights)’ (Kenniscentrum sport & bewegen, 2021; Madureira & Monteiro, 2021; Stewart, 2020; Vidal Yañez et al., 2023). According to (Vidal Yañez et al., 2023), complementing UGI with various urban elements enhances opportunities for physical engagement, benefiting health whilst including vulnerable ones (Madureira & Monteiro, 2021; Stewart, 2020). Additionally, Stewart (2020) highlights the importance of objectively identifiable features in urban green spaces (UGS), such as water fountains and seating possibilities. He shows these are of greater importance for people’s mental health compared to subjective features such as safety. On the other hand, no evidence is found in the literature and handbooks that would suggest a relationship between these urban elements and urban ecological resilience, resulting in a low score. Nevertheless, the inclusion of these elements remains crucial for human well-being when designing UGI.

Table 6 Overview of sources highlighting the essence of multi-scaled UGI networks

	Sources highlighting the essence of the multi-scale network
Academic papers	[1], [4], [5], [6], [8], [9], [18], [20], [24], [26]
Handbooks	[27], [28], [29], [30], [31], [32], [33]

Main strategy Table 1 Designing of a multi-scale network of UGI

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

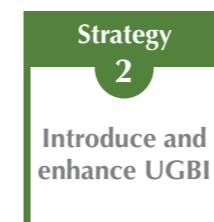
UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
1.1 Site Steppingstones			
1.1.1 Integration on the building scale			
• Designing and greening roofscapes: green, brown, water roofs, sky garden, roof garden [SS]	[1], [2], [3], [9], [13], [16], [20], [21], [26], [27], [28], [32], [33]	5	5
• Designing and greening gardens: green courtyards, green residential yards, private gardens, front gardens [SS]	[1], [6], [13], [17], [23], [25]	5	5
• Designing vertical greenery: façade gardens, green walls and façades [SS]	[2], [10], [15], [21], [24]	4	4
• Introducing balcony greenery and window boxes [SS]	[20], [26], [27], [28]	3	2
• Integrating nesting facilities, insect hotels [SS]	[27], [28], [31]	3	5
1.1.2 UGI through UGBS			
• Introducing and enhancing small-scale green-blue spaces, e.g. ponds [SS]	[1], [6], [7], [15], [17], [24], [26]	3	5
• Introducing edible landscaping, e.g. fruit trees [SS]	[1], [16], [17], [21], [25]	3	3
• Introducing and enhancing NBS: e.g. permeable paving, raingardens, bioswales [SS]	[1], [2], [3], [7], [8], [9], [13], [10], [16], [17], [20], [21], [24], [26], [27], [28]	5	5
• Implement vegetated tree discs and allow for spontaneous vegetation to grow where possible [SS]	[8], [9], [10], [27], [33]	3	5
• Design small playscapes for children, with natural and water elements [SS]	[8], [19], [21], [25], [27], [32], [33]	4	4
• Include ornamental plantings (e.g. planters, grasses, pergola’s or scaffoldings) [SS]	[9], [28]	3	3
• Greening quays and quay walls, and placing of ‘float lands’ in canals [SS]	[21], [26], [27], [28], [31]	3	4
• Centralize parking and converting on-street parking into UGI [SS]	[8], [30]	3	3
• Dense, diverse and layered patches of native flora species: e.g. hedges, bushes, shrubs, grass, flowers [SS]	[26], [27]	5	5
• Maximizing street furniture and amenities in UGI (e.g. benches, water fountains, bike parking, street lights) [SS]	[13], [15], [20], [30]	5	0
1.2 Street Corridor			
1.2.1 UGI connectivity			
• Green fine-grain basis network for slow traffic [SC]	[30]	5	5
• Introduce layered green space through accessible greenways on rooftops [SC]	[21], [27]	3	4
• Defragmenting the landscape by facilitating dispersal across small-scale barriers through e.g. underpasses [SC]	[26]	1	3
1.2.2 Green-blue corridors			
• Green-blue corridors: e.g. urban creeks, waterways, small canals, ditches [SC]	[1], [6], [7], [15], [17], [24], [26]	4	4

Main strategy Table 1 Designing of a multi-scale network of UGI

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
• Introducing a diverse canopy of street trees [SC]	[14], [15], [17], [20], [23], [26]	2	3
• Greening of streets and alleyways [SC]	[9], [10], [15], [18]	5	5
1.3 Neighbourhood Steppingstones			
• Green-blue spaces: e.g. ponds, fountains [NS]	[1], [6], [7], [15], [17], [24], [26]	3	5
• Integrate public: small urban parks (SUPs), pocket parks, green squares, urban gardens, playgrounds [NS]	[2], [3], [6], [9], [10], [11], [12], [13], [15], [16], [19], [20], [21], [24], [26]	5	5
• Integrate communal: communal gardens, allotments, communal farms, communal orchards [NS]	[1], [6], [13], [17], [23], [25]	5	5
1.4 City Corridors			
• Green-blue corridors on city scale: e.g. canals [CC]	[1], [6], [7], [15], [17], [24], [26]	5	5
• Habitat and wildlife corridors [CC]	[5], [6], [8], [26], [27]	2	4
• Facilitation of main green network for slow traffic, maximizing width (walking, cycling, jogging) [CC]	[30], [32], [33]	5	5
• Facilitation of dispersal across major barriers, e.g. green bridges, underpasses [CC]	[26]	1	3
• Greening along linear elements, e.g. boulevards, canals, railways [CC]	[4], [6], [18], [21], [26]	3	3
1.5 City Sites			
• Public city parks, waterfront parks, gardens, green squares and plazas, etc. [CS]	[1], [3], [6], [9], [10], [11], [12], [13], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [30], [32]	4	5
• Urban agricultural areas, allotment gardens, urban orchards [CS]	[6], [17], [16], [20], [25], [29], [33]	5	5
• Urban wetlands, urban wetland parks [CS]	[16], [26], [31], [32], [33]	5	5
• Introducing and enhancing green urban sporting locations, e.g. golf courses [CS]	[30]	5	2
1.6 Region Corridors			
• Introducing and enhancing green-blue corridors at region scale: e.g. rivers, canals [RC]	[1], [6], [7], [15], [17], [24], [26]	5	5
• Introducing and enhancing green belts, green wedges, connecting to the region [RC]	[1], [6], [17], [25]	5	5
• Facilitation of dispersal across major barriers, e.g. eco passages, wooded habitat corridors [RC]	[2], [7], [8], [12], [26]	3	5
• Designing for region-wide green fast cycling routes [RC]	[30], [32], [33]	5	5
1.7 Region Hubs			
• Large green-blue bodies: e.g. lakes, wetlands [RH]	[16], [26], [31], [32], [33]	5	5
• Agricultural lands, orchards [RH]	[6], [17], [16], [20], [25], [29], [33]	4	5
• Forests, woodlands, forestry parks, health landscapes [RH]	[2], [6], [9], [11], [12], [16], [17], [19], [20], [21], [22], [23], [24], [26], [31]	5	5

4.3.3 Main Strategy 2: Introducing and enhancing UGBI



Ten scientific papers and all seven handbooks emphasize the importance of introducing and enhancing urban green-blue infrastructures (UGBI) (Table 7). According to (Russo & Cirella, 2018), UGBI impact a very wide range of human well-being issues, including safety, equality, health, education and recreation.

While promoting social inclusion and provides opportunities for community events and outdoor activities. Moreover, UGBI contributes to the creation of diverse habitat (Kirk et al., 2021). Additionally, UGBI plays a crucial role in mitigating urban heat and buffering water (Russo & Cirella, 2018).

All UGI interventions related to this strategy, are presented in Main Strategy Table 5. Five of the UGI interventions demonstrate a very strong contribution to both human well-being and urban ecological resilience. One example is ‘Introducing new NBS and improving existing where needed’ (Amaya-Espinel et al., 2019; Artmann et al., 2019; Gemeente Amsterdam, 2019; Gemeente Eindhoven, 2020b; Khurana et al., 2023; Kirk et al., 2021; Lennon, 2021; Madureira & Monteiro, 2021; Russo & Cirella, 2018; Scheiber, 2022; Shao et al., 2023; Singh et al., 2020; Stewart, 2020; Tillie et al., 2018; Vega & Küffer, 2021). This measure benefits human well-being by providing a range of advantages, including flood mitigation (Scheiber, 2022), air filtration, temperature reduction (Vega & Küffer, 2021), and capturing of fine particles (Tillie et al., 2018). Besides, NBS introduce green recreational spaces (Tillie et al., 2018). Furthermore, it offers new habitat for local species (Kirk et al., 2021), particularly amphibians, bees and other insects (Gemeente Amsterdam, 2019). Connectivity is improved when NBS function as vegetated corridors between sites (Kirk et al., 2021). Lastly, they facilitate ways of maximizing ground water infiltration (Scheiber, 2022).

For this strategy, none of the UGI interventions scores very low for both key themes. ‘Designing to show water in the streets’ does present a low score for human well-being. However, it is important to note that this UGI measure and intervention primarily focuses on blue infrastructure rather than UGBI.

Table 7 Overview of sources highlighting the essence of multi-scaled UGI networks

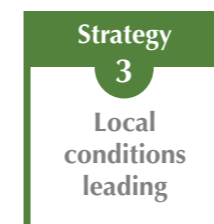
	Sources highlighting the essence of introducing UGBI
Academic papers	[1], [6], [7], [15], [17], [24], [26], [27], [32], [33]
Handbooks	[27], [28], [29], [30], [31], [32], [33]

Main strategy Table 2 Introducing and enhancing Urban Green-Blue Infrastructure (UGBI)

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
3.1 Making water visible			
• Designing to show water in the streets (e.g. open, fluted and covered gutters, hollow roads) [SC, SS]	[32]	3	2
• Designing to show water in the streets through UGBS (e.g. ditches, urban water channels) [SC, SS]	[32]	4	5
• Include water elements (e.g. fountains) [CS, NS, SS]	[13], [30]	5	2
3.1 Buffering and infiltration			
• Reducing road coverage by unsealing soils and using permeable materials [SC]	[2], [9], [21], [22], [24], [32]	3	3
• Introducing new and improving existing waterbodies (e.g. ponds, lakes, wetlands) [RH, CS, SS]	[1], [7], [15], [17], [24], [26], [27], [32], [33]	4	5
• Introducing new NBS and improve existing where needed [SS]	[1], [2], [3], [7], [8], [9], [13], [10], [16], [17], [20], [21], [24], [26], [27], [28]	5	5
• Design natural playgrounds including water elements [SS, NS, CS]	[8], [19], [21], [25], [27], [32], [33]	3	5
• Design green water squares [CS, NS]	[32]	3	3
• Design ecological bioswales and urban infiltration strips, and rain gardens [SS]	[8], [17], [21], [26], [27], [32], [33]	5	5
• Design buffering roofscape: green, brown and water roofs [SS]	[1], [2], [3], [9], [13], [16], [20], [21], [26], [27], [28], [32], [33]	5	5
• Strengthen and introduce urban wetlands [RH, CS]	[16], [26], [31], [32], [33]	5	5
• Greening of blue corridors or introducing green-blue corridors (e.g. creeks, canals, rivers) [RC, CC, SC]	[1], [6], [7], [15], [17], [24], [26]	5	5
• Encouraging green-blue structures in private gardens [SS]	[2], [10], [12], [20]	4	5
• Introducing more green waterfront parks along UGBS and blue corridors [CS, NS]	[1], [3], [6], [8], [19], [20], [21], [22], [23], [25], [27], [30], [32]	5	4
• Implementing more soft, green, ecological quays/ banks, and implementing green quay walls [CS, NS]	[21], [26], [27], [31]	3	5
• Placing of 'float lands' in canals [SS]	[27], [28], [31]	3	3
• Vegetated tree pits (tree discs) and aim at 4m2 to overcome 'crowding effect' [SS]	[8], [9], [10], [27], [33]	3	5
• Implementing greywater usage (systems, tanks in gardens) [32]	[32]	3	2

4.3.2 Main Strategy 3: Local conditions leading



Nine scientific papers and four handbooks specifically emphasize the importance of responding to local conditions, as indicated in Table 8. This strategy is important for various reasons. Firstly, distinctive local 'landscape characters' play a significant role in people's feeling of belonging. It embraces culture and history and helps inhabitants form meaningful connections with their surrounding environment (Natural England, 2023). From an ecological perspective, it is essential to consider local conditions for improvement, due to the dynamic variations within UGI (Chen et al., 2021). For instance, the best way to maintain and enrich diverse species communities is by applying local and native vegetation (Amaya-Espinel et al., 2019).

Main Strategy Table 3 presents the UGI interventions related to this strategy. For this strategy, two UGI interventions have a very strong contribution to the pillars of both human well-being and urban ecological resilience. 'Respecting of heritage features' (Natural England, 2023), is an example of this. According to the 'Green Infrastructure Planning and Design Guide' (Natural England, 2023), these heritage features allow communities to connect to their culture, history and memories, leading to important connections with their environment. Through this, they provide a basis for communities and social cohesion. From an ecological perspective, heritage sites often provide valuable habitat for species and improve their connectivity, they as often house native green elements (e.g. shrubs, hedges, ponds). These historic sites house many 'aged' native trees and plants that contribute significantly to carbon sequestration: age matters.

For this strategy, one one UGI intervention that scores high for human well-being and low for urban ecological resilience, namely 'Maximizing street furniture and amenities in UGI (e.g. benches, water fountains, bike parking, street lights)' (Kenniscentrum sport & bewegen, 2021; Madureira & Monteiro, 2021; Stewart, 2020; Vidal Yañez et al., 2023). As this is the same measure as for main strategy 1, further elaboration is unnecessary.

Table 8 Overview of sources highlighting the essence of local conditions leading

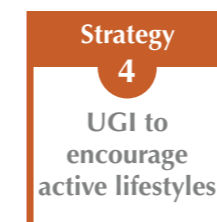
	Sources highlighting the essence of the multi-scale network
Academic papers	[1], [2], [6], [9], [13], [20], [21], [23], [26]
Handbooks	[27], [28], [32], [33]

Main strategy Table 3 Responding to local conditions

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
2.1 Responding to local conditions, based on local ecological characteristics			
• Implementing NBS based on local characteristics and native species [SS]	[1], [2], [3], [7], [8], [9], [13], [10], [16], [17], [20], [21], [24], [26], [27], [28]	4	5
• Ensuring a diverse native vegetation and tree variety [SC, SS]	[2], [6], [7], [8], [9], [10], [15], [17], [18], [19], [20], [21], [22], [23], [26], [28]	3	5
• Maintaining and increasing urban vegetation coverage (quality & quantity) [All]	[2], [6], [8], [9], [13], [15], [23]	2	5
• Allowing spontaneous vegetation growth where possible [SC, SS]	[6], [9]	1	3
• Introducing habitat corridors for native species to connect green spaces [RC, CC, SC]	[5], [6], [8], [26]	5	5
• Retrofitting and improving existing UGI [All]	[1], [6], [7], [8], [9], [13], [17], [19], [26]	5	5
• Integrate periodic maintenance [NS, NC, SS]	[9], [31]	4	5
2.2 Responding to the local character of places, based on cultural and historical characteristics			
• Ensuring multifunctionality and flexibility of UGS [CS, NS, SS]	[8], [17], [20], [21], [29]	3	1
• Respecting of heritage features [CS, NS, SS]	[33]	5	5
• Providing furniture and amenities in public space, based on local typologies [SS]	[13], [15], [20], [30]	5	0
• Stimulation of participatory processes, civic engagement and feedback loops [All]	[5], [8], [11], [16], [23]	5	2

4.3.4 Main Strategy 4: UGI to encourage active lifestyles



Six scientific papers and six out of seven handbooks directly emphasize the importance of designing UGI to encourage physical activity (Table 9). Initially, designing UGI to encourage physical activity seems to primarily impact human well-being over urban ecological resilience, as it is widely known that

physical activity is crucial for human’s mental and physical health (Vidal Yañez et al., 2023). However, designing public space to accommodate this through UGI brings multiple benefits for urban ecological resilience. For instance, the ‘implementation of high-quality green slow traffic routes’ creates opportunities for additional UGI within the urban context, enhancing species mobility, local biodiversity (Kenniscentrum sport & bewegen, 2021) and soil quality (Pötz, 2022).

The UGI interventions of this strategy, are presented in Main Strategy Table 4. Five of the UGI interventions demonstrate a very strong contribution to human well-being and urban ecological resilience. For example, ‘Designing a main green network for slow traffic’ (Kenniscentrum sport & bewegen, 2021; Natural England, 2023; Pötz, 2022). This measure promotes human well-being by facilitating active movement and enhancing safety for slow traffic, while providing opportunities for active recreation (Kenniscentrum sport & bewegen, 2021). Moreover, it contributes to urban ecological resilience by establishing linear green spaces throughout the city, improving local biodiversity and connectivity. Additionally, greening cycle lanes introduces more vegetation, thereby improving soil conditions (Pötz, 2022).

Four UGI interventions have no additional value for urban ecological resilience, which is a higher number compared to previous strategies. This is mainly due to these interventions involving urban elements in UGI. For instance, ‘Maximizing footpath width’ (Scheiber, 2022; Vega & Küffer, 2021) benefits human well-being by promoting active mobility and improving inclusivity of slow traffic paths and lanes (Scheiber, 2022). However, in terms of urban ecological resilience, this measure mainly brings negative effects, as it leads to more soil sealing (Pötz, 2022).

Table 9 Overview of sources highlighting the essence of UGI for active lifestyles

	Sources highlighting the essence of the multi-scale network
Academic papers	[8], [12], [15], [18], [21], [23]
Handbooks	[27], [28], [29], [30], [31], [32], [33]

Main strategy Table 4 UGI to encourage active lifestyles

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
4.1 Active mobility flowscape			
• Designing a main green network for slow traffic (walking & cycling) [RC, CC]	[30], [32], [33]	5	5
• Designing green fast cycling routes [RC, CC]	[30], [32], [33]	5	5
• Designing green, fine-grain basis network for slow traffic [CC, SC]	[30]	5	5
• Implementing of mobility hubs [NS]	[30]	3	1
• Striving for a proximity of UGS (3-30-300 rule) [NS, SC]	[1], [3], [4], [8], [12], [14], [15], [17], [18], [19], [20], [21], [23], [29]	5	2
• Designing child-friendly streets, routes and school zones to mobilize children [SC, SS]	[3], [4], [8], [13], [15], [20], [21], [30]	5	2
• Designing green shared spaces that prioritize slow traffic [SC]	[30]	5	2
• Implementing (nature-friendly) street lighting to maximize safety [SC, SS]	[30]	5	3
• Shift on-street parking to clustered parking facilities [NS, SC, SS]	[8], [30]	3	3
• Designing greenways on rooftops that are accessible from the street [SC]	[21], [27]	3	4
• Planting of diverse canopy trees [SC, SS]	[14], [15], [17], [20], [23], [26]	2	3
• Maximizing footpath width [SC]	[8], [19]	5	0
• Ensure enough bike parking [SS]	[30]	5	0
4.2 Active recreational network			
• Designing main green-blue active recreation network (e.g. walking, cycling, mountain biking, jogging) [RC, RH, CC, CS]	[30], [32], [33]	5	5
• Designing fine-grain network of green-blue pathways [CC, SC]	[30], [32]	5	5
• Designing public parks and gardens [CS, NS]	[1], [3], [6], [9], [10], [11], [12], [13], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [30], [32]	4	5
• Providing natural playgrounds [CS, NS]	[8], [19], [21], [25], [27], [32], [33]	3	5
• Providing furniture and amenities in public spaces	[13], [15], [20], [30]	5	0
• Providing green sporting and playing locations (e.g. skateparks, fitness) [RH, CS, NS]	[30]	5	1
• Designing places to accommodate watersports (e.g. rowing, swimming, canoeing) [CS]	[30]	3	3
• Introducing sports equipment in the public space [NS, SS]	[30]	4	0

4.3.5 Main Strategy 5: UGI for environmental justice and greenspace equity



Data shows ten scientific papers and five handbooks emphasize the significance of designing for environmental justice and greenspace equity (Table 10). Initially, designing UGI to promote environmental justice and greenspace equity seems to primarily impact human well-being over urban ecological resilience. However, it also brings benefits for urban ecological resilience. For example, as stated by Natural England (2023), greenspace equity covers an equal distribution of high-quality UGI throughout the entire city, which is beneficial for biodiversity, connectivity and the fitness of biotic and abiotic factors.

The UGI interventions related to this strategy, are presented in Main Strategy Table 5. The data review shows none of the UGI interventions have a very strong contribution for both key themes. Five UGI interventions score a 5 for their benefit to human well-being, underpinning their importance for enhancing human well-being. Importance for urban ecological resilience can be seen for ‘Implementing urban greening interventions universally and equally across all neighbourhoods’ (Kenniscentrum sport & bewegen, 2021; Pötz, 2022; Stewart, 2020; Vidal Yañez et al., 2023). This brought a score of 5 for urban ecological resilience and a 4 for human well-being.

Three UGI interventions demonstrate having no added value for urban ecological resilience, which is a relatively high number. Especially taking into account this strategy comprises of nine UGI interventions total. The results show that the interventions mainly aim at enhancing human well-being. However, ‘Increasing the building height and density near green spaces’ (Amaya-Espinel et al., 2019; Madureira & Monteiro, 2021; Scheiber, 2022) also scores low for human well-being benefit. While this measure ensures a greater number of people living in proximity to green spaces (Amaya-Espinel et al., 2019), a study conducted in Vienna (Madureira & Monteiro, 2021) revealed that urban densification around greenspaces resulted in reduced perceived quality due to increased perceptions of crowding among the greenspace users.

Table 10 Overview of sources highlighting the essence of greenspace equity

	Sources highlighting the essence of the multi-scale network
Academic papers	[1], [4], [7], [13], [15], [16], [17], [18], [19], [21]
Handbooks	[28], [29], [30], [31], [33]

Main strategy Table 5 UGI for environmental justice and greenspace equity

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
5.1 Ensuring equal access to public green spaces and supporting health benefits			
• Striving for a proximity of UGS (3-30-300 rule) [NS, SC]	[1], [3], [4], [8], [12], [14], [15], [17], [18], [19], [20], [21], [23], [29]	5	2
• Increasing building height/ density near green spaces [CS, NS, SS]	[2], [8], [20]	2	0
• Implementing urban greening interventions universally and equally across all neighbourhoods [NS]	[13], [15], [30], [32]	4	5
• Reducing of 'risk scapes' (areas in which a community's vulnerability to environmental stressors is increased) [All]	[23], [33]	5	2
5.2 Ensuring inclusivity of UGI			
• Design of UGI should indicate people of different ages, gender identifications, cultures, and other socio-demographics [All]	[3], [4], [8], [13], [15], [20], [21], [33]	5	1
• Ensuring multifunctionality of UGS, creating hybrid, flexible and adaptable green spaces	[8], [17], [20], [21], [29]	3	1
• Providing furniture and amenities in public spaces	[13], [15], [20], [30]	5	0
• Planning from the perspective of ES and EDS, e.g. anti-allergenic plants and trees [All]	[11], [20], [23], [33]	5	3

4.3.6 Main Strategy 6: UGI for human-nature interaction

Strategy 6 UGI for human-nature interaction

Eleven scientific papers and six out of seven handbooks emphasize the importance of designing opportunities for human-nature contact, as indicated in Table 11. Contact with nature offers various benefits for physical and mental health (Stewart, 2020), gives a sense of place, allows for spiritual experiences (Chang & Chen, 2015), cooling effect and air purification (Stewart, 2020). Often UGI serves as the only available source of human-nature interaction within reasonable distance (Russo & Cirella, 2018). By creating everyday experiences with UGI, people have the opportunity to reconnect with biodiversity, encouraging them to support its preservation (Kirk et al., 2021).

All UGI interventions related to this strategy are presented in Main Strategy Table 6. Four UGI interventions have a very strong contribution to both key themes. An example of this is 'Encouraging wildlife and native species gardening in gardens, balconies' (Gemeente Amsterdam, 2019; Kirk et al., 2021). This encourages positive interactions between people and nature (Kirk et al., 2021), while supporting a healthy bee population. Which plays a crucial role in cross-contamination of our fruits and vegetables (Gemeente Amsterdam, 2019), thus promoting healthy diets. A Handbook on Nature-inclusivity (Gemeente Amsterdam, 2019) suggests that enhancing local biodiversity through inexpensive and creative solutions, such as nesting facilities, can significantly improve the overall connectivity of the UGI network.

Furthermore, none of the UGI interventions has no added value for either of the key themes. However, the measure 'Designing for passive activities bringing people in contact with nature' (Kirk et al., 2021; Natural England, 2023; Pötz, 2022; Stewart, 2020; Vidal Yañez et al., 2023) is presents 'slight' win-win potential. This is primarily because it represents a passive relationship where people do not actively contribute to nature. Nevertheless, it is still possible that UGI is improved to accommodate this measure.

Table 11 Overview of sources highlighting the essence of UGI for human-nature interaction

	Sources highlighting the essence of the multi-scale network
Academic papers	[3], [4], [5], [8], [9], [13], [14], [15], [16], [19], [26]
Handbooks	[27], [28], [29], [30], [31], [33]

Main strategy Table 6 Designing opportunities for human-nature contact and interaction

UGI network scale: Region hub [RH], Region corridor [RC], City site [CS], City corridor [CC], Neighbourhood steppingstones [NS], Street corridor [SC], Site steppingstones [SS]

UGI interventions [UGI network scale]	Sources [DID]	Contribution to human well-being [1-5]	Contribution to urban ecological resilience [1-5]
6.1 Designing for active contact			
• Designing for activities to bring people in contact with nature (e.g. green routes, natural playgrounds, gardening) [All]	[27]	5	4
• Stimulation of participatory processes, civic engagement and feedback loops [All]	[5], [8], [11], [16], [23]	5	2
• Providing natural playgrounds [CS, NS, SS]	[8], [19], [21], [25], [27], [32], [33]	3	5
• Encouraging wildlife and native species gardening in gardens, balconies (e.g. nesting facilities, insect hotels) [SS]	[26], [27]	5	5
• Creating urban allotment garden space (Recommended plot is 300-500 m2 each) [CS, NS]	[6], [17], [20], [25], [29], [33]	5	5
6.2 Designing for passive contact			
• Designing for passive activities bringing people in contact with nature (e.g. view from window) [CS, SC, SS]	[13], [15], [26], [32], [33]	5	1
• Integrating green on the building scale (e.g. façade gardens) [SS]	[27], [28], [31], [33]	3	3
• Planning from the perspective of ES and EDS, e.g. anti-allergenic plants and trees [All]	[11], [20], [23], [33]	5	3
• Allowing spontaneous vegetation growth where possible [SC, SS]	[6], [9]	2	5
• Designing for human-wildlife interactions (e.g. bird watching locations, floatlands, integrated nesting) [SS, RH]	[27], [28], [31]	3	3
6.3 Designing for different types of ownership			
• Designing of private green facilities (e.g. private garden, façade garden, front garden, green balcony)	[2], [10], [12], [20], [25], [26]	4	5
• Designing of shared green facilities, leading to communal active usage (e.g. communal gardens and farms, residential yards, roof gardens, allotment gardens)	[1], [6], [13], [17], [23], [25]	5	5
• Designing of public green facilities (city parks, small urban pocket parks, urban forests, green plazas/ squares)	[2], [3], [6], [9], [10], [11], [12], [13], [15], [16], [19], [20], [21], [24], [26], [31]	5	5

4.4 Critical policy review

There are several policies operating at different scale levels influencing Eindhoven significantly concerning the key concepts. To conduct a comprehensive review of policy, multiple scale levels are included: global, national and municipal. The national scale level refers to the Netherlands and the municipal to the municipality of Eindhoven. To classify as relevant all policy documents include at least two of the key themes. The nature of the policy documents is initially determined, such as vision documents or mission statements.

In this review, six policy documents are critically evaluated. An overview of these documents and their DID-number can be found in Appendix A.3. The six strategies present ways for promoting urban ecological resilience and human well-being in densifying urban contexts through UGI, and will be referred to by the number assigned to them in Table 12. This research investigates if the key themes and the six main strategies are currently supported by existing policies and legislations. From this, discrepancies in policy and legislation are identified, and specific (spatial) policy recommendations are formulated to enhance human well-being and urban ecological resilience through UGI in a densifying context. The following subquestions will thus be answered:

- 1 To what extent are the strategies for UGI implementation incorporated in current policy?
- 2 What are recommendations for future policy?

Table 12 Overview of policy documents, the executive scale level, the policy type and the covered strategies

DID	Document name	Scale level	Policy type	Covered strategies
[34]	The 2030 Agenda for Development	Global	Mission statement	All
[35]	Omgevingswet Geconsolideerde versie	National	Law	Potentially 1
[36]	Nederland Natuurpositief	National	Ambition document	1 + 2 + 4
[37]	Verdichtingsvisie Binnenstad Eindhoven	Municipal	Vision and guideline	1 + 2 + 4 + 5 + 6
[38]	Groenbeleidsplan 2017	Municipal	Policy plan	1 + 2 + 3 + 4 + 5 + 6
[39]	Gezondheid Telt voor Iedereen: Gezondheidsnota 2022-2025	Municipal	Policy note	4

4.4.1 Global

In 2015, the United Nations (2015) have adopted 17 sustainable development goals (SDGs) in the 2030 Agenda for Sustainable Development. These goals present a framework for promoting peace and prosperity for both people and the planet. Four of these SDGs are specifically relevant to the strategies of this research Figure 17. These goals are set at a global level, however, SDG Nederland (n.d.) states that the 'Centraal Bureau voor de Statistiek' (CBS) delivers a yearly report, presenting measurements on how the Netherlands are doing in pursuing these goals. The municipality of Eindhoven does not specifically address these goals.



Figure 17 UN Sustainable Development Goals relevant to this research (United Nations, 2015)

4.4.2 National

The forthcoming 'Omgevingswet' in the Netherlands (Informatiepunt Leefomgeving, 2023), effective from 2024, offers an opportunity to integrate UGI considerations into policy and regulations. Currently, this is not yet involved, however this can be done by, for example, including nature-inclusive regulations into the 'Building Code' (Meijer, 2023), aligning with main strategy 1.

Furthermore, the 'Landelijke nota Gezondheidsbeleid 2020-2024' (Ministerie van VWS, 2020) aims to integrate health as a permanent element in spatial policy decision-making. This addresses main strategy 4, by emphasizing the essence of encouraging physical activity through attractive UGI. Furthermore, 'Nederland Natuurpositief' (Ministerie van LNV, 2019) covers the goals of strengthening of UGBS and their interconnectedness, which addresses main strategies 1 and 2. However, both documents lack specific guidelines and actions to ensure the effective implementation of UGI at the local level.

4.4.3 Municipal

The 'Verdichtingsvisie Binnenstad Eindhoven' (Gemeente Eindhoven, 2020c) shows guidelines posed by the municipality of Eindhoven for the densification process of the city center. This document touches almost all strategies (strategies 1, 2, 4, 5 and 6), except for strategy 3. This vision of the municipality demonstrates a focus on enhancing the large-scale UGBI aligning with strategies 1 and 2. Furthermore, they mention to aim at designing inclusive (strategy 5) green spaces, that encourage physical activity (strategy 4) and human-nature contact (strategy 6). However, there is a clear lack of guidelines for the design of UGI in public spaces, raising questions about the actual realization of these goals. Further development of policy guidelines and actionable steps are crucial for effective implementation.

Also in the 'Groenbeleidsplan' (Gemeente Eindhoven, 2017), highlight two main priorities: enhancing the green-blue structures and connecting small-scale ecological networks to the wider region, aligning with strategies 1 and 2, respectively. It also emphasizes the significance of accessibility to the UGI network (strategy 5), promoting both active and passive engagement with nature (strategy 6), including physical activity (strategy 4). However, the document only very briefly mentions the importance of native species and local

ecology characteristics (strategy 3). Furthermore, the document does not provide any type of actionable plan, limiting its effectiveness in guiding practical implementation.

Finally, the 'Gezondheidsnota 2022-2025' (Gemeente Eindhoven, 2022) sets clear goals for achieving a healthy green environment that promotes physical activity (strategy 4), and even proposed multiple actionable ways to achieve this. However, since this document is limited to the topic of health, none of the other strategies are incorporated.

4.4.4 Policy recommendations

The first recommendation for policy, is the integration of UGI considerations in national policies though the 'Omgevingswet 2024'. This new national policy framework provides an opportunity to incorporate UGI considerations into policy and regulations, through for example the 'Building Code'. This will help create a policy framework that supports the implementation of UGI interventions across different scale levels and ensures that it will become a standard practice in all municipalities in the Netherlands to include UGI in projects.

Furthermore, it is evident that strategy 3, responding to local characteristics, is mentioned in only one policy document. This emphasized the importance for its greater implementation. The same is true however, for most strategies, as only for strategy 4, designing to encourage physical activity, has been provided with clear ambitions and actionable ways of achieving this goal. Furthermore, most documents only describe visions and ambitions and lack clear guidance on how to implement these on a local scale. Through this, it is evident that clear actionable plans or roadmaps are crucial for proper implementation of visions and ambitions. Because of this, is of importance that the policy and design guide (Section 4.5) succeeds at addressing this gap by offering practical information and actionable steps for local implementation.

4.5 Urban Green Guide

The design and policy guide, created as part of this research, serves as a practical tool to bridge the gap between theory and practice. It is designed to assist urban designers and planners in effectively implementing urban green infrastructure (UGI) interventions within densifying contexts to enhance both human well-being and urban ecological resilience. The guide encompasses eight chapters, each dedicated to one scale level in the UGI network (7 chapters), including one city-wide intervention chapter. Furthermore, a catalogue and a reading manual to ease navigating through the book are included.

For each UGI measure and intervention, the guide provides data creating an understanding of the benefits of UGI for both human well-being and urban ecological resilience. By consulting the design and policy guide, urban designers, planners and decision makers can access practical insights, evidence-based examples, and guidance on how to incorporate UGI effectively. A preview of the cover page and contents can be seen in Figure 18 below. Additionally, the 'Multi-scale network of UGI', related to strategy 1, is visualized based on the included UGI. This visualisation can be found in Appendix B.2.

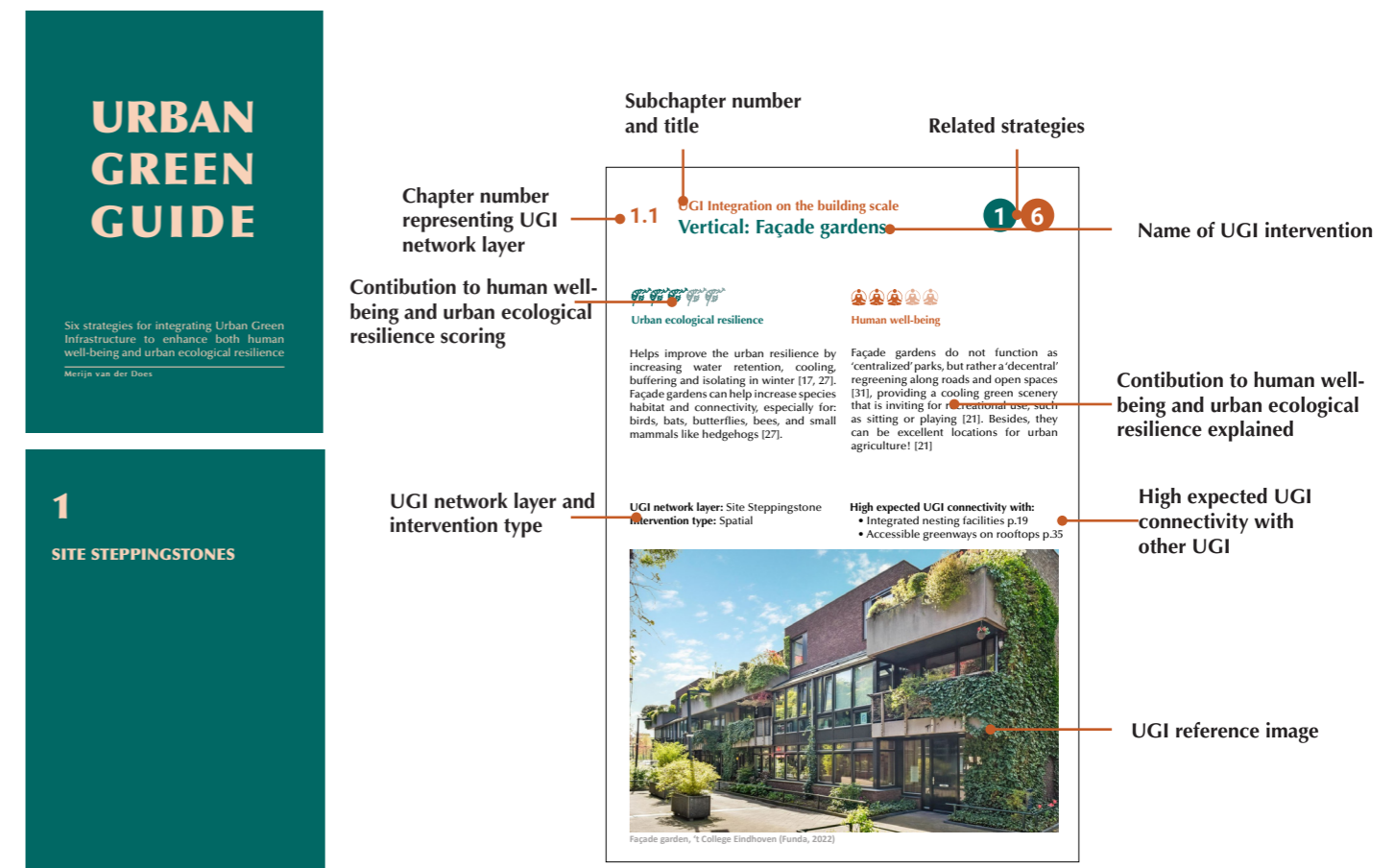


Figure 18 The Urban Green Guide

5. Critical reflection literature

This reflection section consists of three parts: conclusion, limitations of the research and recommendations for further research.

5.1 Conclusion

The goal of this research was to answer the research question: 'How can urban green infrastructure (UGI) enhance both urban ecological resilience and human well-being in a densifying Eindhoven?'. The main aim was to investigate how UGI interventions can enhance both human well-being and urban ecological resilience in a densifying context. Through a systematic literature review and a handbook review six main strategies were identified for the implementation of UGI in densifying cities to enhance the key themes. Additionally, a critical policy review was conducted to assess the alignment of these strategies with current policies and legislations at different scale levels. Which have resulted into policy recommendations.

The findings of this study have been combined into a comprehensive policy and design guide, providing evidence-based practical examples for urban designers, planners and decision makers in Eindhoven and beyond. By further bridging the gap between theory and practice, this guide aims to facilitate proper integration into densifying urban contexts. The strategies and the UGI interventions offer valuable insights for maximizing the benefits for human well-being and urban ecological resilience.

Overall, this research contributes to the understanding of the role of UGI in densifying environments and provides a framework for incorporating UGI into urban planning, design and decision making practices. It is hoped that the outcomes of this study will inform and inspire future initiatives to prioritize the potential of UGI for enhancing human well-being and urban ecological resilience.

5.2 Limitations of the research

This section presents several limitations of this research that should be taken into consideration. Firstly, it should be noted that for many UGI interventions, a lack of qualitative evidence exists in the literature and handbooks consulted. This limitation results from the insufficient scientific basis on relations between UGI interventions and the key concepts.

Another limitation comes from the imbalance in the focus of some UGI interventions on either human well-being or urban ecological resilience. Some interventions may predominantly prioritize one key concept over the other. However, it is important to note that interventions excelling in one key concept should not be disregarded in design and planning, as they still hold significant value.

For the scoring system, the assumption is made that all pillars are of equal weight. Nevertheless, it is plausible that the relationship between these key themes and their pillars is far more complex, suggesting that the equal importance of all pillars might not apply.

Additionally, the formulation of the six strategies relied on a combination of data analysis and intuitive judgement. While efforts were made to ensure the relevance of UGI interventions, the process itself remains subjective and influenced by personal impressions.

Finally, the data presented in the results is based only on the data found in the papers, handbooks and policy documents. This means the results are limited to the data provided in these documents and relevant data might be missing.

5.3 Recommendations for further research

These limitations show the need for further research in two key areas. Firstly, to deepen the understanding of the qualitative impacts of UGI interventions on human well-being and urban ecological resilience. While exploring the complex relationships between the key themes and their pillars. This can be achieved through qualitative studies that explore the experiences and perceptions of individuals and communities, providing valuable insights into the specific ways in which UGI influences different aspects of well-being and resilience.

In line with this, it is essential to examine the possible variations in the relationship between UGI interventions and human well-being across different demographic, ethnic, social, and cultural groups. Future research should aim at identifying potential interventions that can address the specific needs and preferences of diverse urban populations. By considering the perspectives of different groups, more tailored and inclusive UGI strategies can be developed to enhance human well-being and urban ecological resilience.



Figure 19 Vestdijk (wUrck, 2019)

part II

city



6. City scale analysis

Two different types of spatial mapping are performed in this study. Initially, a QGIS analysis is conducted to evaluate the current status of human well-being and urban ecological resilience at the city scale of Eindhoven, analyzing data per neighbourhood. Based on this information, an intervention neighborhood is identified which will be redeveloped in the design phase. Following this, a city-wide spatial mapping analysis is performed, transcending neighborhood boundaries to consider elements on a broader city and regional scale. This approach is necessary as urban networks often extend beyond neighbourhood averages. Combining the results from both types of analyses, a city strategy has been created.

6.1 Neighbourhood status assessment

To find an intervention neighbourhood, data is collected to assess the current status of human well-being and urban ecological resilience at the city scale of Eindhoven. Initially, a QGIS mapping analysis is conducted to examine key themes across neighborhoods, providing an overview of areas with varying states of well-being and resilience (Figures 20 & 21).

6.1.1 Data

The city-scale mapping entails the utilization of diverse data sources, including both directly relevant and proxy data, for a comprehensive understanding of each key theme pillar. The data sources utilized for urban ecological resilience are listed in Table 15, and the data sources utilized for human well-being are listed in Table 16. By incorporating various datasets, the overall quality of the analysis is enhanced.

The collected data, was not always presented per neighbourhood, but also as e.g. raster data or grids. To be able to compare the neighbourhoods, the data is transformed into neighbourhood-specific formats using QGIS. Additionally, considering substantial variations in numerical scales and units (e.g., kilometers, percentages, and raw numbers), the data in this report has been standardized to a 0-100 percent scale.

Finally, two conclusion maps are made to show the status of human well-being and urban ecological resilience per neighbourhood in Eindhoven. To combine all different data, the importance of the pillars is determined. This is done based on the relation between UGI and

the pillars for human well-being and urban ecological resilience found in the literature and handbook review. The number of relations of a certain nature (positive, neutral, negative) are counted and multiplied by the factor related to this nature. To apply this, the following formula has been used:

$$\text{Total} = (\text{No of positive relations} * 1) + (\text{No of neutral relations} * 0) + (\text{No of negative relations} * -1)$$

The highest scoring total is given a weight of 1, and the following formula is applied to determine the weight of the other pillars: **Weight = Total pillar / highest scoring total**

An overview of the application of this can be found in Tables 13 & 14 below. This table shows that the pillars 'biodiversity' and 'health' have the highest total and have been awarded the weight of 1. According to the literature and handbook review, the other pillars are of a slightly lower importance. However, it should be stated that also these pillars are of quite high importance as their total scores do not deviate from the total score of the highest scoring pillars. The conclusion maps for human well-being and urban ecological resilience can be seen in figure 22.

Table 13 Weights of the pillars for urban ecological resilience

Pillar	Positive (*1)	Neutral (*0)	Negative (*-1)	Total	Weight
Biodiversity	60*1 = 60	23*0 = 0	3*-1 = -3	57	1
Connectivity	55*1 = 55	32*0 = 0	1*-1 = -1	54	0.95
(a)Biotic fitness	52*1 = 52	32*0 = 0	3*-1 = -3	49	0.86

Table 14 Weights of the pillars for human well-being

Pillar	Positive (*1)	Neutral (*0)	Negative (*-1)	Total	Weight
Health	83*1 = 83	7*0 = 0	0*-1 = -0	83	1
Social development	81*1 = 81	8*0 = 0	1*-1 = -1	80	0.96
Belonging	70*1 = 70	25*0 = 0	2*-1 = -2	68	0.82

Table 15 Overview of sources utilized for spatial indicators urban ecological resilience

Pillar	Quantity	Data source
Biodiversity	Species richness	Atlas Natuurlijk Kapitaal
	Bee species richness	Atlas Natuurlijk Kapitaal
	Green/ neighbourhood	Eindhoven Open Data
Connectivity	Defragmentation	Atlas Natuurlijk Kapitaal
	Pollination	Atlas Natuurlijk Kapitaal
	Hedge density	Atlas Natuurlijk Kapitaal
(a)Biotic fitness	Environmental problems	De Buurtkijker Eindhoven
	Earth worm abundancy	Atlas Natuurlijk Kapitaal
	Noise pollution	Atlas Leefomgeving

Table 16 Overview of sources utilized for spatial indicators human well-being

Pillar	Quantity	Data source
Health	Limited by health	Buurtatlas
	Complies with excersize recommendations	Buurtatlas
	Good perception of own health	Buurtatlas
	Overweight population	Buurtatlas
	High risk for depression	Buurtatlas
	People experiencing stress	Buurtatlas
Social development	Has a starting diploma	Eindhoven in Cijfers
	Netto employment rates	Eindhoven in Cijfers
	Distance to recreation	Eindhoven in Cijfers
	Regularly visits big parks	Eindhoven in Cijfers
	Feeling of unsafety	Eindhoven in Cijfers
	Walk and cyclability	Eindhoven in Cijfers
Belonging	Feels at home in neighbourhood	De Buurtkijker Eindhoven
	Social loneliness	Atlas Natuurlijk Kapitaal
	Distance to cooling	Klimaat Atlas van Eindhoven
	Noise pollution	Atlas Leefomgeving
	Satisfaction with public space	De Buurtkijker Eindhoven

6.1.2 Spatial indicator analysis

The assessment of urban ecological resilience in Eindhoven which can be seen in Figure 20, reveals the following interesting patterns. ‘Species richness’ and ‘bee species richness’ exhibit a notable decline in proximity to Eindhoven Airport, suggesting a correlation with the (a) biotic fitness indicator ‘noise pollution’. In contrast, the highest levels of biodiversity and connectivity are concentrated in and around the green fingers. These green fingers and their adjacent neighbourhoods consistently emerge as high-scoring areas across various indicators, emphasizing their significance in fostering urban ecological resilience in Eindhoven.

Looking at the assessment of human well-being, presented in Figure 21, diverse outcomes can be noticed. Noteworthy is that residents within the city ring tend to score lower on various health-related indicators, including ‘limited by health’ and ‘perception of own health’. Additionally, neighborhoods within the city ring exhibit the highest percentages of ‘overweight population’, contrasting with a commendably high percentage of inhabitants ‘complying with exercise recommendations’. Furthermore, the distance to cooling facilities registers notably low scores in inner-city neighborhoods and districts Woensel and Tongelre. Most of which being located further away from the green fingers.

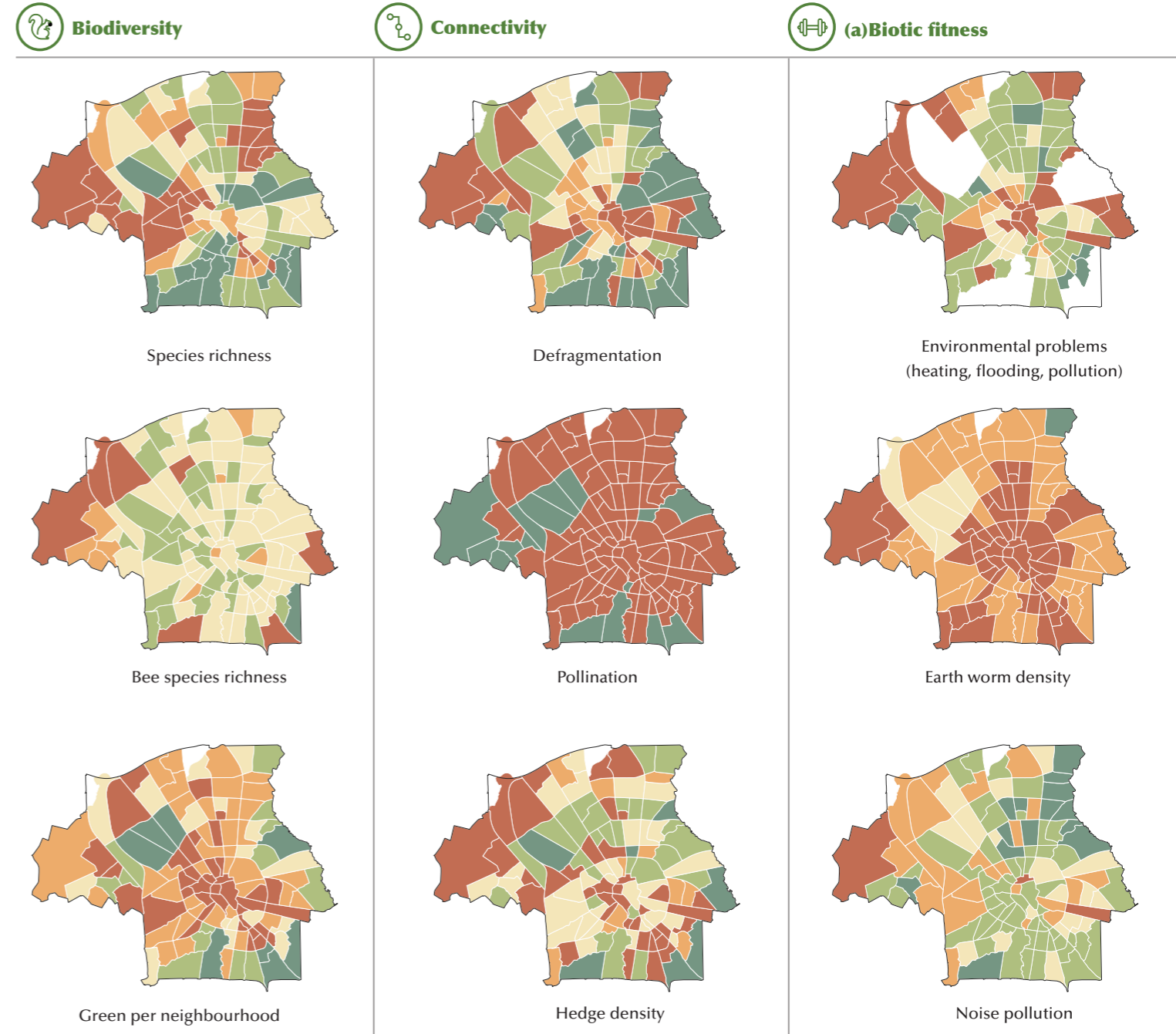


Figure 20 Spatial indicators urban ecological resilience

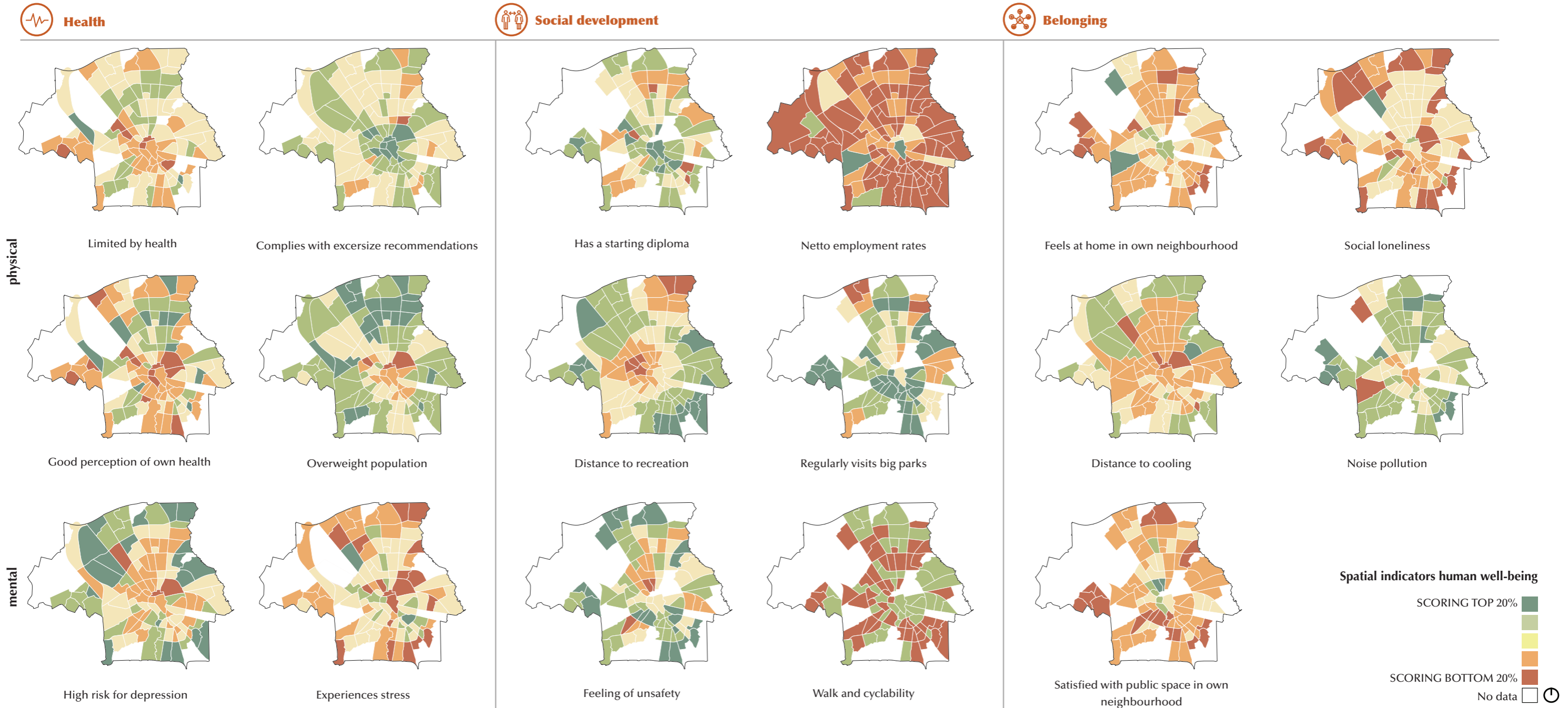


Figure 21 Spatial indicators human well-being

6.1.3 Neighbourhood selection

In Figure 22, the two conclusion maps are presented that show the status of human well-being and urban ecological resilience per neighbourhood in Eindhoven. The weights presented in Tables 13 & 14 have been applied to the indicators of the different pillars. Based on these results, the neighbourhood Muschberg, Geestenberg has been identified as suitable for redevelopment. Situated in the Tongelre district in the Eastern part of Eindhoven, this choice is informed by considerations of both human well-being and urban ecological resilience.

While not falling within the lowest 20% for ecological resilience, it ranks within the lowest 40%. The main factor in selecting this neighborhood is its strategic location between high-scoring neighborhoods associated with the green finger 'Karpen' and high-scoring area the 'Urkse Zeggen'. The expectation is that the redevelopment of Muschberg, Geestenberg will elevate its scoring percentage, thereby reinforcing the green finger's connectivity into the city center of Eindhoven.

From a human well-being perspective, Muschberg, Geestenberg also registers within the lowest 40%. However, given its placement in between neighborhoods with comparable or even lower scores, the redevelopment is envisioned not only to enhance the well-being of

Muschberg, Geestenberg but also to positively impact the adjacent neighborhoods in the Tongelre district.

Concluding, the redevelopment of Muschberg, Geestenberg will function as a strategic intervention, aiming to enhance both urban ecological resilience and human well-being, with broader implications for the adjacent neighborhoods.

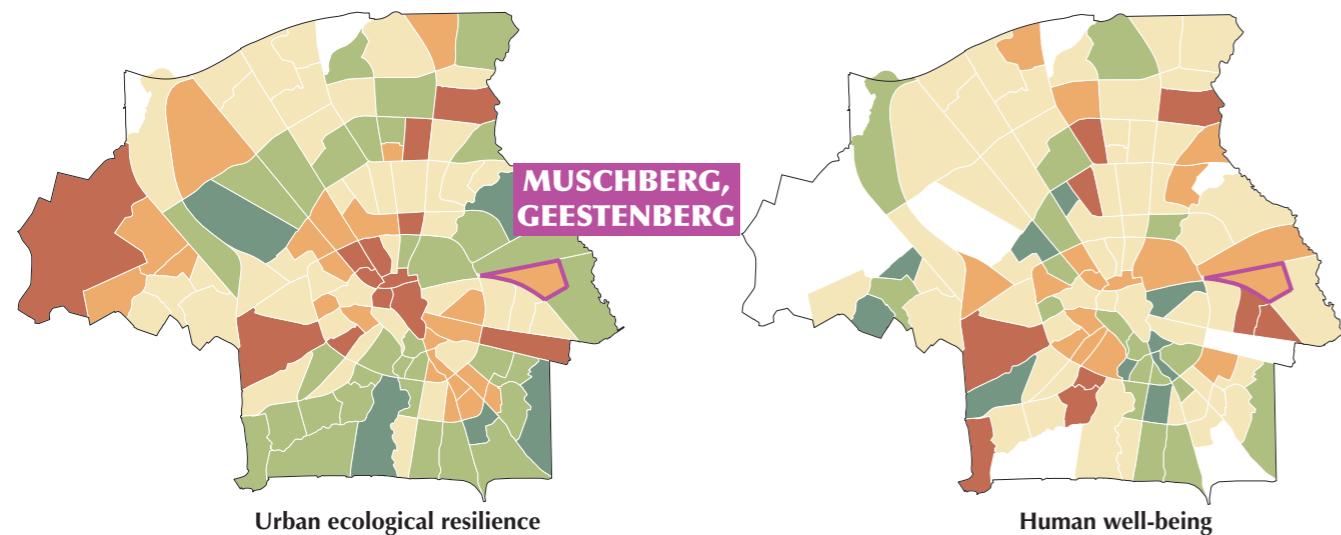


Figure 22 Intervention neighbourhood Muschberg, Geestenberg



Figure 23 Clausplein (Mulken, n.d.)

6.2 City-wide spatial mapping

In this section, a city-wide spatial mapping analysis is performed, transcending neighborhood boundaries to consider elements on a broader city and regional scale. This approach is necessary as urban networks often extend beyond neighbourhood averages. Within this analysis, the key themes are critically analyzed by looking at their current performance and potential improvements at a city scale. The three key themes are divided into analysis layers to create a coherent overview, following the structure of this report.

- Built environment:** Densification strategies, Train mobility, Bus mobility
- Urban ecological resilience:** Connectivity (region and city scale), Biodiversity, (a)Biotic fitness
- Human well-being:** Health, Social development, Belonging

6.2.1 Densification

The analysis of current and potential future densification zones in Eindhoven is illustrated in Figure 24 and elaborated in this section. The municipal vision for the densification of the city center is outlined in the Ontwikkelperspectief 2040 (Gemeente Eindhoven, 2020a). This vision designates specific densification areas within the city ring and its immediate proximity, recognizing them as high-potential zones for urban densification. However, it is noteworthy that certain neighbourhoods in Eindhoven are identified as ‘Groenstedelijk’ (Gemeente Eindhoven, 2024a). Characterized by a low Floor Space Index (FSI) and substantial amounts of greenspace many of these neighbourhoods also hold significant cultural heritage for the city. Given their vital role in the current state of urban ecological resilience and human well-being, preserving these areas is essential. Because of this, these areas will not be densified within this study.

Furthermore, it is highly essential to decentralize the densification, taking pressure from the city center and fostering a more evenly distributed urban growth. To achieve this, this study examines larger redundant industrial areas as main potential zones for urban densification outside of the city center (e.g. de Hurk, Kanaalzone, Sectie-C). Additionally, other zones with higher amounts of amenities or smaller industrial sites are under consideration (e.g. Winkel centrum Woensel, Kastelenplein, Dirigentplein).

Urban Densification City Scale 1:70.000

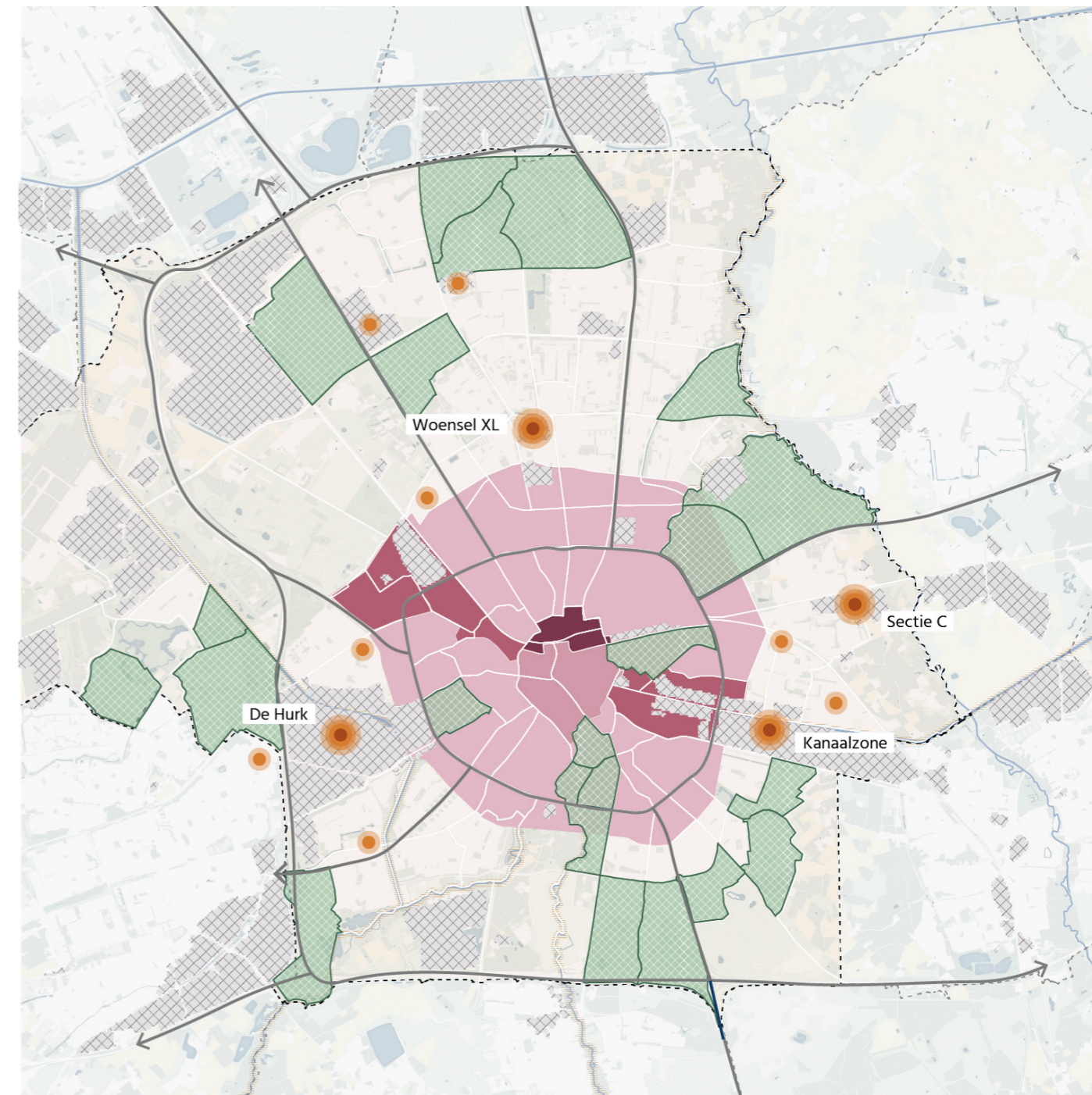
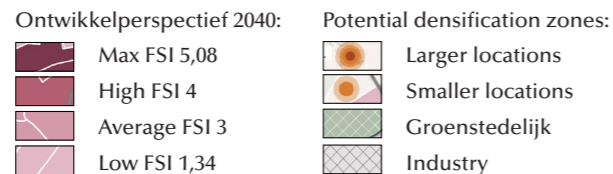









Figure 24 Built environment: Densification strategies

6.2.2 Mobility: Train mobility

With a preference for public and slow mobility modes over car-dependent options in densifying contexts, bus and train mobility are analyzed. Examining train mobility, Eindhoven currently houses two train stations: Eindhoven Centraal in the city center and Eindhoven Strijp-S in the Strijp-S neighbourhood. These stations collectively serve the entire city ring and multiple neighborhoods west of the city center. This is confirmed by calculating the serving areas of a 30-minute walk and a 10-minute bike ride from these stations, using the 'MapitOut-tool' (I amsterdam, 2023). These serving areas are illustrated in Figure 25.

The figure indicates, that the existing train stations cover only three of the potential densification zones, with only one of them being a larger zone (WoensXL). For this reason, the possibility of an additional train station in the eastern part of the city is explored to enhance the public transportation network. A strategic location for this new station is identified at the Sectie-C site. This placement would not only benefit Sectie-C but also improve train connections for the Kanaalzone and two smaller potential densification zones. The additional station aligns with a direct line connecting the Brainport Industries in Best, Strijp-S, Eindhoven Centraal, Sectie-C, and the Brainport Industries in Helmond. Given the significance of these locations as employment and innovation hubs, the proposed additional connection would be highly beneficial.

Train Mobility City Scale
1:70.000 ☺

-  Train rails
-  Existing train station
-  Station reach: 30 min walk, 10 min bike
-  Search location: train station
-  Search station reach: 30 min walk, 10 min bike
- Potential densification zones:
-  Larger locations
-  Smaller locations

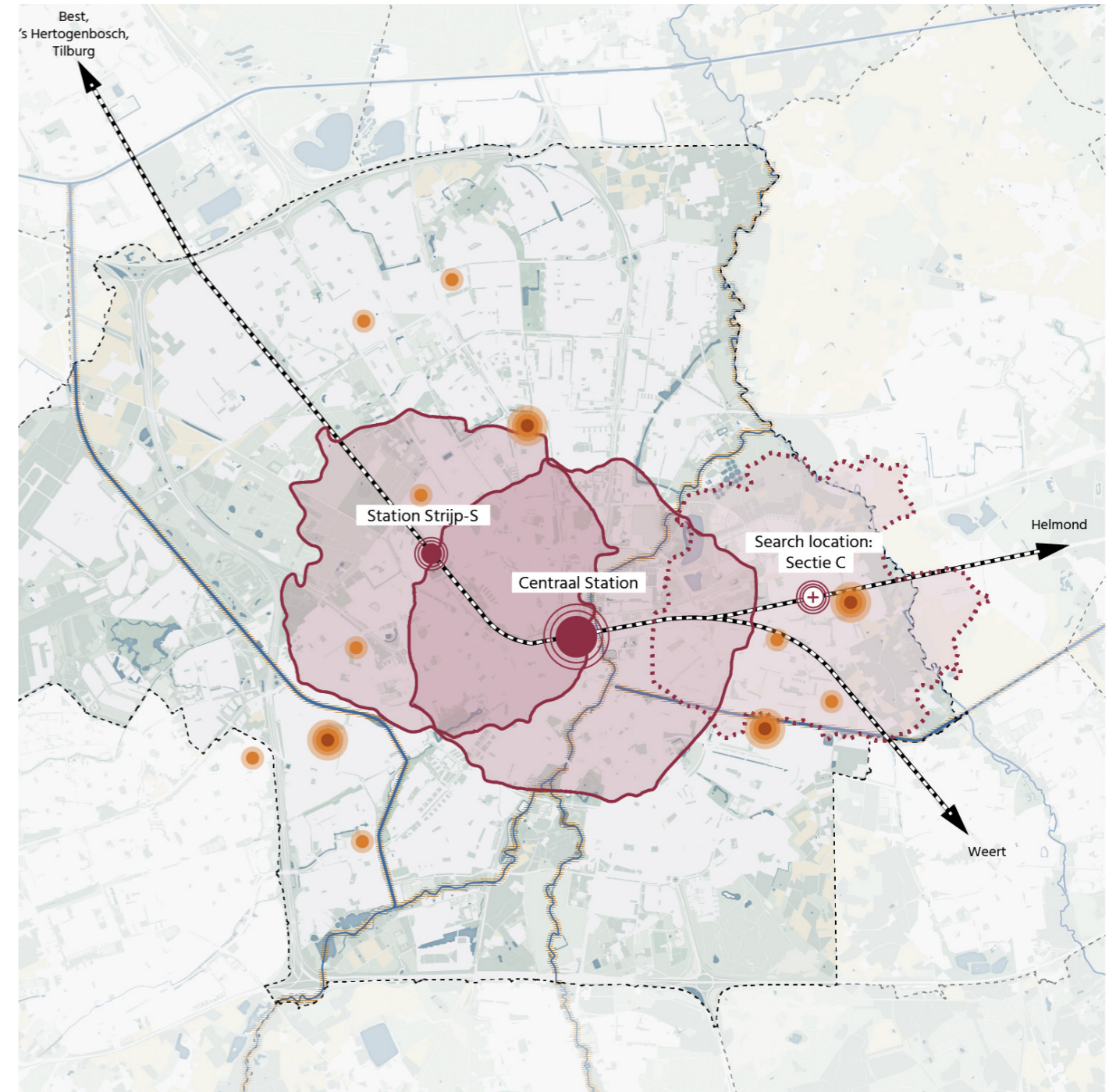







Figure 25 Built environment: Train mobility

6.2.3 Mobility: Bus mobility

The primary mode of public transportation facilitating mobility between locations in Eindhoven and nearby surroundings is the bus. Eindhoven currently has multiple HOV-lines ('Hoogwaardig Openbaar Vervoer', High-Quality Public Transport). These are bus lines living up to certain standards as they meet high-quality requirements: enhanced speed, reliability and sustainability (Gemeente Eindhoven, 2024b). The regular and HOV bus lines are visualized in Figure 26, which shows that the majority of potential densification zones are situated within a 500m radius from a standard or HOV bus stop.

However, the Hurk and the Kanaalzone both lack adequate coverage from either bus or train services. To optimize the functionality of these zones as densification areas, it is necessary to have them situated within a 500m proximity to a bus stop, preferably one along an HOV line. Otherwise, fall within the service area of a train station. Based on the location of both these areas, opting for bus connections seems to be the most viable solution.

Bus Mobility City Scale 1:70.000

-  Central bus station
-  HOV bus line with 500m buffer
-  Regular bus line with 500m buffer
- Potential densification zones:
-  Larger locations
-  Smaller locations

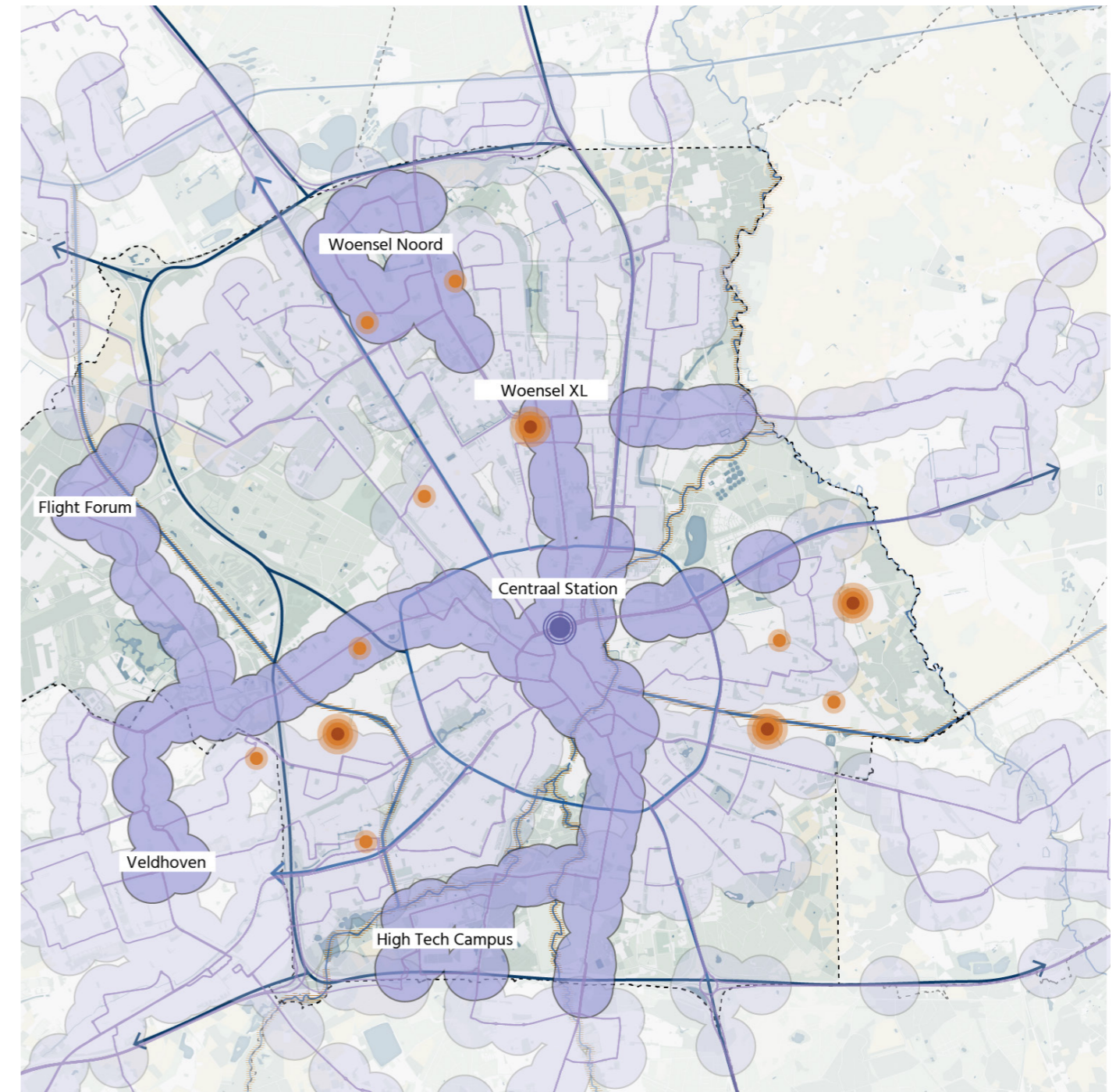


Figure 26 Built environment: Bus mobility

6.2.4 Urban ecological resilience: Connectivity (region)

Within the region (Figure 27), there are significant Natura 2000 protected areas, including the Strabrechtse Heide, Groote Heide, segments of the Dommel Valley, and a portion of the Buikheide (Ministerie van LNV, 2022). These heathlands and forested areas play a crucial role in the ecological richness of the region. Despite this ecological importance, an even more substantial portion of the land is dedicated to agriculture. Furthermore, outside of Eindhoven a significant portion of land is occupied by other urbanized areas such as Helmond, Veldhoven, Best, and smaller surrounding villages.

The ecological connectivity of the region faces challenges, predominantly arising from these large urbanized areas, as well as from infrastructural elements, large industrial zones, and rigid canal quays. These factors pose obstacles to the integration of ecosystems. While essential ecological connections exist through the three green fingers, particularly the Southern (Genneper parken) and Eastern (Karpen), bringing the landscape into the city, many missing ecological links and hard quays hinder a more connected region and inner city. Consequently, these obstacles pose potential disruptions to important ecological connections.

Connectivity Region Scale
1:100.000

-  Urbanized area
-  Heath land
-  Agricultural land
-  Forest
-  Industry
-  City parks
-  Riverbed
-  Brainport Park
-  Genneper Parken
-  De Karpen
-  Harsh borders
-  Missing ecological link
-  Link needs to be strengthened
-  Protected Natura 2000 area

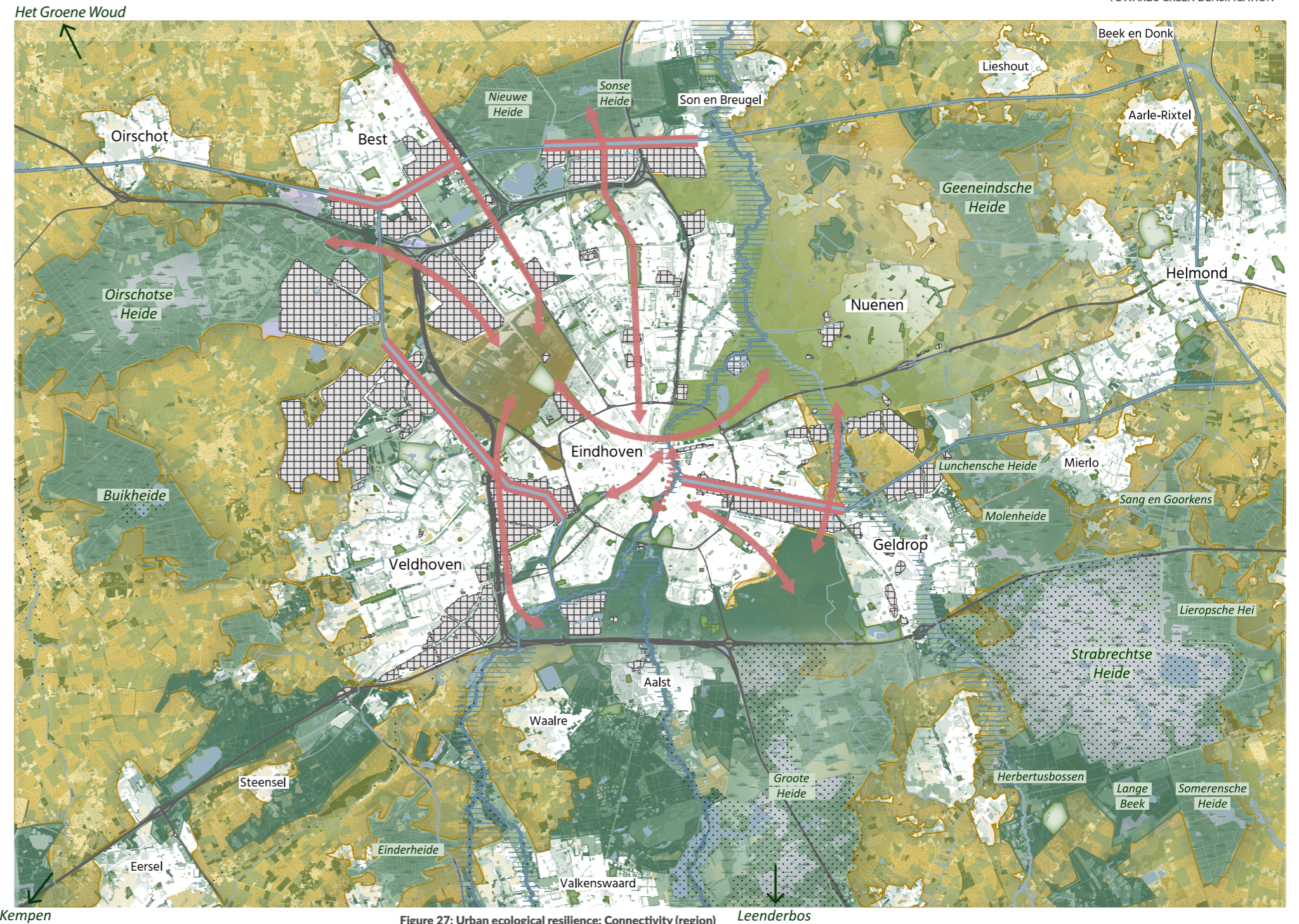


Figure 27: Urban ecological resilience: Connectivity (region)

6.2.5 Urban ecological resilience: Connectivity (city)

Eindhoven's green structure is defined by three green wedges extending from the outskirts to the city center (Figure 28). These wedges, namely Genneper Parken in the south, De Karpen in the northeast, and Brainport Park in the northwest, serve as vital connectors between urban green spaces and regional landscapes, contributing significantly to the city's identity.

Genneper Parken: Located in the southern part of Eindhoven, this wedge is where the Dommel and Tongelreep river valleys converge. Combining an ecologically valuable landscape with intensive recreational facilities, it provides a balanced mix of nature and sports, featuring large sporting locations, such as the swimming stadium.

De Karpen: On the city's northeast side, the De Karpen wedge houses water bodies like the Dommel, De Kleine Dommel, and the Karpendonkse Plas. Zoned for varied human activities, it includes the TU/e campus, Wandelpark Eckart and the Karpendonkse Plas, offering a diverse range of recreational opportunities.















Brainport Park: Situated in the northwest, the Brainport Park represents a landscape where living, working, and recreation co-exist. This area is still evolving with the development of the Brainport Industries Campus. The municipality of Eindhoven has purchased Landgoed De Wielewaal, which will be transformed into 142 hectares of city forest available for all inhabitants (Gemeente Eindhoven, 2023).

Finally, road verges, street trees, private and corporate gardens, vacant plots, forested areas, and green property boundaries, function as the city's green veins. They facilitate ecological connections, stormwater drainage, and mitigates heat stress. Additionally, they facilitate recreational pathways like the Slowlane, which contribute to enhancing the city's overall green connectivity and ecological experience.

Furthermore, within the municipal boundaries of Eindhoven, there are several green areas that do not align with urban characteristics but rather rural characteristics: e.g. Gilzenrooi, Stratumse Heide, Urkhovense Zeggen. These are remnants of small-scale cultural landscapes found in Brabant. Due to their isolated location near the city and being surrounded by roads, there has been no land consolidation (ruilverkaveling) in these areas (Gemeente Eindhoven, 2017). These areas offer rural zones close to home to the inhabitants of Eindhoven.

While Eindhoven's green structure provides a strong foundation for connecting urban and rural landscapes, critical ecological links are missing. Links through hard canal quays, industrial zones, infrastructural elements, and urban fabric are absent in many locations. Through this, the significance of UGI becomes clear in ensuring an ecologically sustainable network that enhances the overall connectivity.

Connectivity City Scale
1:70.000

- | | | | |
|---|-------------------|---|---------------------------|
|  | Urbanized area |  | Wedge: Brainport Park |
|  | Industry |  | Wedge: Genneper Parken |
|  | City parks |  | Wedge: De Karpen |
|  | Riverbed |  | Harsh borders |
|  | Natura 2000 |  | Missing ecological link |
|  | Structural green |  | Strengthening potential |
|  | Agricultural land |  | Potential green-blue link |

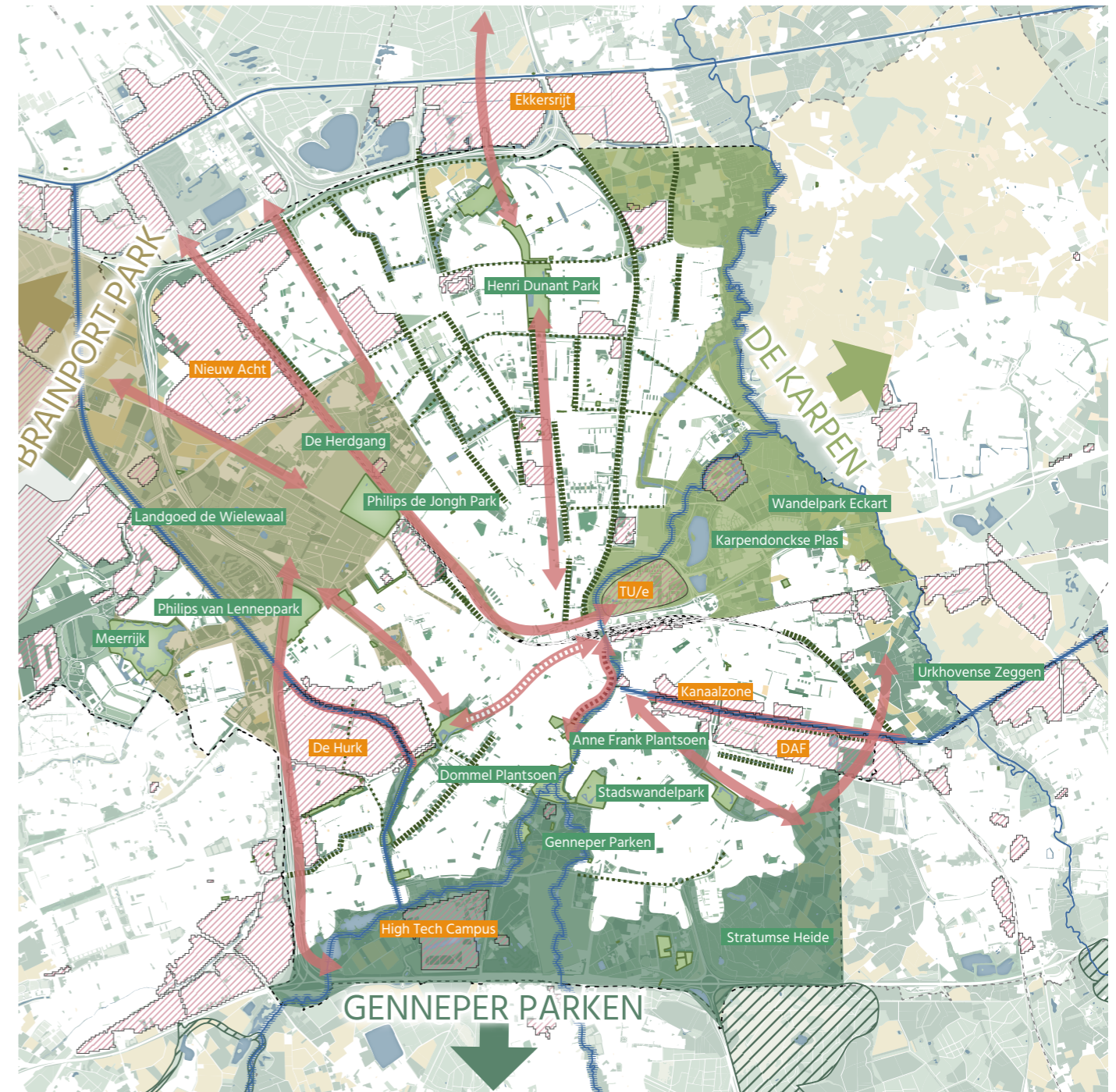


Figure 28 Urban ecological resilience: Connectivity (city)







6.2.6 Urban ecological resilience: Biodiversity

As aforementioned, Eindhoven has neighbourhoods that are 'Groenstedelijk'. These neighbourhoods have higher values for biodiversity compared to other neighbourhoods in the city. However, as can be seen in Figure 29, many neighbourhoods in Eindhoven have low values for biodiversity (Nationaal Georegister, 2017). According to Gemeente Eindhoven (2017), UGI should be incorporated into the urban fabric more and design and management practices should aim at increasing biodiversity where needed. Furthermore, residents and property owners should be educated to contribute to nature on their properties.

Besides, research from Gemeente Eindhoven (2017) indicates that, when ecologically designed and managed, green spaces within industrial areas can significantly contribute to biodiversity in cities, emphasizing the need for the Brainport Industries and other industrial zones to not only provide green aesthetics, but also ensure ecological functionality, a great example of this is the High Tech Campus in the South. Furthermore, concentrating on vulnerable species and urban species is essential for the development of UGI to improve biodiversity, as found in the literature review.

Finally, due to the hard canal quays in the Hurk and Kanaalzone large opportunities arise for the softening of these quays to allow for more biodiversity. Besides, the Dommel valley within the city center has high potential for strengthening. Finally, the stream 'Gender' has been 'culverted' in the past. A big opportunity for the improvement of biodiversity and connectivity within the city center is bringing back the Gender (Theeuwen, 2022).

Biodiversity City Scale 1:70.000

-  Urbanized area
-  Area with low biodiversity
-  'Groenstedelijk' with high biodiversity
-  Opportunity for biodiversity: Dommeldal
-  Opportunity for biodiversity: re-introducing Gender
-  Opportunity for biodiversity: softening canal quays

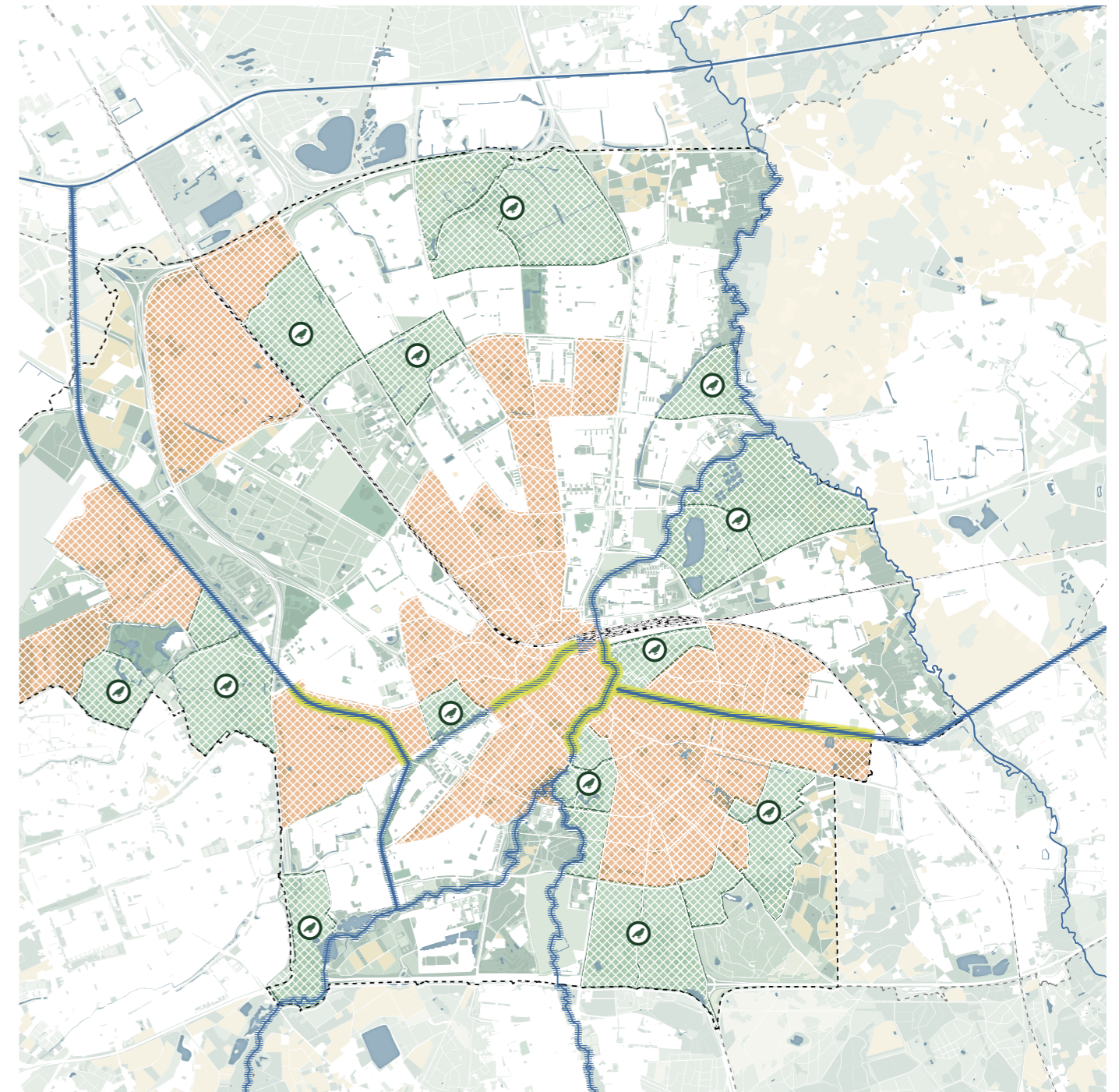


Figure 29 Urban ecological resilience: Biodiversity

6.2.7 Urban ecological resilience: (a) Biotic fitness






The current city-wide state of biotic and abiotic fitness is visualized in Figure 30. Firstly, high environmental risk zones exist, as highlighted by Buurtkijker (2023), mainly at industrial sites and highly impervious neighbourhoods. In these areas, issues such as urban heating, flooding, and air pollution have a significant impact, posing risks to the soil, species and the residents.

Furthermore, high noise pollution zones, as appointed by Rijksinstituut voor Volksgezondheid en Milieu (2020), primarily generate from industrial sites and Eindhoven Airport. This poses disruptions for both human inhabitants and local wildlife, underscoring the need for effective mitigation strategies in these noise-affected areas.

On a more positive note, high potential climate buffer zones, as outlined by Klimaateffectatlas (2023c), present an opportunity for increased infiltration and carbon sequestration. When these zones overlap with existing agricultural areas, there is a unique opportunity for implementing regenerative agriculture practices. This approach can contribute to increased carbon capture and enhanced water infiltration.

(a) Biotic Fitness City Scale

1:70.000 ☉

-  Urbanized area
-  High environmental risk zone (urban heating, flooding, air pollution)
-  High noise pollution zone
-  High potential climate buffer zone (increased infiltration and carbon sequestration)
-  Opportunity: increased carbon capture and water infiltration through regenerative agriculture

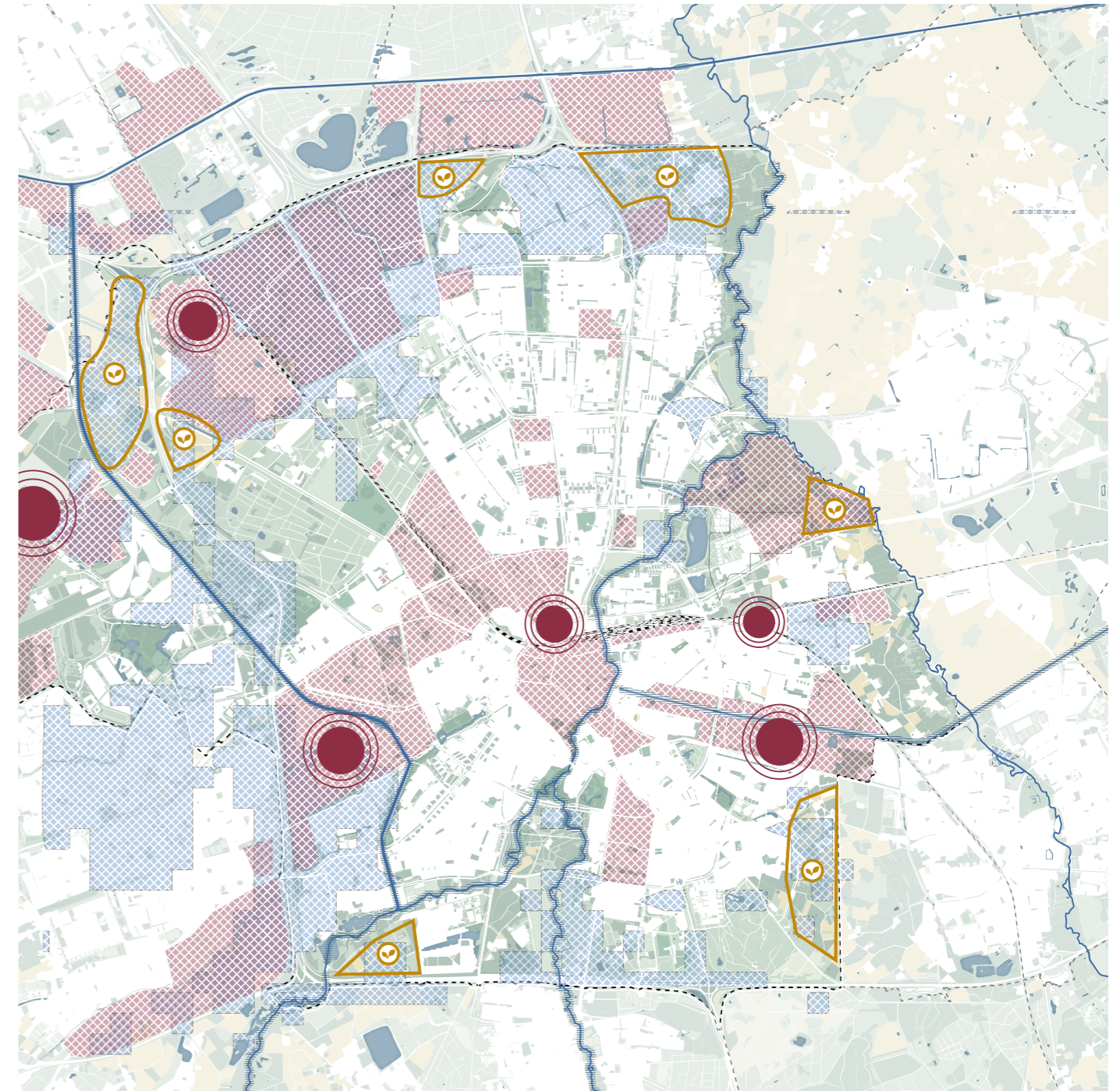







Figure 30 Urban ecological resilience: a) (biotic) fitness

6.2.8 Human well-being: Health

The challenges related to mental and physical health in Eindhoven are evident, particularly in neighborhoods highlighted in Figure 31. Based on combined information from GGD'en, CBS and RIVM (2020), the areas highlighted in orange face both high numbers of inhabitants experiencing stress and high risks for depression. The zones highlighted in red are zones reporting relatively high obesity rates compared to the rest of the city.

A potential solution can be cycling. This is a form of active mobility, which can provide numerous mental and physical health benefits. In the Brabant province, a network of fast cycling lanes, known as 'Snelfietsroutes,' has been established (SJEES, n.d.). These dedicated cycling lanes connect the inner city of Eindhoven to surrounding villages and work centers, and also offer green cycling zones. Besides, in certain areas, these lanes get priority over cars, promoting a healthier and more sustainable mode of transportation. The integration of such cycling infrastructure contributes to both physical fitness and mental well-being by providing an alternative, environmentally friendly means of commuting. For this, expanding the existing fast cycling network to the high risk zones for obesity, stress and depression is a potential solution.

Health City Scale 1:70.000

-  Urbanized area
-  High risk zone for stress and depression
-  High obesity rate zone
-  'Snelfietspad' fast cycling lane
-  Search location: 'Snelfietspad'

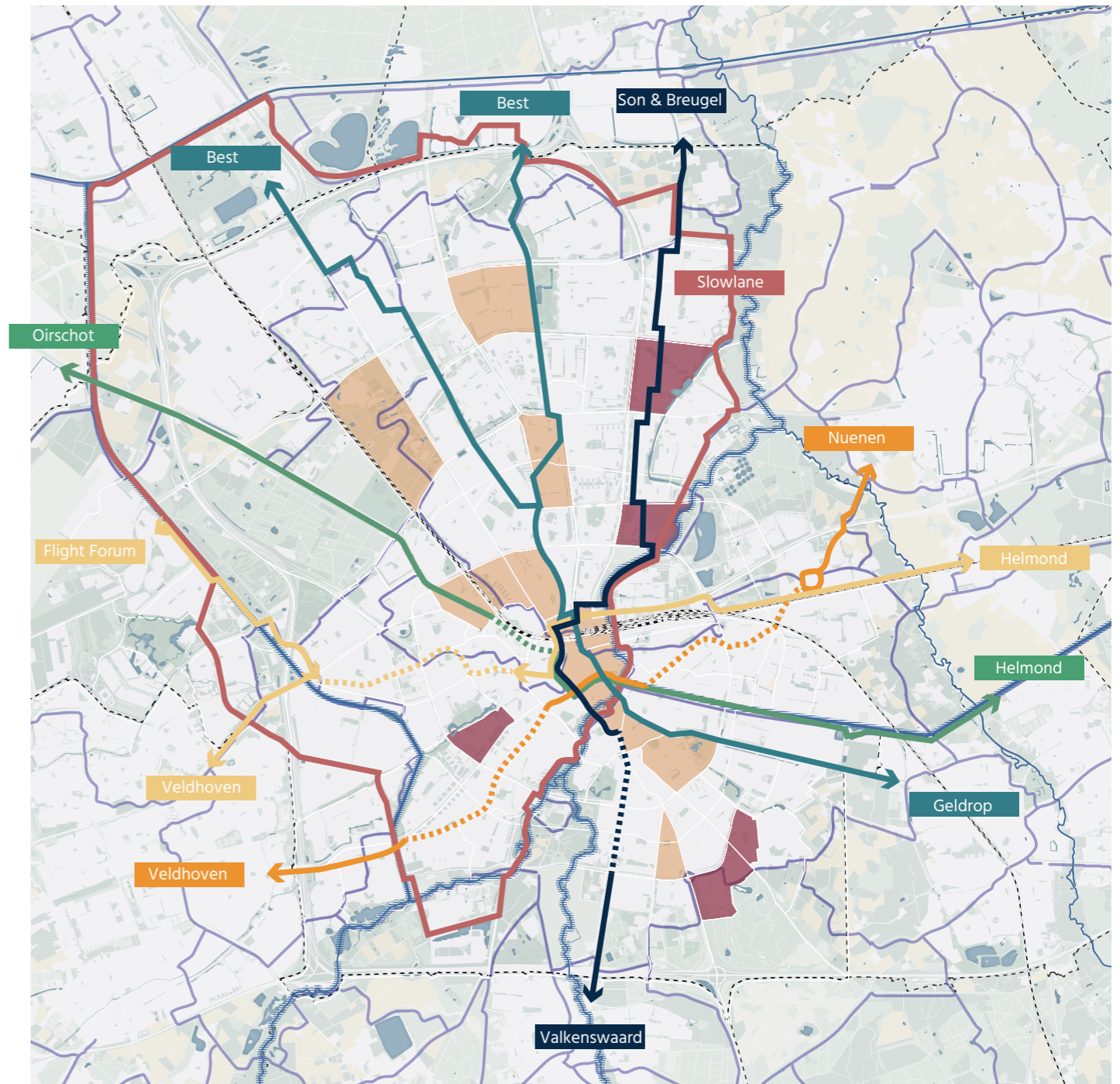


Figure 31 Human well-being: Health

6.2.9 Human well-being: Social development








The areas highlighted in orange on Figure 32 reveal a troublingly high rate of inhabitants feeling unsafe in their neighborhoods (Eindhoven in Cijfers, 2022). Addressing these feelings of unsafety is crucial, given the significant impact they can have on mental well-being.

In Figure 32, neighborhoods with low rates of people walking or cycling to school or work are marked in red (Eindhoven in Cijfers, 2022). These areas are predominantly located farther away from the city center and include industrial zones, green areas with few inhabitants, which are areas with limited public transport connections. Besides, it is essential to recognize that in some residential areas, the lower rates can probably be linked to longer distances to work or school. Examining the locations of primary and secondary schools supports this, with only a few primary schools and none of the secondary schools situated within these neighborhoods.

Despite these challenges, the presence of Green Wedges and remnants of small-scale cultural landscapes, as discussed in the context of city connectivity, ensures that green and rural zones exist close to the homes of Eindhoven's inhabitants. These natural spaces provide a unique opportunity for residents and workers to engage with local flora and fauna on a daily basis. The regional network for walking (Nationaal Georegister, 2019a) and cycling (Nationaal Georegister, 2019b), connects these green spaces and connects them to the broader region. However, in many neighborhoods, these networks are not as evident yet, and here a focus on improving the walking and cycling networks is needed to enhance the recreational value of green in Eindhoven.

Social Development City Scale

1:70.000 📍

-  Urbanized area
-  High rate of feeling of unsafety
-  Low rate of people walking/ cycling to school/ work
-  Primary school
-  Secondary school
-  Recreational network: cycling
-  Recreational network: walking

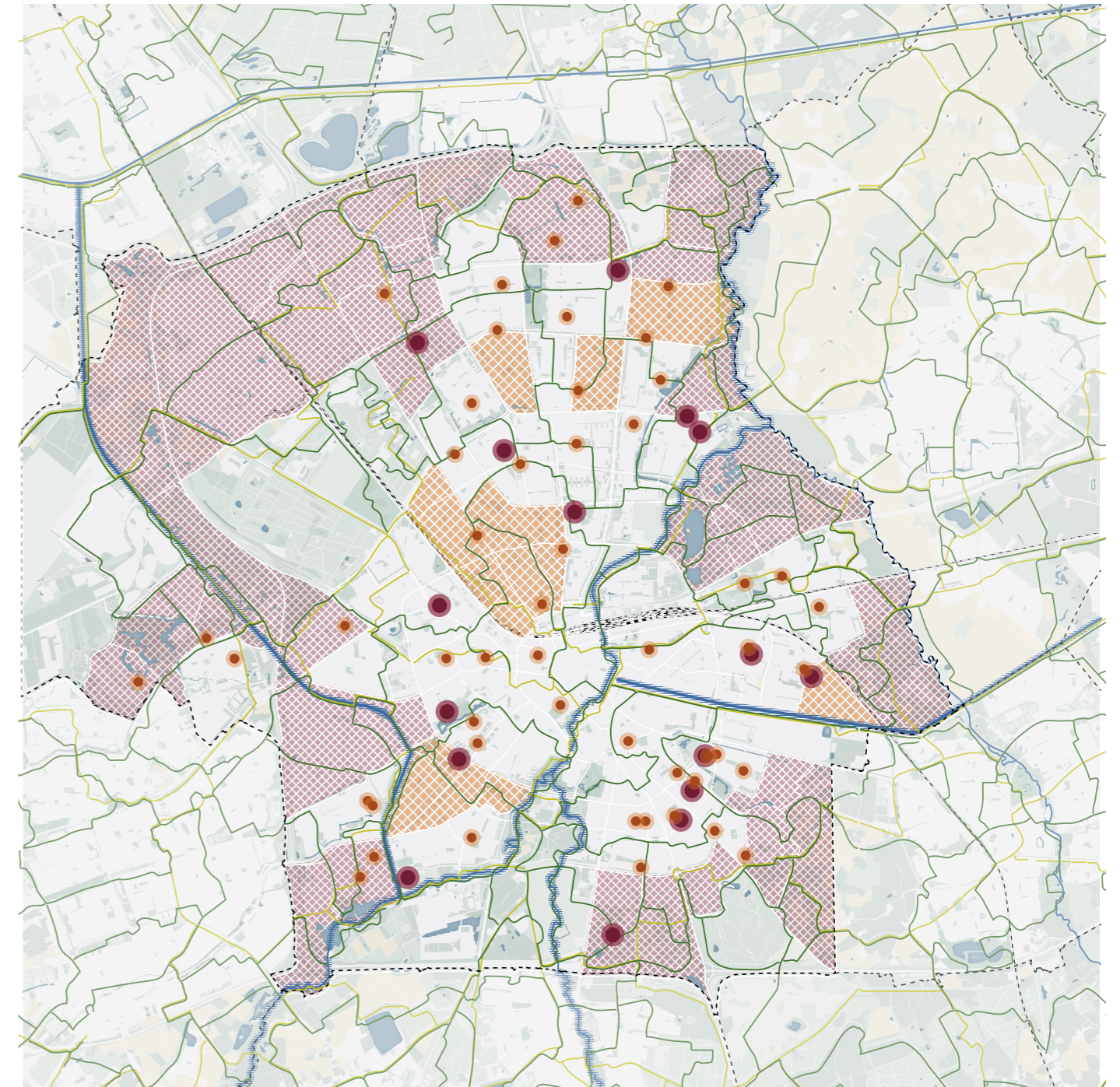


Figure 32 Human well-being: Social development






6.2.10 Human well-being: Belonging

Belonging is defined by the social and spatial belonging of inhabitants. Social belonging is tested by looking into where the biggest hotspots of social loneliness exist in Eindhoven (GGD'en et al., 2020). The spatial belonging is tested based on the following: green space proximity, environmental nuisance and the critical zones where these two overlap. These are all highlighted in Figure 33.

The green space proximity is tested according to the 3-30-300 green space rule (Nieuwenhuijsen et al., 2022) and these are spatially defined using data on the distance to green spaces (Klimaat-effectatlas, 2023a). The rule requires that every citizen should be able to see at least three trees from their home, have 30 percent tree canopy cover in their neighbourhood and not live more than 300 m away from the nearest park or green space. On the city scale, the seeing three trees from their home is hard to look into. For this reason the rule is comprised to the 30-300 rule to test if the green space proximity is sufficient or insufficient.

Zones with high environmental nuisance cope with problems such as flooding, urban heating, air pollution and noise pollution (Buurtkijker Eindhoven, 2023). These zones mainly arise in industrial areas and highly impervious neighbourhoods. Where the environmental nuisance zones and zones with insufficient green space proximity overlap, the spatial belonging is considered to be the lowest.

Belonging City Scale 1:70.000 ☉

-  Urbanized area
-  Hotspots of social loneliness
-  Does not comply with greenspace proximity 3-30-300 rule
-  Zones with high environmental nuisance
-  Overlapping of: does not comply with 3-30-300 rule and high environmental nuisance

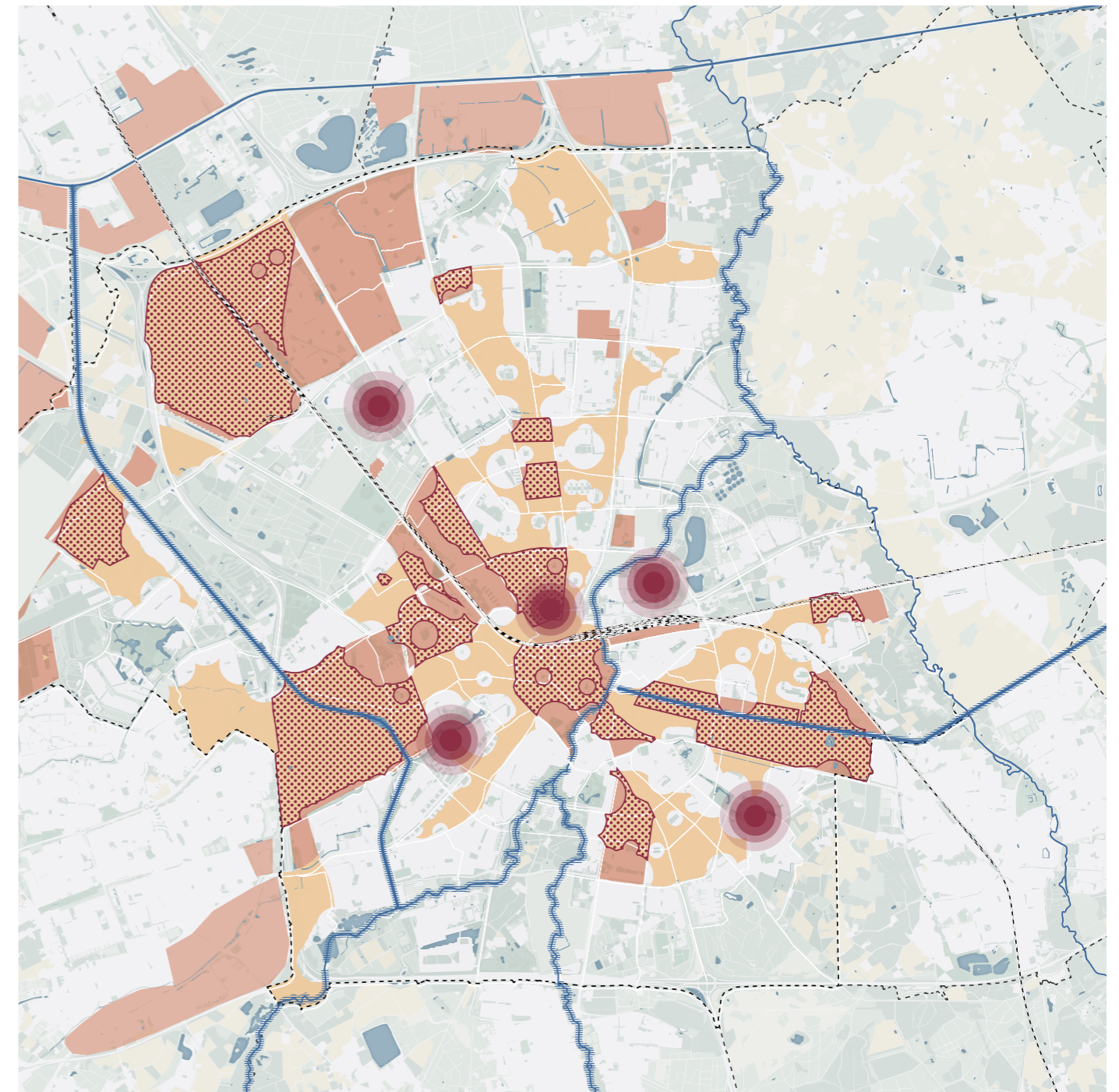


Figure 33 Human well-being: belonging

7. City Strategy

In this section, three city-wide strategies are presented for Eindhoven 2040: (1) built environment strategy, (2) urban ecological resilience strategy, (3) human well-being strategy. All strategies are built upon the analysis presented in chapter 6. However, the strategies for urban ecological resilience and human well-being are also based on the six main strategies for improving urban ecological resilience and human well-being through the application of UGI, based on the literature and handbook review. Finally, the three strategies are combined as a city strategy for Eindhoven 2040.

7.1 Densification and mobility strategy

The city strategy for urban densification and mobility is illustrated in Figure 34. Below is explained how this strategy has arisen from the analysis.

Eindhoven’s urban development has historically revolved around industrial centers, resulting in a diverse urban fabric that includes residential, mixed-use, and industrial typologies. Recent years have demonstrated the potential of (former) industrial zones for transformation into vibrant mixed-use areas, such as Strijp-S and NRE. Consequently, the city’s densification strategy is strategically centered on identified future densification zones in industrial areas such as de Hurk, Sectie-C, and the Kanaalzone. The focus of redevelopment is not only on increasing density but also on carefully assessing which functions should remain in these areas as part of the mixed-use development. Simultaneously, consideration is given to relocating functions that are better suited for industrial zones on the city’s edge.

The main objective is to achieve a high Floor Space Index (FSI) within and around the city ring while maintaining ‘Groenstedelijke’ neighborhoods. The primary high-density development will follow a diagonal trajectory from Strijp-S, through the city center and KnoopXL, to the Kanaalzone. However, to decentralize and distribute urban densification more evenly, smaller locations like Kastelenplein and Dirigentplein are designated as potential growing zones.

To support this densification, a shift towards alternative mobility solutions diverging from car-centric development is needed. To achieve this, a key component of this strategy is the introduction of a new train station: ‘Station Sectie-C’. This station will make train

mobility more accessible for the district Tongelre and the Kanaalzone. Additionally, enhancements to the bus network are proposed, including the improvement and expansion of HOV-lines, particularly catering to areas like de Hurk and the Kanaalzone.

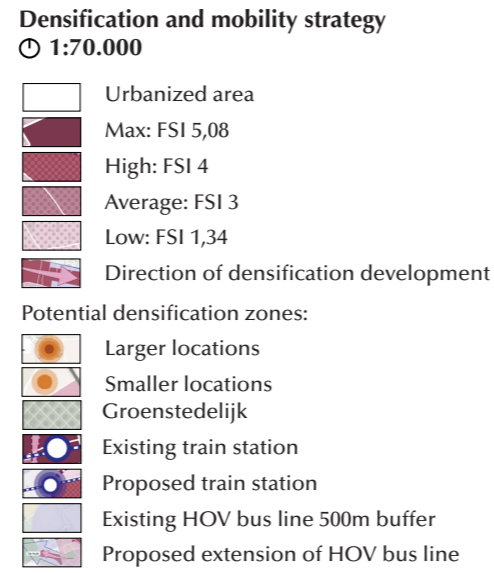
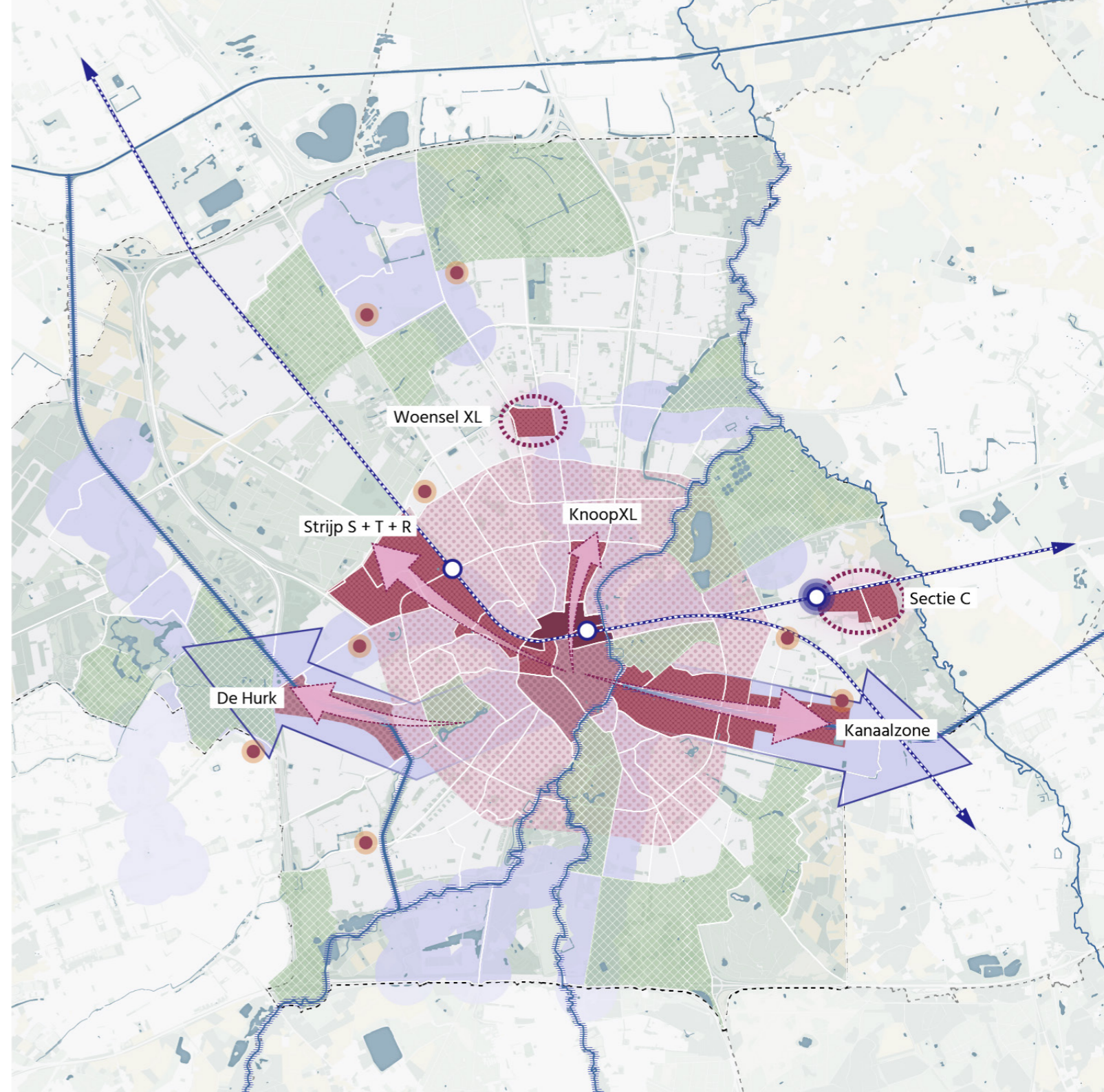


Figure 34 Built environment strategy



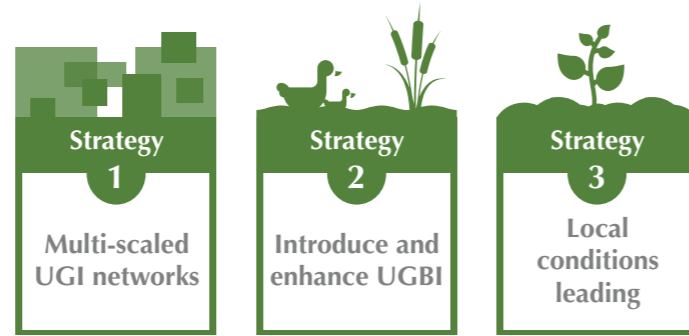
7.2 Urban ecological resilience strategy

The city strategy for urban ecological resilience is illustrated in Figure 35. Below is explained how the strategies for UGI application to create urban ecological resilience are applied on a city scale.

Strategy 1: Designing Multi-scaled Networks of UGI for Enhanced Urban Ecological Resilience. The three green wedges of Eindhoven show the significance of multi-scaled networks of UGI. These multi-scale networks span from regional hubs and corridors to integration on the building scale. A focal point for this strategy is the preservation and enhancement of the Green Wedges, as well as interconnecting them and reinforcing their connection to the city. Leveraging Eindhoven's radial and ring structures, elements such as road verges, street trees, private and corporate gardens, vacant plots, forested areas, and green property boundaries will serve as the city's green structural veins. Beyond ecological benefits, these elements will facilitate stormwater drainage, mitigate heat stress, and establish recreational pathways, thereby enhancing overall green connectivity and ecological experiences within the city.

Strategy 2: Introducing and Enhancing UGBI for Strengthened Urban Ecological Resilience. Eindhoven's existing blue corridors—the Dommel, Eindhovens Kanaal, and Beatrixkanaal—form integral components for elevating urban ecological resilience. Strategic enhancements and expansions are proposed, particularly focusing on the Dommel Valley in the city center to address future high-water scenarios and improve ecological connections between de Karpen and Genneper Parken. The potential of greening the quays of the canals presents an opportunity to enhance ecological resilience by creating habitats for diverse plant and animal species. The revitalization of the damped stream 'Gender' offers a unique prospect to restore an old green-blue structure, establishing a new ecological connection on the Eastern side of the city center, bridging the Beatrix Kanaal to the Dommel.

Strategy 3: Prioritizing Local Conditions in UGI Design for Enhanced Urban Ecological Resilience. When focusing on strengthening the Dommel Valley, native species should be prioritized, contributing to heightened ecological resilience. This principle extends to the greening of blue canals and the introduction of the Gender, emphasizing the importance of adapting plant choices to local conditions. Particularly



within the evolving Brainport Park and Landgoed de Wielewaal, influenced by changes in Brainport industries, incorporating native and local species becomes crucial. Additionally, regenerating agriculture based on climate buffer potential-zones presents an opportunity for the municipality to incentivize farmers. By subsidizing the redevelopment of fields to enhance water infiltration and act as carbon sinks, agriculture can become a key component of urban ecological resilience.

Urban Ecological Resilience Strategy
 1:70.000

- Urbanized area
- Strengthening Dommeldal
- Greening blue corridors
- Re-introducing Gender
- Regenerating agriculture: climate buffers
- Strengthening 'Groene Wiggen'
- City parks
- Radial and concentric green corridors

Figure 35 Urban ecological resilience strategy



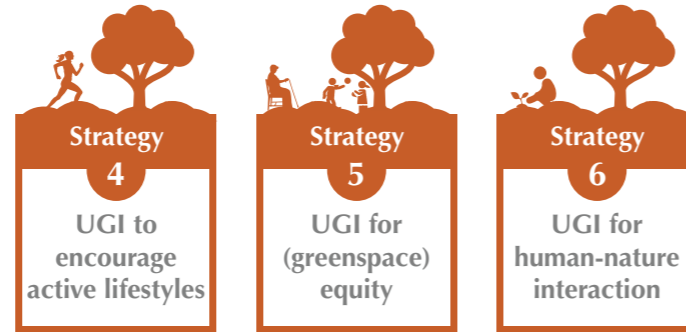
7.3 Human well-being strategy

The city strategy for human well-being is illustrated in Figure 36. Below is explained how the strategies for UGI application to create human well-being are applied on a city scale.

Strategy 4: Designing UGI to Encourage Active Lifestyles for Enhanced Human Well-being. Creating an environment that promotes active lifestyles is central of Eindhoven’s Human Well-being strategy. Primary is the establishment of a city-wide green recreational and fast cycling mobility network. This network is strategically designed to connect important work locations and key green recreational zones in the city, ensuring a pleasant walking, cycling, and jogging environment. By facilitating easy access to larger recreational areas and encouraging more frequent bicycle commuting, this network will contribute to the overall well-being of residents. The strategy extends to a finer-grain network for slow mobility modes, bringing the benefits of active transportation closer to residents’ homes. The inclusion of green structures enhances the network, maximizing the health benefits and ecosystem services provided by UGI.

Strategy 5: Designing UGI for Greenspace Equity and Environmental Justice to Enhance Human Well-being. Promoting environmental justice and greenspace equity is done by proposing the implementation of the following measures. Firstly, to aim at the reduction of ‘riskscares’ to ensure safe and pleasant living environments for all inhabitants in Eindhoven. For this, the municipality should aim at establishing interventions, such as a pleasant micro-climate, providing opportunities for cooling and enhancing groundwater infiltration to mitigate flooding issues through various nature-based solutions. Furthermore, the expansion and greening of the recreational network will contribute to improved access to greenspaces, fostering a more equitable distribution. This approach ensures that all residents, regardless of their location within the city, can benefit from the positive impacts of UGI on well-being.

Strategy 6: Designing UGI to Facilitate Human-Nature Interactions for Enhanced Human Well-being. Creating more connections between humans and nature is the final core element of Eindhoven’s Human Well-being strategy, particularly through the enhancement of (green-)blue corridors. A key proposal involves making the Dommel

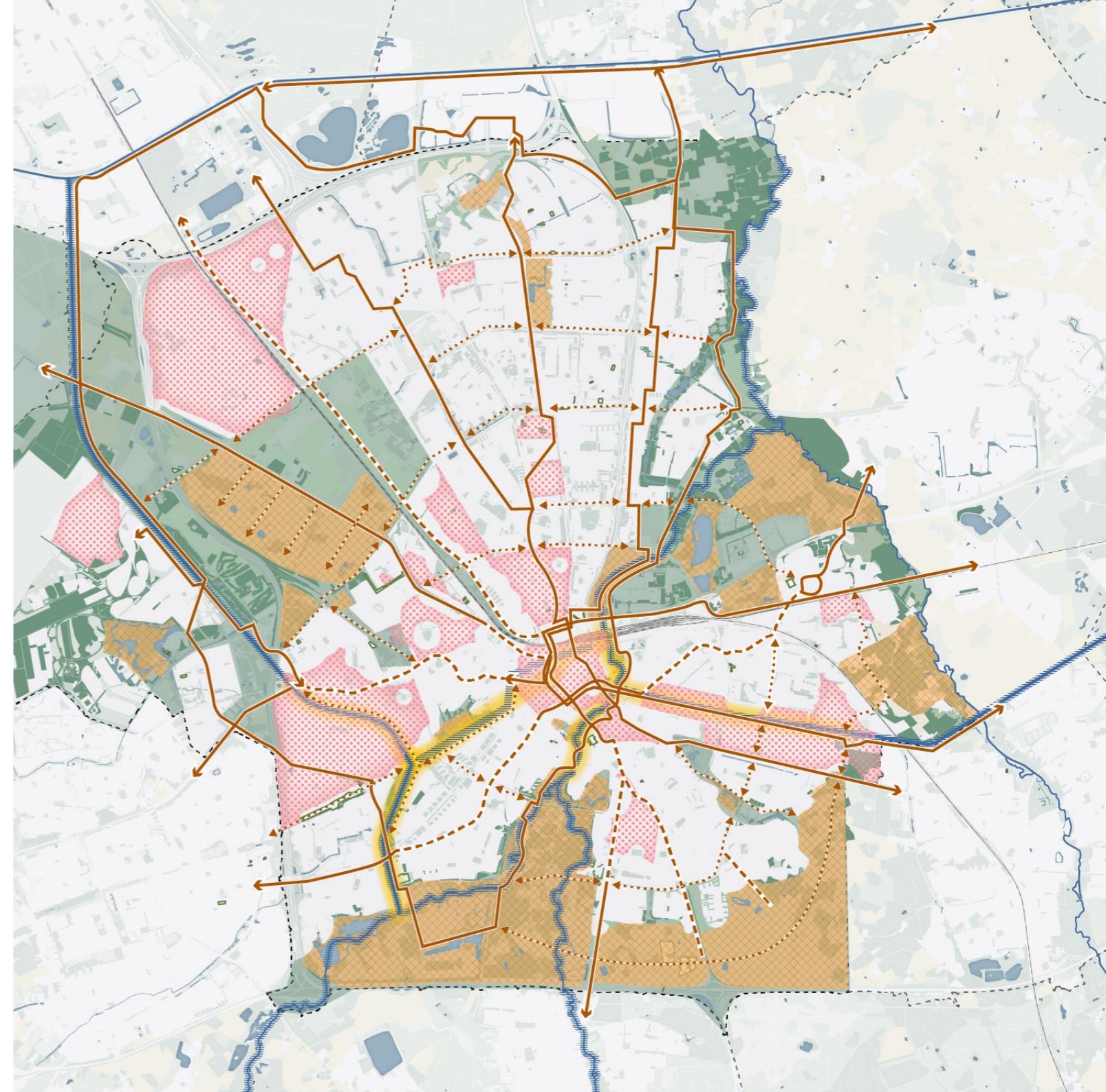


Valley more accessible for leisure, transforming it into a significant recreational scape within the city center, an existing example of which is the Anne Frankplantsoen. Furthermore, the introduction of the green-blue corridor the Gender, presents further opportunities for human-nature contact, envisioning the creation of Victoriapark as a major park in which the Gender plays the central role. Simultaneously, the greening of the blue canals is paired with the development of additional leisure facilities, bringing residents closer to nature within their immediate surroundings. These interventions aim to enrich the lives of city residents by fostering meaningful interactions with the natural environment.

Human well-being Strategy
 1:70.000

- Urbanized area
- Reducing risk scapes
- Greenspace of significant recreational value
- Fast cycling lanes
- Proposed fast cycling lanes
- Proposed fine-grain recreational network
- Strengthening human UGBS connections

Figure 36 Human well-being strategy



7.4 City strategy for Eindhoven 2040

Figure 37 presents the collective strategy for Eindhoven in 2040, showing how the three strategies for the key themes urban densification, urban ecological resilience and human well-being come together through the application of UGI strategies.

By focusing on strategically located high-density development zones distributed across Eindhoven and by proposing a mobility plan promoting slow-traffic and public transportation modes, an interconnected mixed-use urban landscape is created deviating from a car-centric approach.

Furthermore, by improving the multi-scaled network of UGI, introducing (Gender) and enhancing (Dommel) the UGBI and greening mayor blue corridors, and by prioritizing the local conditions the urban ecological resilience of Eindhoven is greatly promoted. Together, these strategies create a more resilient and green city environment, mitigating environmental challenges and elevating the well-being of species and inhabitants.

Finally, the human well-being strategy enhances the urban experience by promoting active lifestyles through an extensive recreational and cycling network. Additionally, by promoting greenspace equity and environmental justice, it is ensured that all residents have access to the physical and mental health benefits of nature. Lastly, opportunities for human-nature interactions are created by making green-blue corridors accessible for leisure, creating vibrant recreational green spaces within the city.

As Figure 37 illustrates, these strategies are not isolated domains, but integral facets creating a unified strategy for an ecologically resilient Eindhoven 2040 that prioritizes the well-being of its inhabitants.

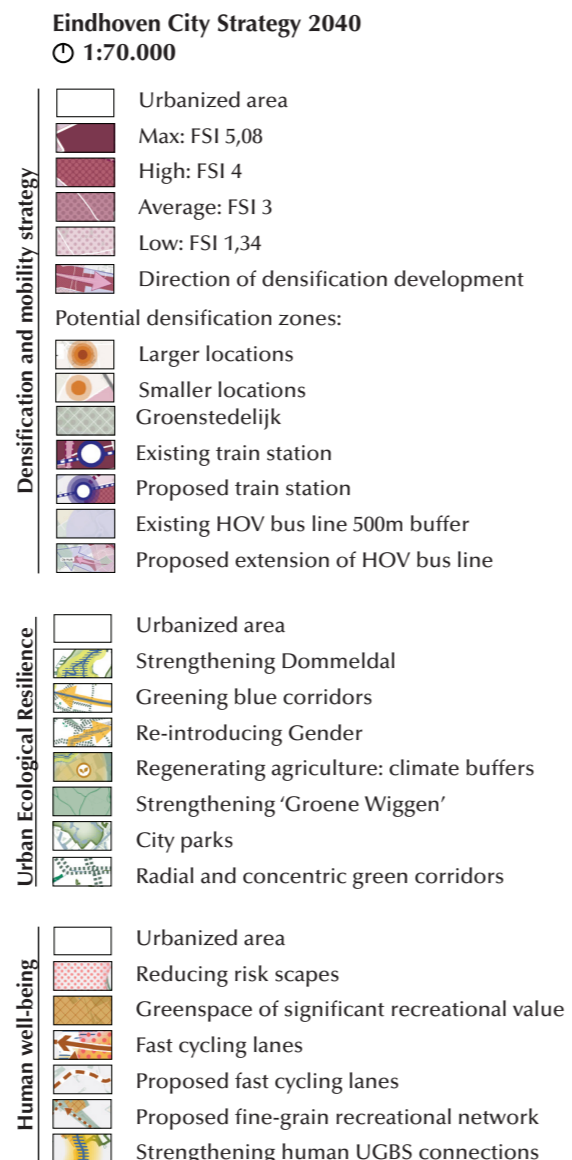
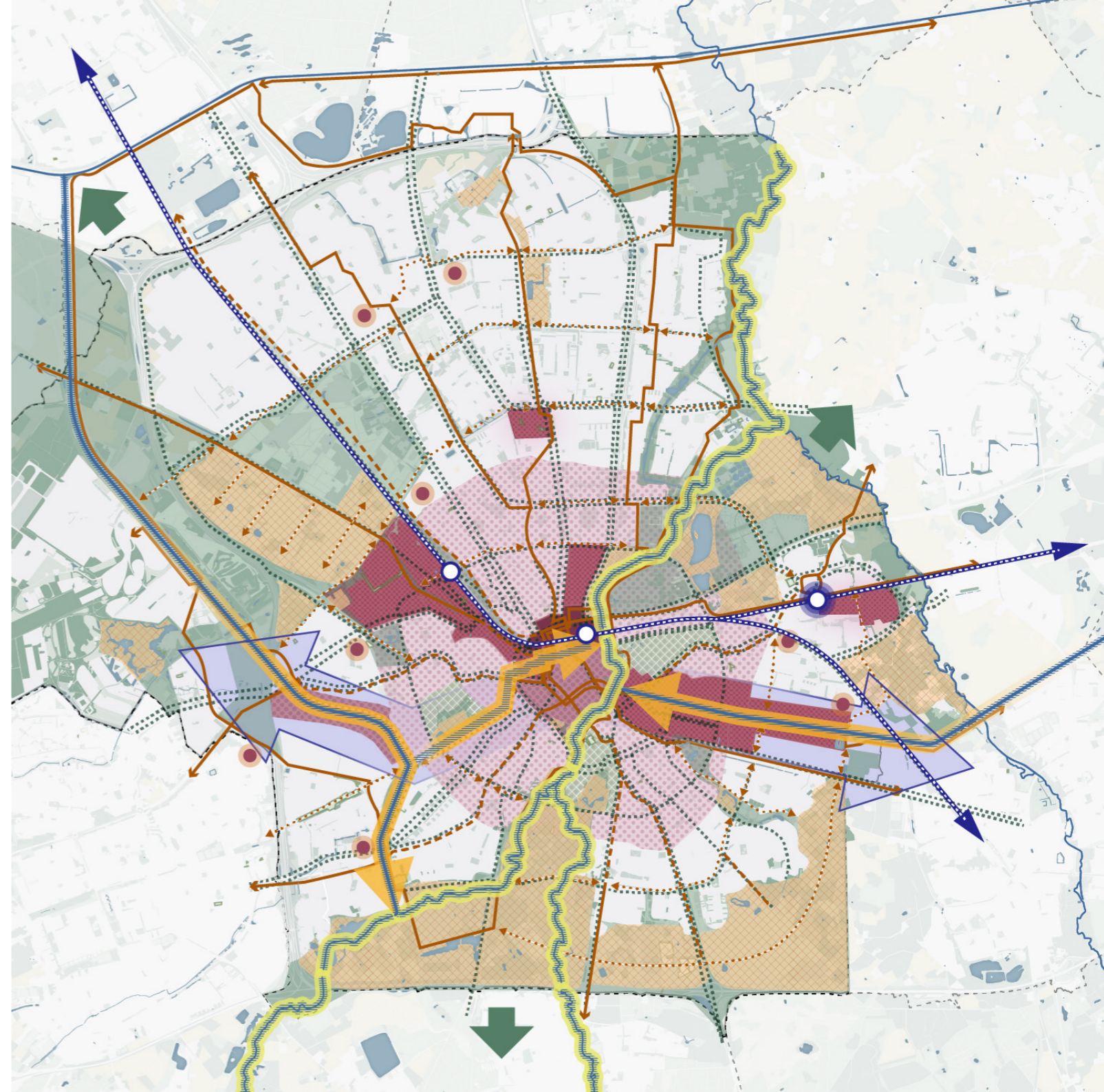


Figure 37 City strategy for Eindhoven 2040





part III

design

8. Neighbourhood analysis and framework

This section delves into the analysis of the neighbourhood Muschberg, Geestenberg, both demographic and urban mapping analyses. The mapping analysis traces the historical development of the neighborhood and examines the current Floor Space Index (FSI) and the public transportation infrastructure. Subsequently, the mapping analysis focuses on the state of human well-being and urban ecological resilience of the neighbourhood, providing a spatial overview of the current state of the key themes within the area.

8.1 Introduction

Situated in the city district of Tongelre (Figure 38), Muschberg, Geestenberg is a predominantly residential neighbourhood characterized by diverse developmental phases throughout history. Housing a total of 3,884 inhabitants, constituting approximately 18% of the entire Tongelre district's population of 21,530 (CBS, 2023). This and further socio-demographic and neighbourhood characteristics are highlighted in Figure 39 below.

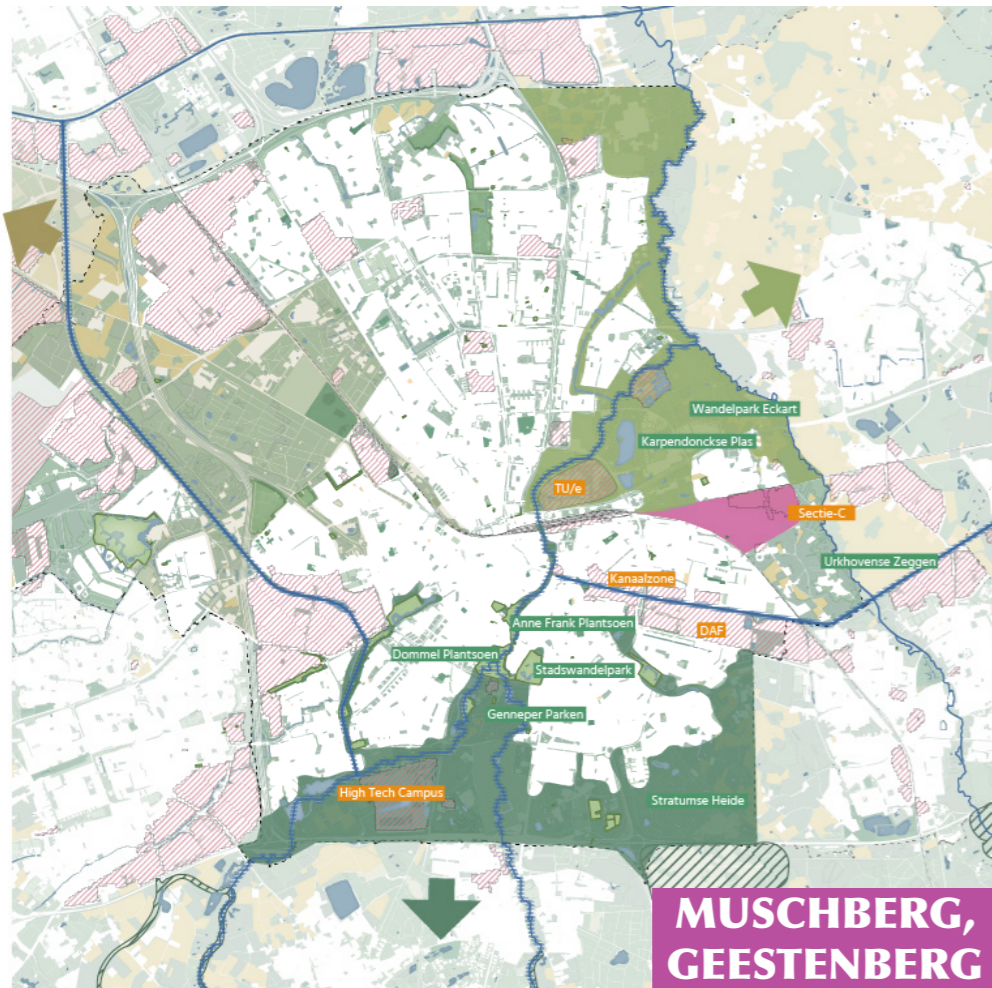


Figure 38 Neighbourhood location in urban context, scale: 1:100.000

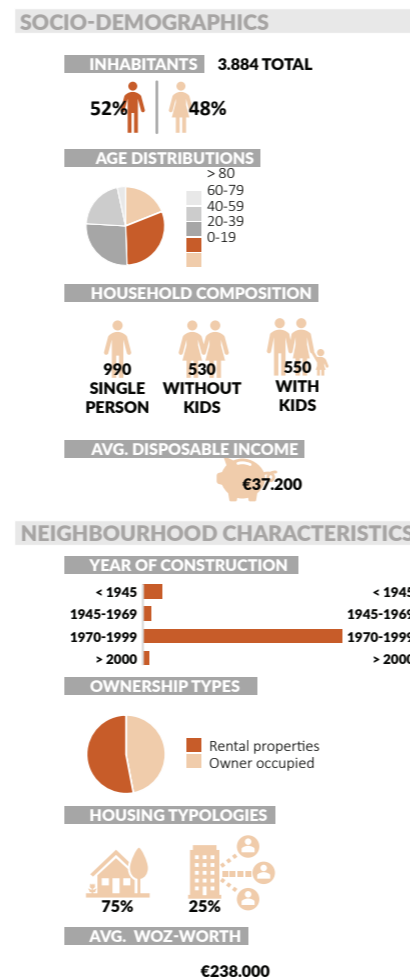


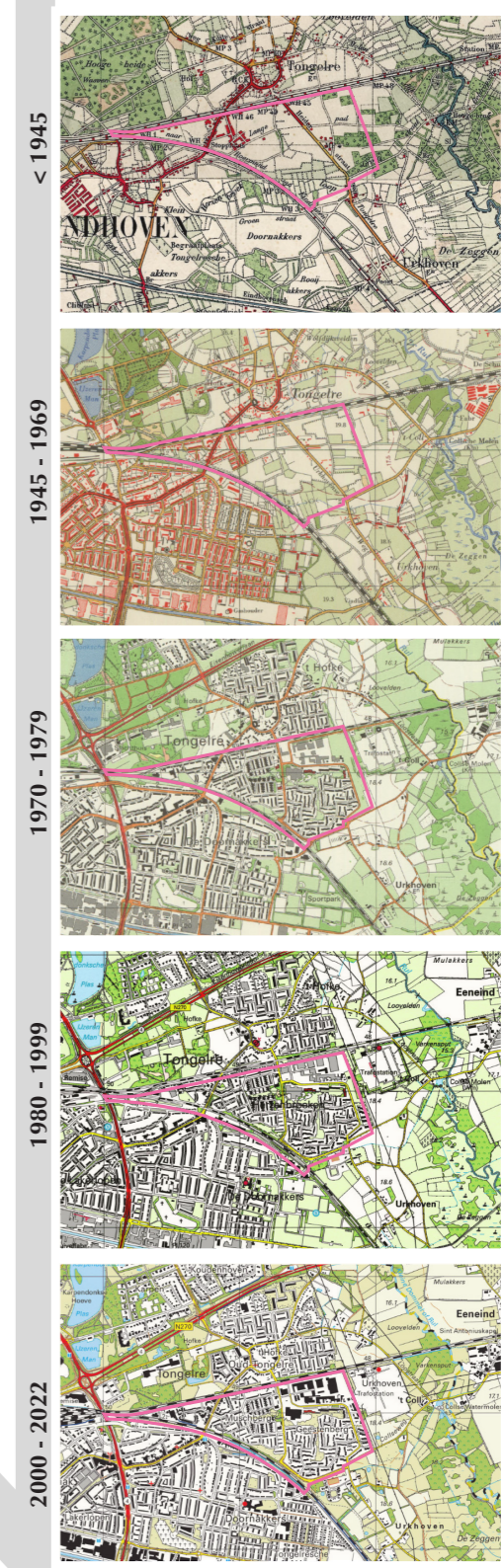
Figure 39 Demographic profile (Eindhoven in Cijfers, 2023)

As illustrated in Figure 40, the neighbourhood's roots trace back to pre-World War II, with initial small agricultural developments and development occurring around the historic radial 'Tongelresestraat'. This radial road once connected Eindhoven to the village of Tongelre. Furthermore, housing emerged along the 'Urkhovenseweg'. The neighbourhood within its direct context is illustrated in Figure 41 for reference.

Post-war housing developments emerged South of the southern railway, in the areas Doornakkers-Oost and -West. Yet the Muschberg, Geestenberg area remained an almost exactly similar rural building structure, only with the addition of housing along the Northern railway. The bulk of the neighbourhood's construction unfolded around the '70s, during this period the area 'Herzenbroek' was introduced, consisting of the two subareas Muschberg and Geestenberg. Both areas predominantly feature terraced housing, with Muschberg serving as an experimental neighbourhood construction with a typical 'Bloemkoolwijk' design (Architectuurcentrum Eindhoven, 2020). A central green park integrating both the Muschberg and Geestenberg areas was designed with the intention of functioning as the neighbourhoods 'green lungs'. 't Karregat (Figure 42 image 7), established as 'a roof for the community', an experimental communal space (Architectuurcentrum Eindhoven, 2020), takes up a prime role in the park. No serving as a primary school, daycare center and supermarket, maybe fulfilling its role as center of the community more than ever... Within the same development process, large apartment buildings were introduced edging this park on the Northern and Eastern sides. These buildings now form a border between the industrial site Sectie-C and the rest of the Muschberg, Geestenberg area.

During the same time period, the 'firma Nolte', a traffic sign production company housed itself in the part of the neighbourhood now known as Sectie-C (Sectie-C, n.d.). The company developed into an industrial zone which lost its original industrial function in 2007. Sectie-C, once housing the production company, has evolved into a crucial hub for Eindhoven's creative industries, accommodating over 250 artists in its vibrant workspace community.

Figure 40 Historic development (Topotijdreis, n.d.)



Post-2000, the landscape of Muschberg, Geestenberg saw minimal alterations, except for the addition of a work and industrial zone in the convergence of the two railways. During this time, the development of Tongelrescheekers to the south unfolded, contributing to the district's expansion with terraced and free-standing housing options for families.

8.2 Muschberg, Geestenberg analysis

8.2.1 Energy labels

Observing Figure 43 (page 90), it becomes evident that the majority of housing and structures in Muschberg, Geestenberg that were established in the post-war era and during the 1970s, falling within the G to B range of energy labels (RVO, 2022). Notably, only recent constructions in the Tongelrescheekers neighborhood attain classifications of A+ or higher, with a solitary building in the Sectie-C

area also achieving this higher energy efficiency standard. With soon to be implemented rules for energy labels, many houses are in need of improvements.

8.2.2 Current FSI

The current FSI is visualized in Figure 44, based on the dataset 'RUDIFUN, 2022' (Arjan et al., 2022). The highest FSI is observed along the central park zone, featuring tall apartment buildings that surpass an FSI of 2.5. The lowest FSI in the area can be found in the Sectie-C zone, exhibiting a general FSI of below 0.5. This area is characterized by spacious industrial structures, predominantly one or two stories in height. Given that the remainder of the neighborhood primarily comprises residential terraced housing, the FSI remains relatively consistent throughout.

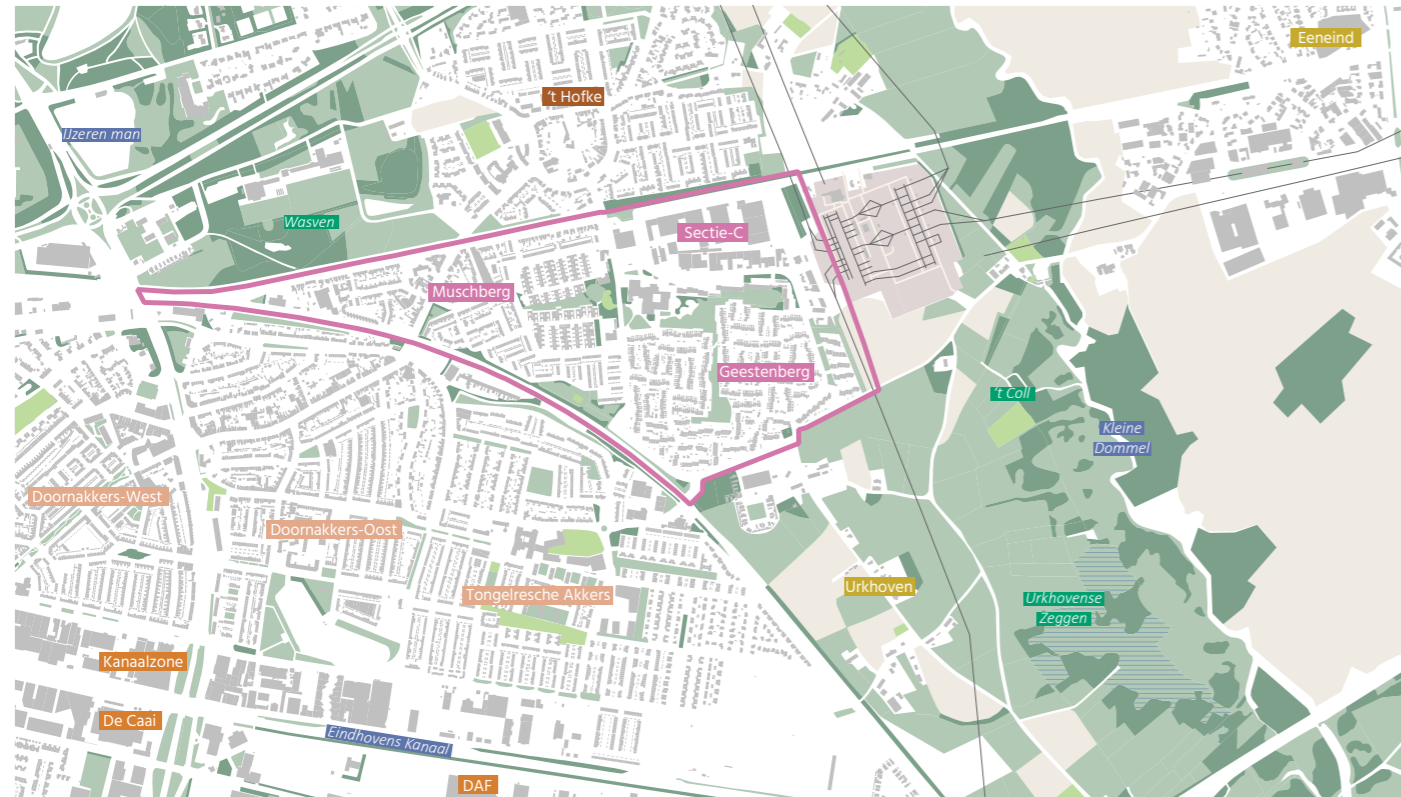


Figure 41 Neighbourhood in context, scale 1:20.000



Figure 42 Muschberg, Geestenberg (1): (van der Hoeven, 2012), (2): (Jansen, 2017), (3): (Huislijn.nl, 2023), (4) (5): (Google Maps, 2023), (6): (Diederendirix, 2020), (7): (Base Photography, n.d.)

A zoom-in of the city densification strategy, is visualized which appoints Sectie-C as a key area for future densification. Additionally, two smaller-scale zones are appointed in the Tongelre district, namely Dirigentplein and a large parking area, both situated in Doornakkers-Oost. These areas are marked as potential areas for future densification aligning with the larger urban strategy of decentralizing the densification development.

8.2.3 Public transportation

Examining the current bus transportation connectivity in the neighbourhood reveals one bus line operating at a frequency of twice per hour. However, resident feedback indicates that these buses often depart early or arrive late, leading to dissatisfaction with the reliability of the only available public transport link. Alternative bus connections are situated too far away. The train reach of a 30 minute walk and 10 minute cycle (I amsterdam, 2023) from Station Eindhoven Centraal only caters to the area enclosed by the two railways and the Tongelresestraat. However, this zone has a very sparse population. This has all been illustrated in Figure 45.

To address the transportation challenges and explore the potential introduction of an additional train station, a viability assessment was

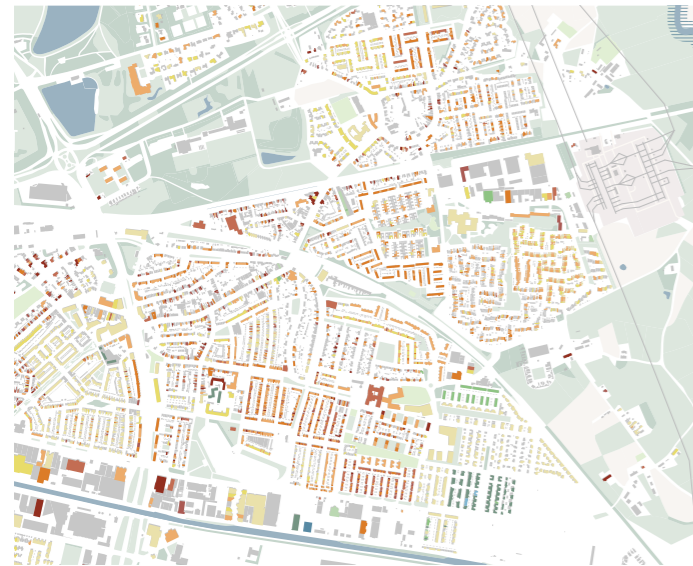


Figure 43 Energy labels (RVO, 2022)

conducted. Following the method adopted in the report 'Quicksan haalbaarheid station Loenersloot' by Royal HaskoningDHV (2020), the study suggests that for every 500 inhabitants residing within a 500m radius from the station, 75-125 individuals would use the station daily. In the 500-1000m radius, this number ranges from 50-100 people. The introduction of a new station becomes viable starting from 1,000 projected daily users.

Applying these criteria to the current population yields the following:

<500m: Muschberg, Geestenberg with 3884 inhabitants:

- $3884/500 = 7.77$,
- Minimum amount of users: $7.77*75 = 582$ users,
- Maximum amount of users: $7.77*125 = 971$ users.

500-1000m: approximately the inhabitants of Koudenhoven and Doornakkers-Oost together:

- $2879 + 526 = 3405$ inhabitants: $3405/500 = 6.81$,
- Minimum amount of users: $6.81*50 = 340.5$ users,
- Maximum amount of users: $6.81*100 = 681$ users.

These calculations suggest a minimum of $582 + 340.5 = 922.5$ users and a maximum of $971 + 681 = 1652$ users based on the current situation. Notably, even without densification, the minimum threshold just falls short of the required 1,000 users, while the maximum significantly exceeds it.

Considering the anticipated densification of Sectie-C in the future, the population within a 500m radius would substantially increase, surpassing the minimum required 1,000 users. This highlights the viability of establishing a train station in this location.

Energy labels
📍 1:30.000

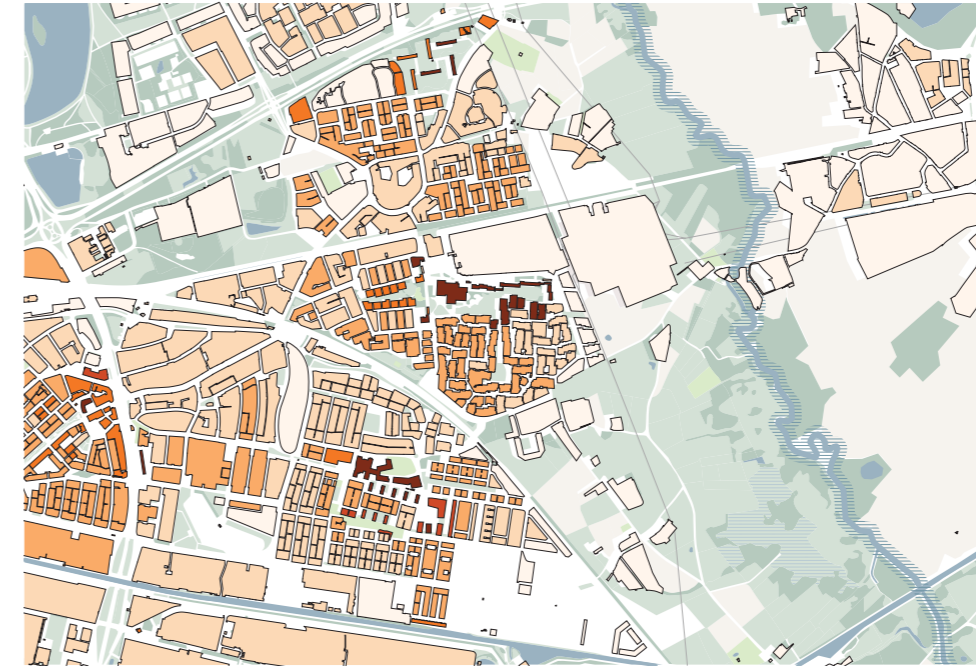
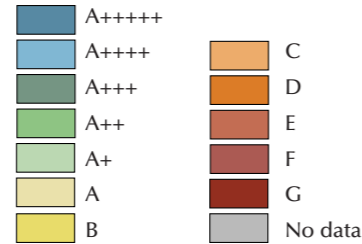
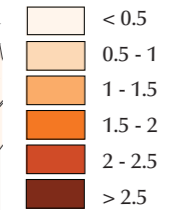


Figure 44 Current FSI (Arjan et al., 2022)

FSI 2022
📍 1:30.000



Zoom-in city strategy urban densification

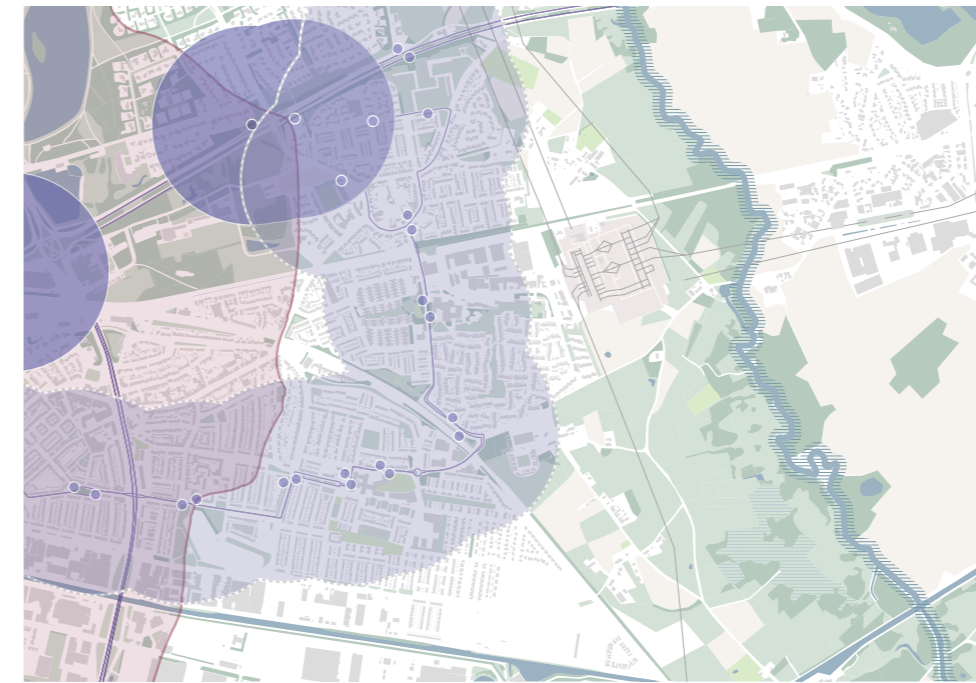
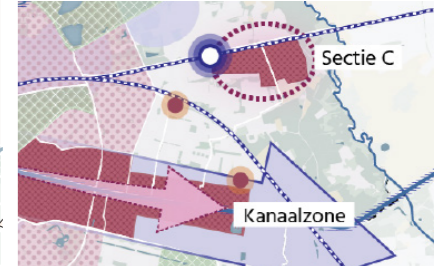
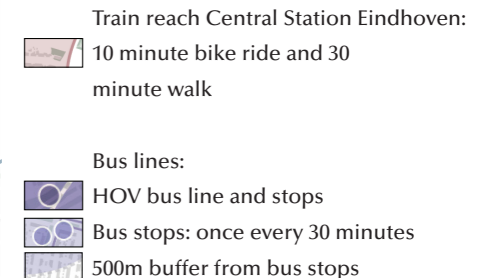


Figure 45 Bus connections and train reach

Mobility: Public Transportation
📍 1:30.000



8.2.4 Biodiversity

Surrounding the neighbourhood, various ecosystem types can be identified. The Municipality of Eindhoven (2018) has compiled an overview of what different nature target types can exist where, as illustrated in Figure 47. Along the neighbourhood, forested landscapes and agricultural lands connect to the 'Urkhovense Zeggen — one of the last remaining blue-grasslands in Brabant — and the valley of the Kleine Dommel. This is the main biodiverse hotspot near the neighbourhood, where many different types of species thrive on wetter lands.

Contrastingly, the neighbourhood park does not exhibit the same richness in biodiversity. This might relate to a lack of connectivity to larger structures (more information on this will be provided in the following section '8.2.5 Connectivity'). Furthermore, the planted flora does not bring much variety, which can be seen in image (5) in Figure 42: only planted grass and little variety in tree species.

Furthermore, within the neighbourhoods a large biodiversity gap exist in Sectie-C. Although bordered by some green structures, the area lacks sufficient UGI, with only a few small and isolated patches present. Additionally, the electricity transmission hub to the East of Sectie-C contributes to this gap in biodiversity. Collectively, the two zones form a substantial barrier for species habitat and interaction.

Figure 46 highlights key species in the surrounding natural areas, ranging from butterflies to trees. Given their significance for the existing ecosystems, these species should be factored into future UGI designs. Many of these species thrive in green-blue environments, aligning with the proximity of the Kleine Dommel and Urkhovense Zeggen.

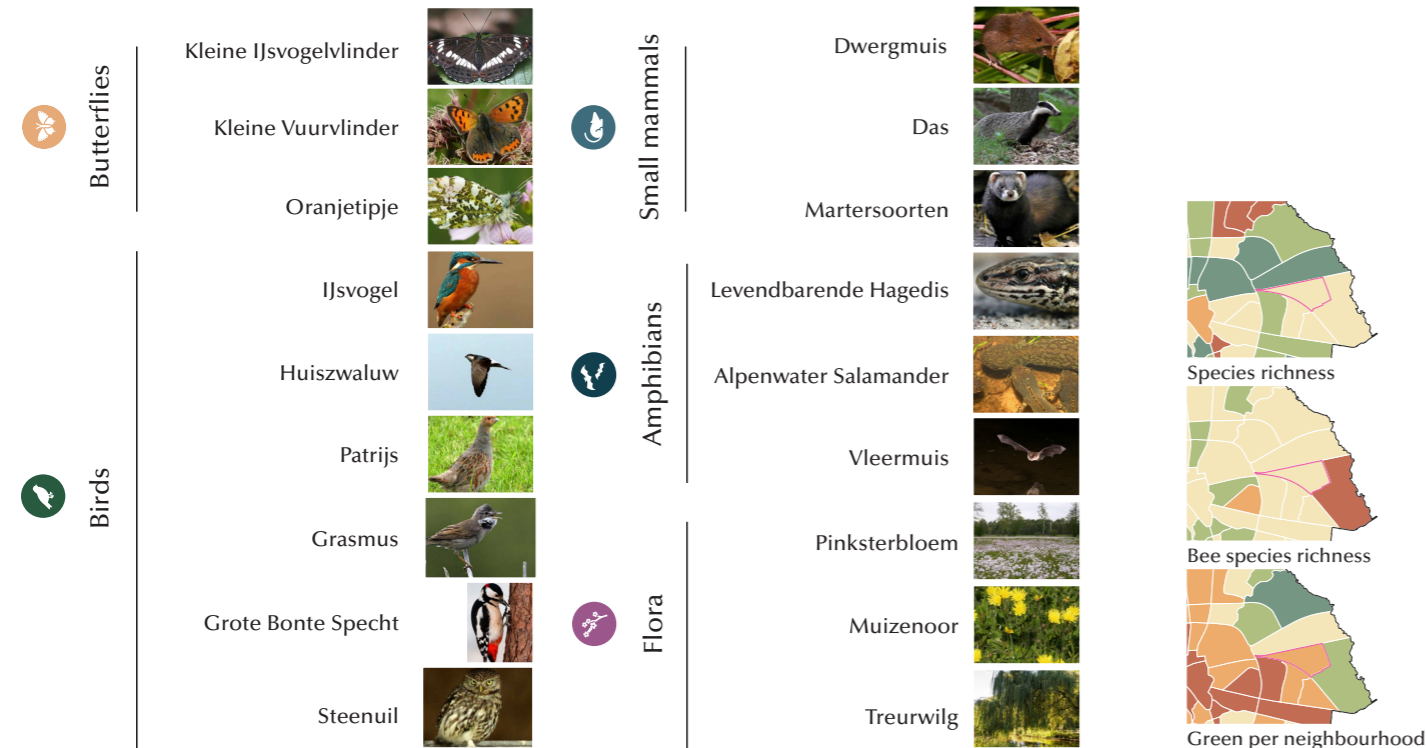


Figure 46 Important species in the area (Gemeente Eindhoven, 2018) (IVN, n.d.) (City Tours Eindhoven, n.d.)

Biodiversity

1:20.000

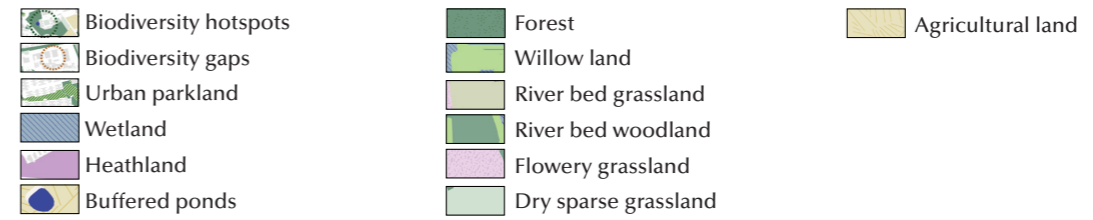


Figure 47 Biodiversity Muschberg, Geestenberg

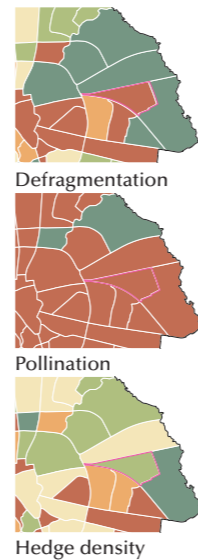
8.2.5 Connectivity

Figure 48 maps the green structures and barriers that exist in the area. The neighbourhood is situated between two railways, which has significant implications for the connectivity of the existing green structures, as these function as large ecological barriers. An additional large obstacle can be seen on the eastern side of the neighbourhood, where a large electricity transmission hub blocks the linkage from ecological hubs the Urkhovense Zeggen (wetland agriculture) and Kleine Dommel valley. Further blocking the ecological linkage into the neighbourhood is Sectie-C, as this area is only presents a few smaller scale green structures along its edges. The south-eastern corner of the neighbourhood has the least obstructing barriers formed by roads: the Collseweg and the Heerbaan. On these sides, the neighbourhood closely connects to the Urkhovense Zeggen blue-agricultural lands and the Kleine Dommel valley.

To the North of the railway the Wasven domain is situated. This area is easily accessible for people, but presents constraints for species movement to and from the region. However, both the Wasven domain and Urkhovense Zeggen exemplify rural characteristics from remnants of small-scale cultural landscapes in Brabant. The Urkhovense Zeggen presents a characteristic wetland agricultural land, while the Wasven presents a typical heath and forested area. Due to their isolated locations near the city and surrounded by roads, these areas have remained untouched by land consolidation (ruilverkaveling), providing significantly important ecological zones.

Furthermore, the neighbourhood provides a sizable central park which particularly integrates into the Geestenberg area. However, this park lacks connection to the broader region and holds a significantly low ecological value. Where along the southern railway UGI brings green-blue elements into the neighbourhood through a large infiltration zone and a park, the western part of the neighbourhood faces a significant scarcity of green structures.

Despite the challenges posed by the elements hindering connectivity, the neighbourhood has a large potential for improvements arising from the enclosed Sectie-C area, green structures along the railways and the large central neighbourhood park.



Connectivity

📍 1:20.000

-  Buildings
-  Street Corridor
-  Region Hub
-  Infrastructural barrier
-  Region Corridor
-  Electricity station
-  City Site
-  Transmission towers
-  Neighbourhood Steppingstone

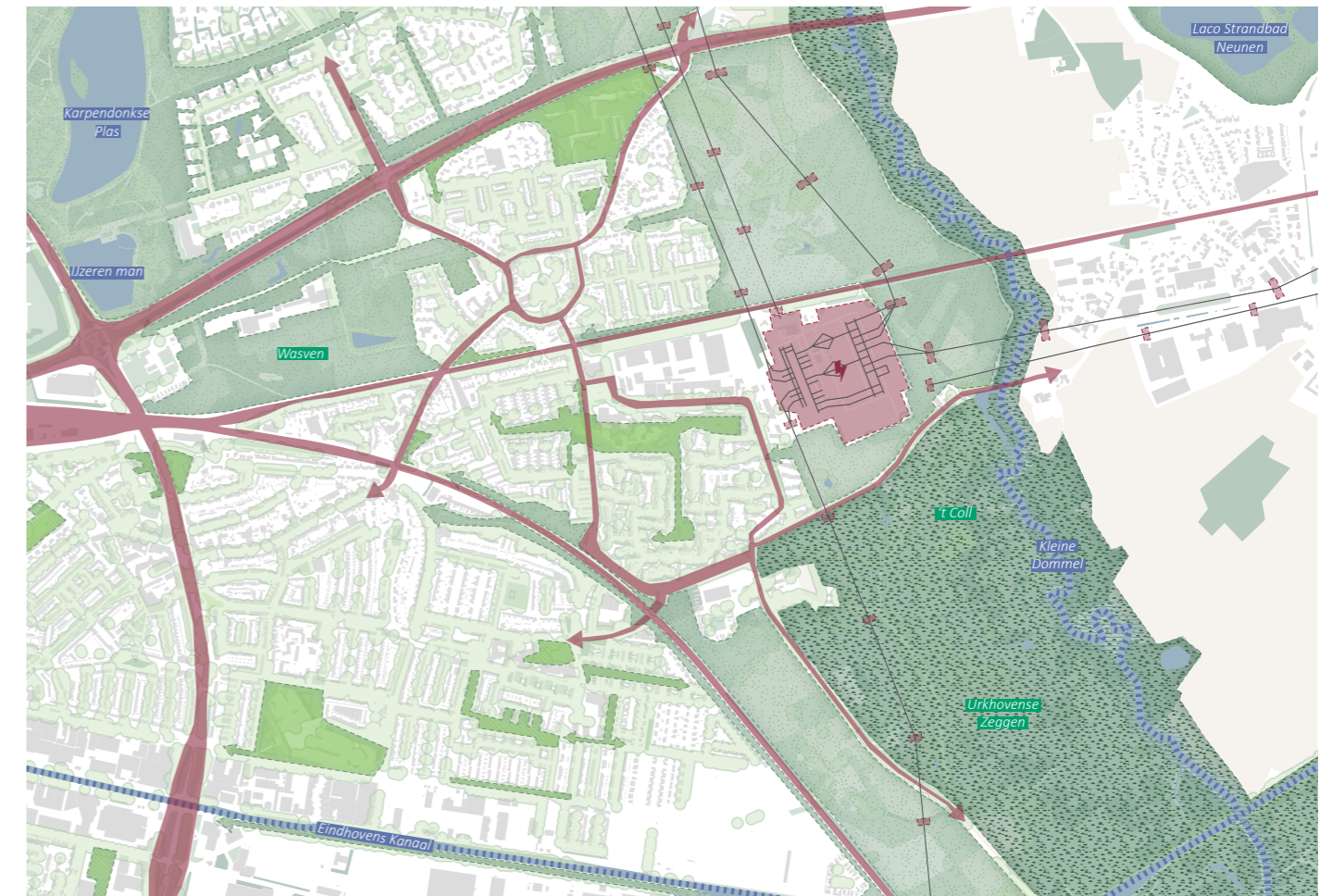


Figure 48 Connectivity Muschberg, Geestenberg

8.2.6 (a) Biotic fitness

The vitality of both biotic and abiotic systems in the environment largely depend on the local climate and environmental factors. Figure 49 shows research into imperviousness (Copernicus, 2018), noise pollution (Rijksinstituut voor Volksgezondheid en Milieu, 2020), heating effect (Klimaat-effectatlas, 2023d) and flooding risk (Klimaat-effectatlas, 2023e). These high-risk zones arising from this have been indicated in Figure 50. Certain areas, notably the industrial Sectie-C zone, industrial areas along the canal, and the electrical transmission hub, exhibit elevated levels of impervious soil. Furthermore, noise pollution can be attributed to the railway structures, affecting many parts of the neighbourhood. Particularly those parts closely situated along the railway with minimal buffering, as exemplified in Figure 42 (image 2).

Moreover, the considerable temperature difference between rural and built environments emphasizes the benefits of the neighbourhoods location along the region. Despite infrastructural barriers, the cooling effect comes into the neighbourhood, indicating the potential for this neighborhood to mitigate temperatures in adjoining areas further into the city.

Finally, the Geestenberg neighborhood, situated in the lowest part of the area, faces challenges with flooding during heavy rainfall. Leveraging the extensive neighborhood park as a sponge or infiltration zone holds the potential to alleviate flooding issues in this particular region, offering a sustainable solution for water management.

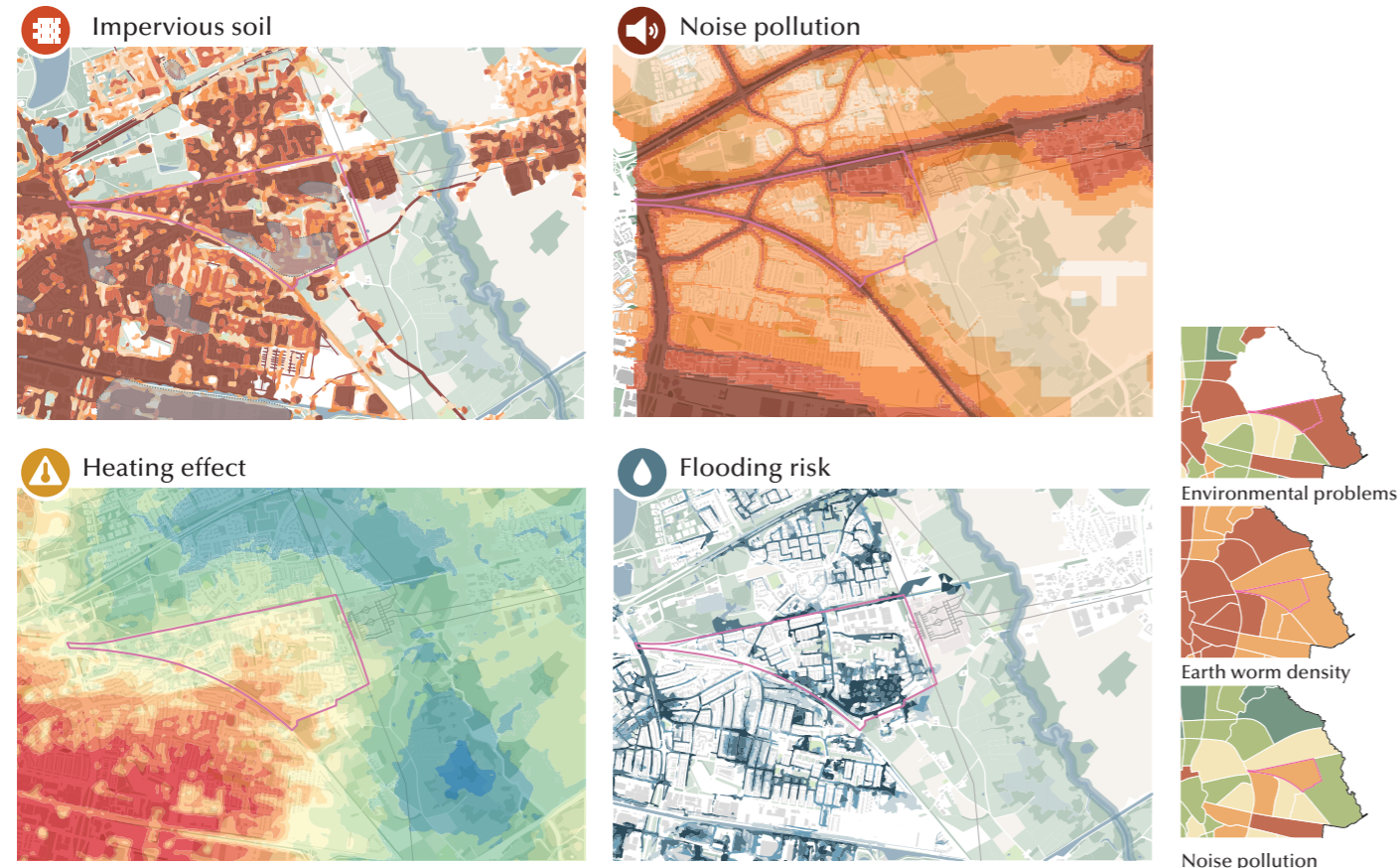


Figure 49 Environmental problems (Copernicus, 2018), (Rijksinstituut voor Volksgezondheid en Milieu, 2020), Flooding (Klimaat-effectatlas, 2023d), (Klimaat-effectatlas, 2023e)

(a) Biotic fitness

🕒 1:20.000

- Buildings
- High-risk zone:
- Noise pollution
- Heating
- Flooding
- Sealed soils

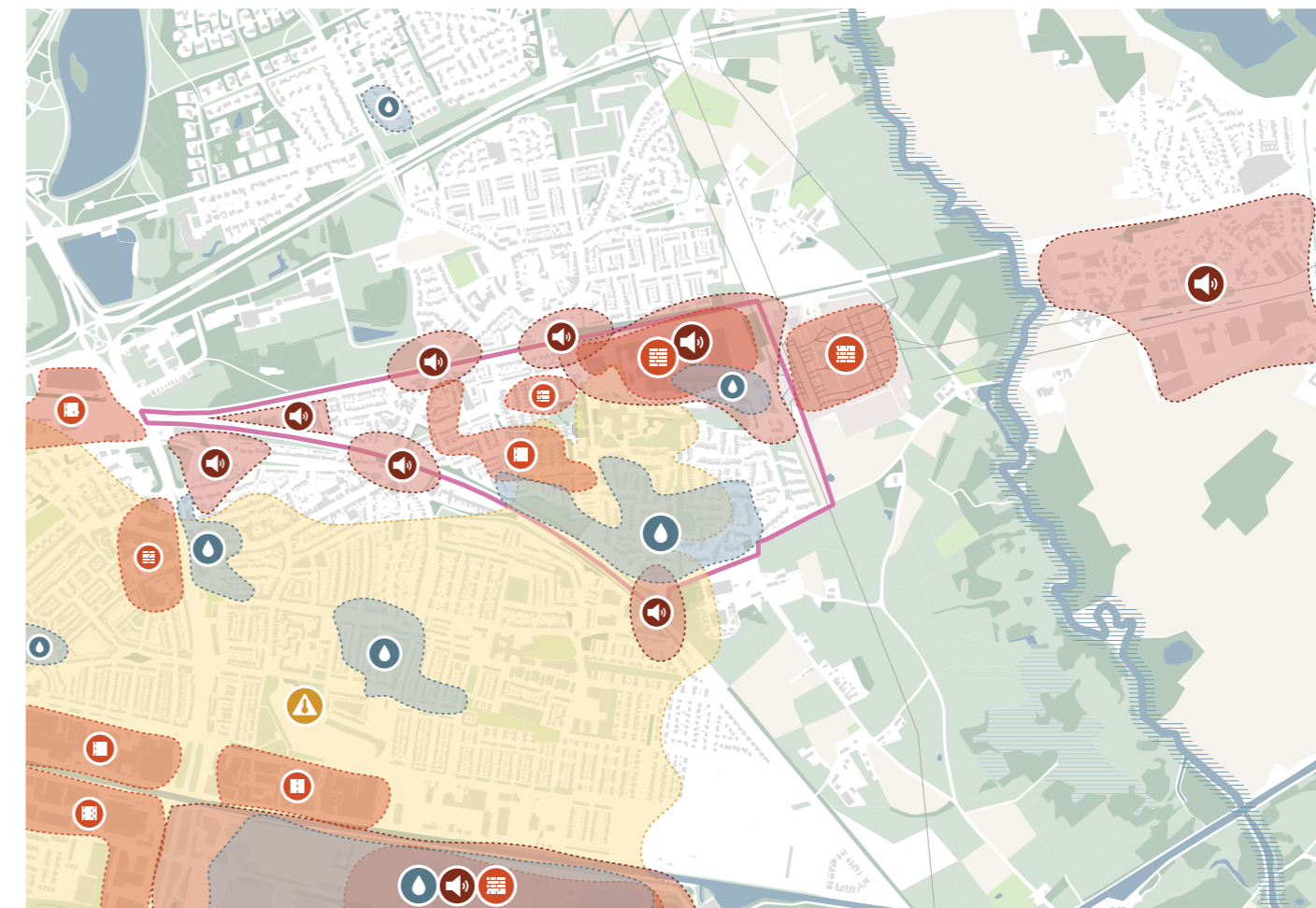


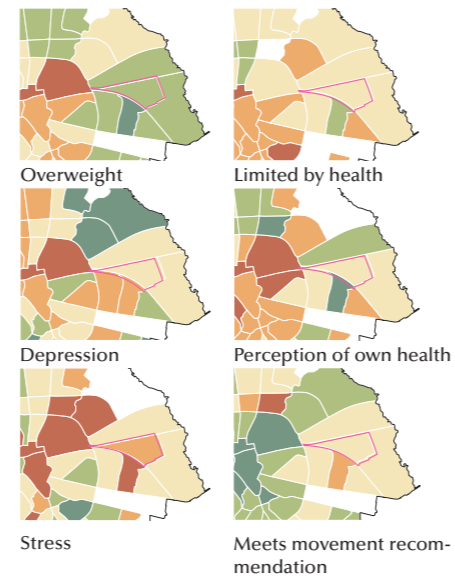
Figure 50 (a) Biotic fitness Muschberg, Geestenberg

8.2.7 Health

Figure 51 provides an overview of healthcare facilities, sports amenities, and active routes in the area. Presently, healthcare services, including a physical therapist, dentist, and therapist, are primarily situated outside the neighborhood. Notably, a health-care center along the city ring road is relatively accessible, yet with the anticipated rise in inhabitants, there is a pressing need for the integration of additional facilities, such as a general practitioner and a drugstore, to prevent overburdening existing practices.

In terms of sports facilities, Sectie-C accommodates a cross-fit gym, and a small gym is located in the same building as the physical therapist. However, broader sporting options are found farther away from the neighborhood.

Despite the neighborhood's proximity to rural areas, there is a scarcity of internal walking and cycling routes. The only cycling lane in the neighbourhood is along the Tongelresestraat, which is the busiest road. This highlights a significant potential for the development of increased slow-traffic and recreational routes, as depicted in Figure 51. Enhancing these routes will not only create improved connections for inhabitants but also facilitate access to greenspace within the neighborhood, promoting overall well-being and active lifestyles.



Health
🕒 1:20.000

- | | | |
|------------------------|----------------|------------------------------|
| Healthcare: | Sports: | Active routes: |
| 🏠 General practitioner | 🎾 Tennis | 🚲 Bike routes |
| 🦷 Dentist | ⚽ Soccer | 👤 Missing bike route links |
| 🏥 Physical therapist | 🏋️ Gym | 👤 Hiking and running network |
| 🧘 Therapist | | |

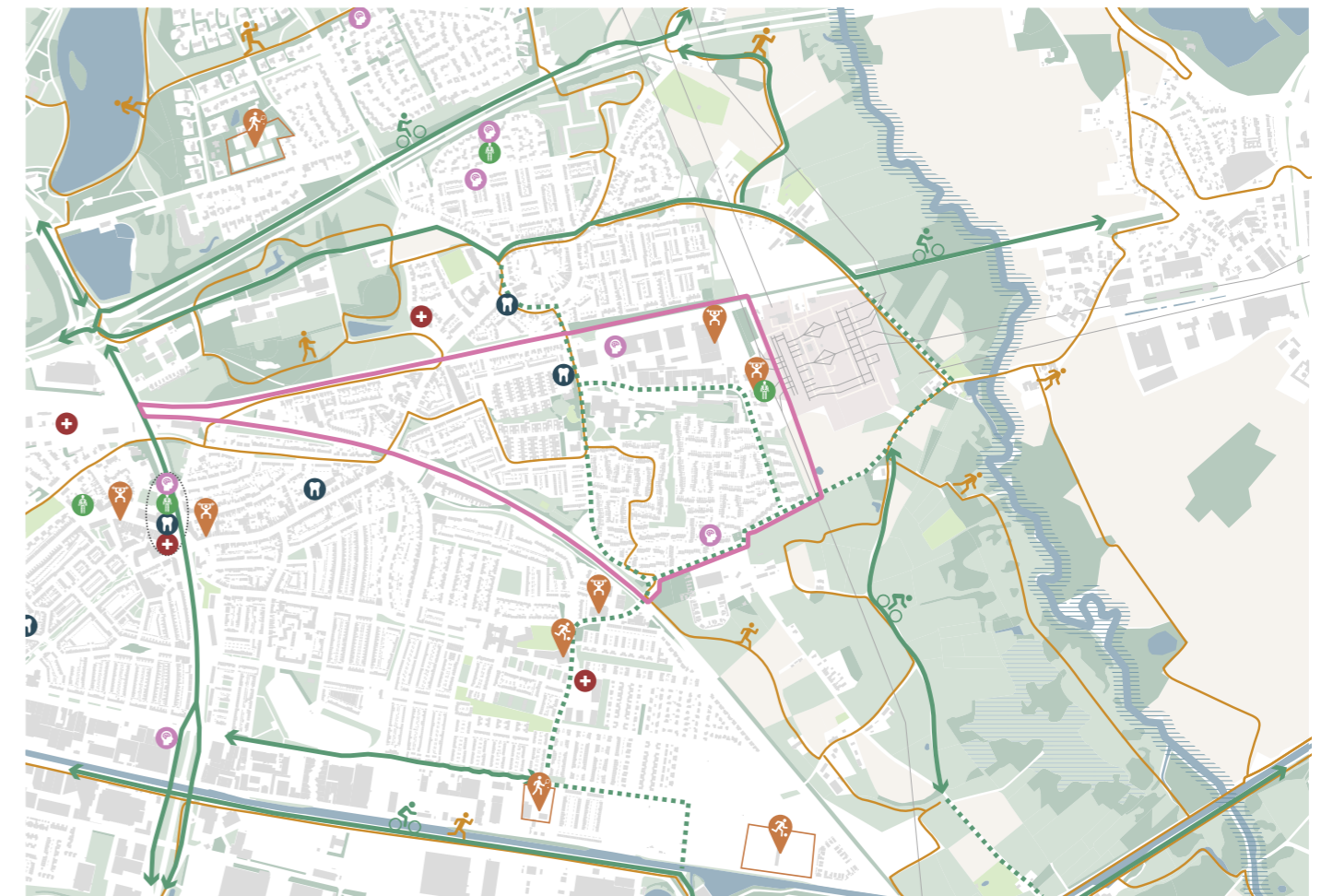


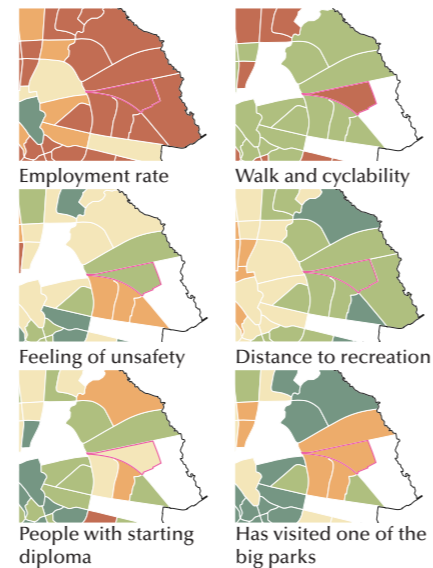
Figure 51 Health Muschberg, Geestenberg

8.2.8 Social development

To analyze the state of social development in the neighbourhood, Figure 52 maps the education, recreation and subjective safety. 't Karregat provides the only form of education in the neighbourhood: a primary school. Furthermore, the building has a daycare within. A gymnasium is situated in the Wasven domain, offering only a limited level of education by catering to only a specific level of education. Doornakkers-Oost and West house a range of functions, encompassing two primary schools, four daycare facilities, and various sporting locations.

Based on subjective resident feedback, two larger areas within the neighborhood are identified as having heightened feelings of unsafety—namely, the Sectie-C area and the western tip of the neighborhood. This perception may be attributed to their industrial nature, lacking social control during nighttime when these areas are not operational. Similar concerns regarding safety extend to the industrial zones along the canal.

Additionally, spatial indicator analysis reveals low walk and cyclability within the neighborhood. This aligns with findings in the previous section on health (8.2.7), emphasizing the potential for significant enhancements in human well-being through the development of improved slow-traffic and recreational routes within the neighborhood. Addressing safety perceptions and promoting active transportation can contribute to fostering a more secure and healthier living environment for residents.



Social Development

1:20.000

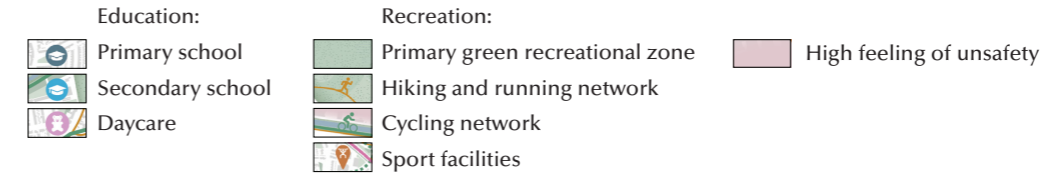


Figure 52 Social development Muschberg, Geestenberg

8.2.10 Belonging

Finally, Figure 53 illustrates aspects influencing the sense of social and spatial belonging in the neighbourhood, based on the factors distance to cooling, distance from greenspace (Klimaateffectatlas, 2023a) and hotspots of very lonely elderly (Klimaateffectatlas, 2023b).

With the increasing temperatures in cities, lonely elderly can become even more isolated as it can become too hot for them to go outside. The Muschberg Geestenberg neighbourhood stands out for having a substantial population of very lonely elderly residents, emphasizing the importance of enhancing cooling options to alleviate their potential isolation during rising city temperatures.

Although, the distance to cooling and greenspace is generally reasonable, notable deficiencies exist in Sectie-C area and a strip of housing along the Northern railway. These areas require substantial improvements to meet proper greenspace proximity and cooling facility standards.

Inhabitants of the neighborhood report low levels of satisfaction regarding feeling at home in their own neighborhood and their contentment with public spaces. Addressing these concerns in future development plans presents an opportunity for improvement. Incorporating UGI interventions in public spaces can play a pivotal role in enhancing residents' sense of belonging and overall satisfaction with their living environment.

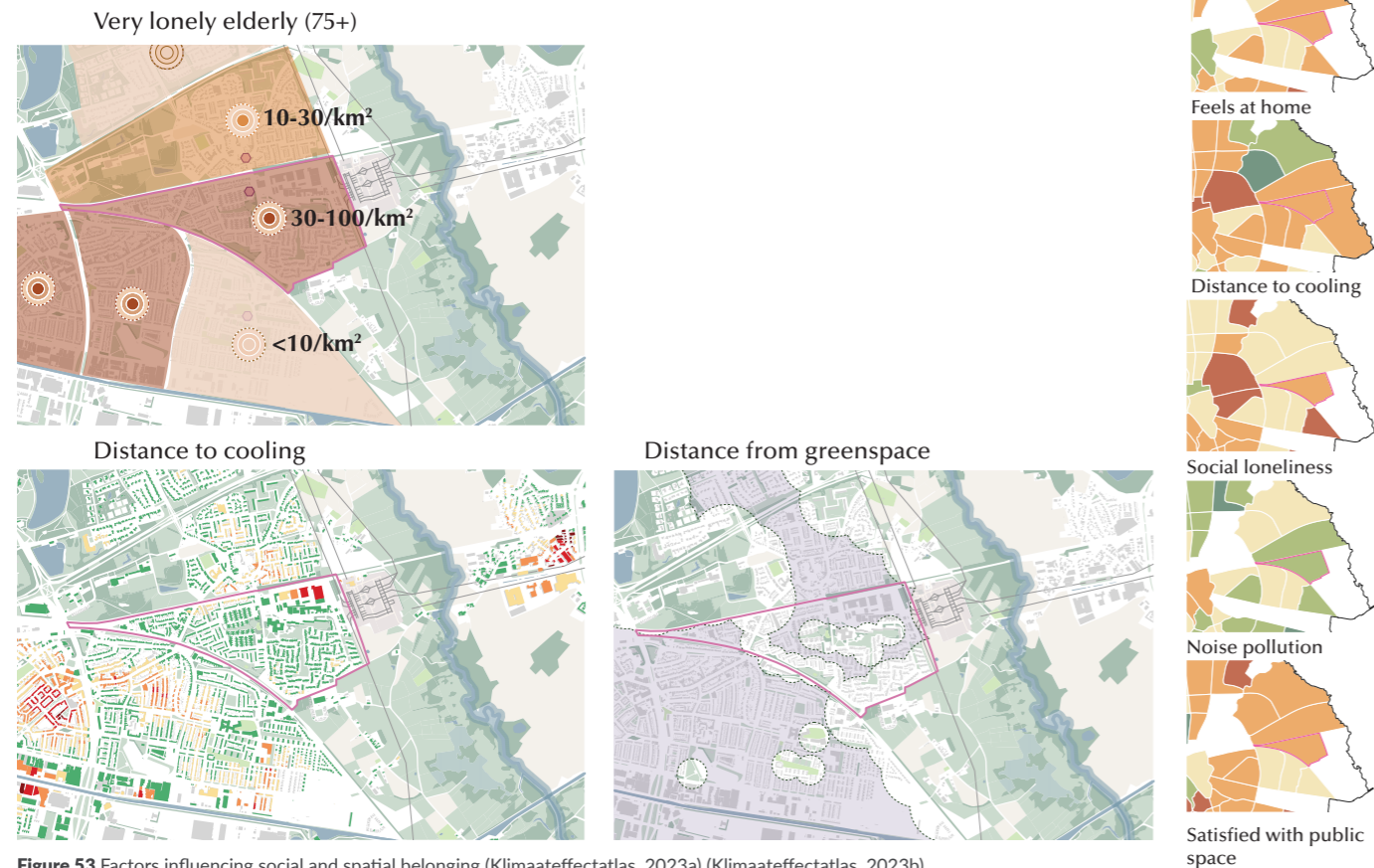


Figure 53 Factors influencing social and spatial belonging (Klimaateffectatlas, 2023a) (Klimaateffectatlas, 2023b)

Belonging
 Ⓞ 1:20.000

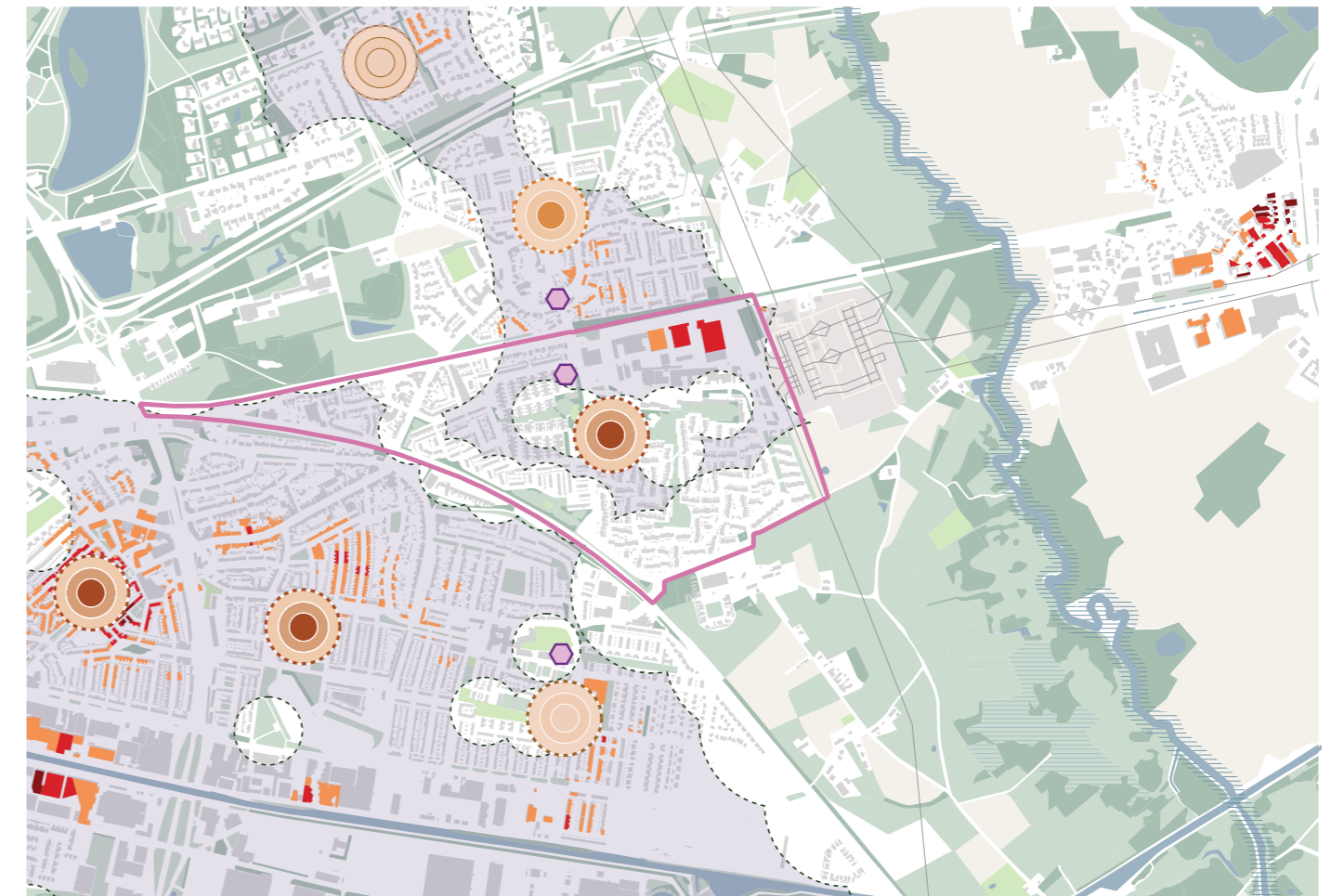
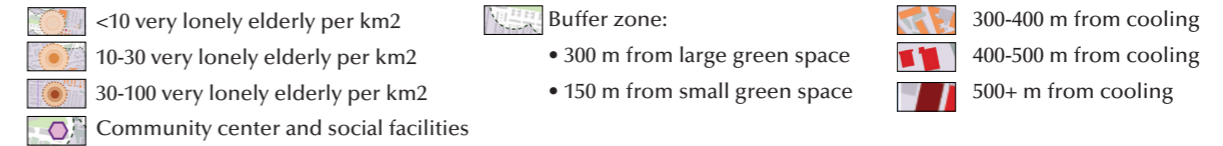


Figure 54 Belonging Muschberg, Geestenberg

8.3 Concept and framework

Based on the analysis presented in this chapter, a concept is formulated, based on the three main themes: human well-being, urban ecological resilience and densification. These are presented separately in Figure 55, these concepts are combined in Figure 56 creating the framework masterplan for the neighbourhood.

8.3.1 Densification and mobility concept

The primary focus for redevelopment and densification in the neighborhood centers on Sectie-C as a key zone. To decentralize this, additional locations within the neighborhood are identified based on current functions or need for redevelopment. Zones 1 and 2 (Figure 56) in the central area will follow the principles of Strijp-R, featuring a central green structure for leisure and connectivity. This green zone can be expansive in location 1, gradually narrowing into zone 2. A new train station, Station Sectie-C, will become the neighborhood's main public transport hub, improving accessibility. A crucial goal is to enhance walkability and cyclability by minimizing car dominance on larger roads, allocating space for diverse active mobility types, fostering a more pedestrian and cyclist-friendly environment.

8.3.2 Urban ecological resilience concept

This concept revolves around the expansion of the existing central park, creating a connection from the rural landscape throughout the entire neighbourhood. To further enhance the connectivity, the existing ecological barrier in Sectie-C will be removed by extending the green structure through this industrial zone. Finally, a Spoorpark will be implemented along the entire border of the neighborhood. This park will serve as a multifunctional space, while also providing essential buffering from the adjacent railways and improving species movement throughout the neighbourhood.

8.3.3 Human well-being concept

Lastly, the concept for human well-being emphasizes establishing an activity zone stemming from Sectie-C, linking to 't Karregat, Station Sectie-C, and the community center Orka to ensure this activity zone is extended into the neighbourhood. Additionally, the network of active green routes is expanded to encourage active recreation and connections to surrounding green recreational zones. Finally, the Spoorpark will offer leisure facilities and walking and cycling routes.

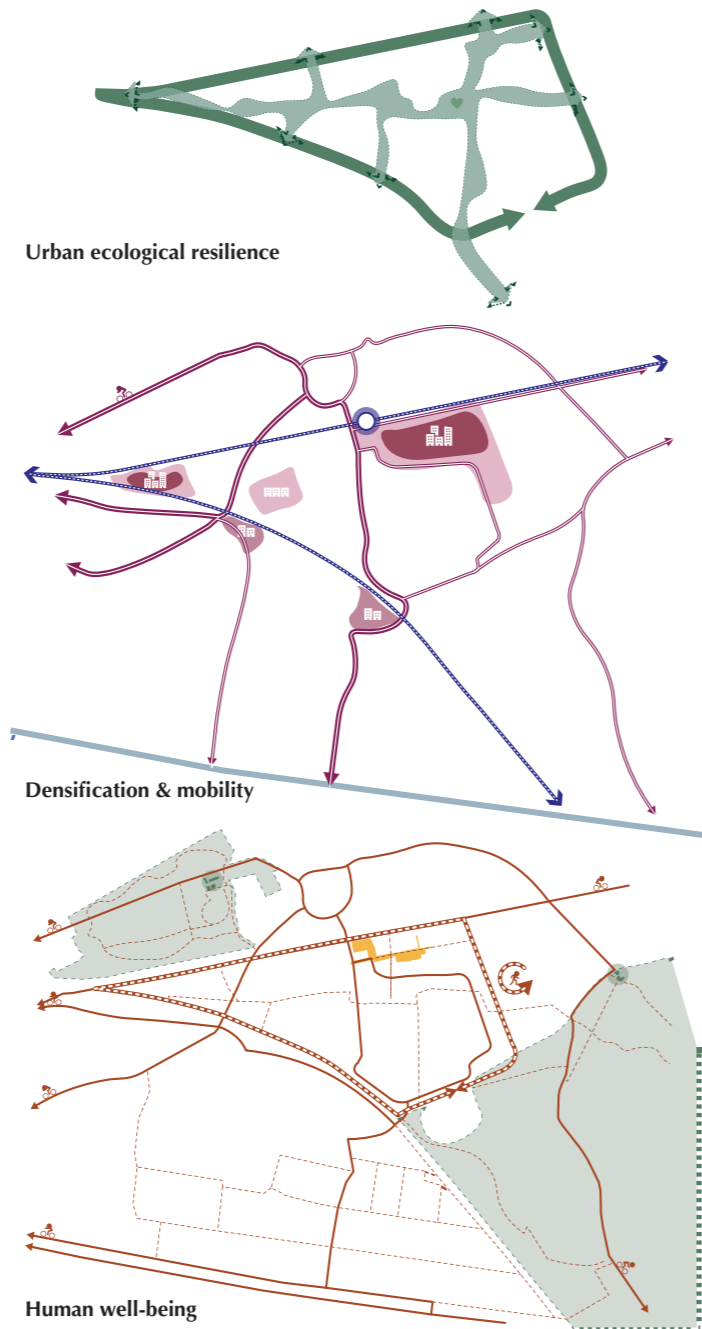


Figure 55 Neighbourhood concepts

Masterplan Framework Muschberg, Geestenberg

1:10.000

- Redevelopment zones
- Main activity zone
- Internal green structures
- Spoorpark

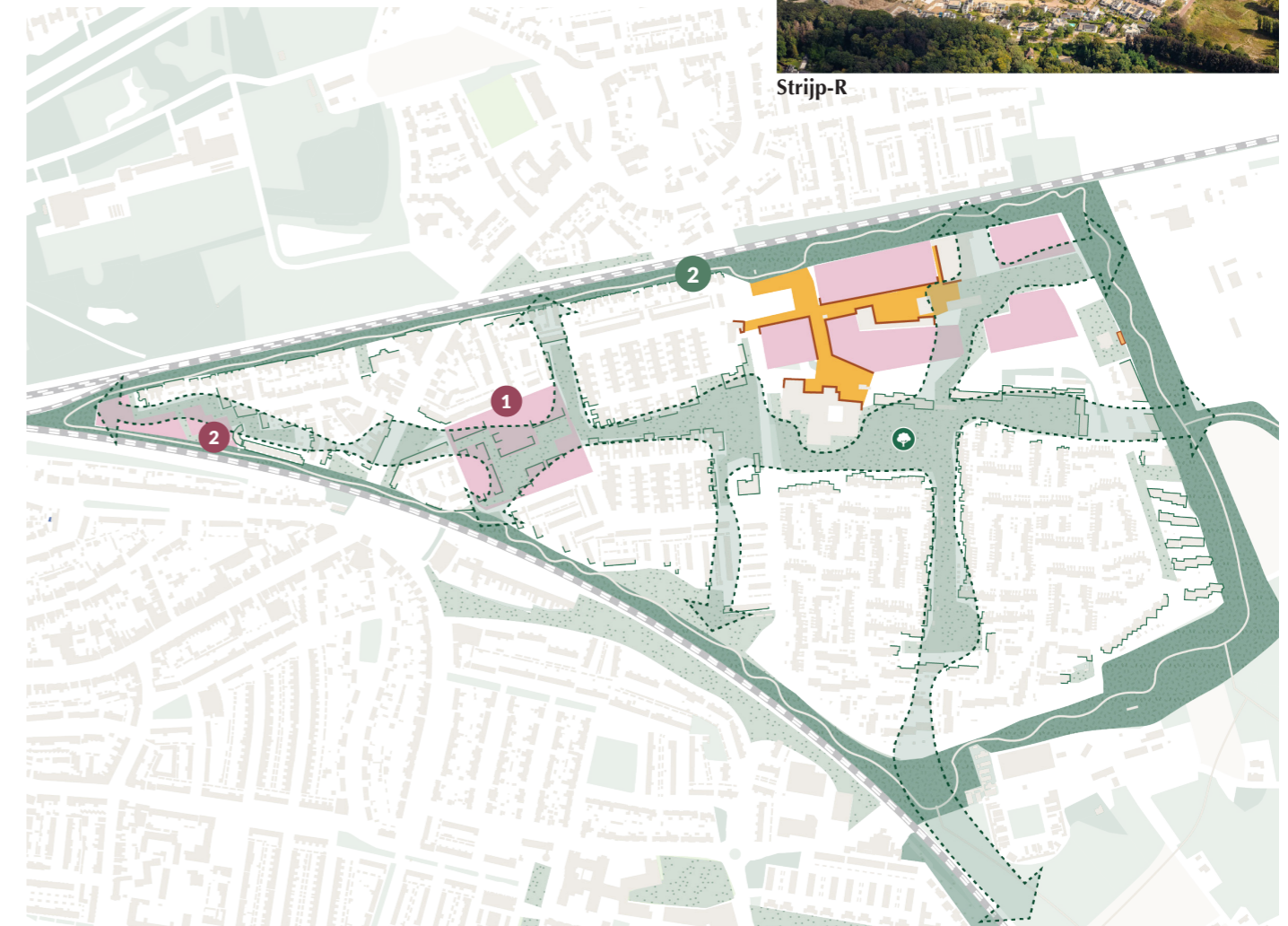


Figure 56 Masterplan Framework Muschberg, Geestenberg. Image Strijp-R (Gijssels, 2019)

9. Sectie-C

9.1 Site introduction

Sectie-C is a former industrial area in Tongelre (Figures 57 & 58), once home to the 'firma Nolte', a traffic sign production company that lost its function in 2007 (Sectie-C, n.d.). From 2010 Sectie-C has undergone a transformative journey from its industrial roots. At this time, a creative community started to settle, gradually repurposing more and more of the buildings in the area.

Currently, a characteristic combination of individual agency and strong community define Sectie-C, as described by Wassink et al. (2018). With experimentation and self-discovery as central values, the vibrant community attracts creative students and starters, eager to learn. With over 250 settled artists, designers, musicians, entrepreneurs, writers, and craftsmen currently shaping the community, Sectie-C keeps growing and evolving. With the redevelopment of this area, it is of utmost importance to acknowledge that this community is not indispensable, but the creative community should be fostered. Beyond the creative industries, Sectie-C also hosts smaller companies, a cross fit, and eateries.

Within the previously conducted analysis, key challenges for urban ecological resilience and human well-being were found. The current



Figure 57 Sectie-C site (Google Maps, 2023), scale 1:7000



With **experimentation** and **self-discovery** as central values, the vibrant community attracts creative students and starters, eager to learn.

state of urban ecological resilience can be shortly described using the three pillars for urban ecological resilience: (1) **Biodiversity**: Currently Sectie-C stads as a biodiversity gap between the city and landscape, with high potentials for the development of wet landscapes. (2) **Connectivity**: Issues with connectivity built upon this, as existing green structures fail to bridge this ecological gap by connecting Sectie-C to the landscape. The location brings the opportunity the connect the ecological structures of neighbourhood Muschberg, Geestenberg to the region. (3) **Biotic and abiotic fitness**: The former industrial site is a high-risk zones for the environment. Due to the enormous amount of sealed soils, urban heating and flooding cause problems, and due to the railway proximity without sufficient buffering, noise pollution plays a big role in this site.

Furthermore, the analysis revealed concerns related to human well-being in Sectie-C, which can also be explained through the key theme's pillars. (4) **Health**: A lack of healthcare facilities, particularly in anticipation of future densification, raises red flags. Additionally, the area shows a lacking of provided sports facilities and active recreational networks.

(5) **Social development**: The former industrial site now has very closed off borders, which causes high feelings of unsafety around the area. (6) **Belonging**: The sense of belonging is hindered by the problematic distance from cooling greenspaces and the disruptive noise from adjacent railways.

These challenges underscore the potential of implementing UGI to address both ecological resilience and human well-being in and around Sectie-C.



Figure 58 Photo impressions Sectie-C (2) (6): (Focus Real Estate, n.d.), (1) (4): (Martens & DCI Media, 2022), (3) (5): (Google Maps, 2023)

9.2 Current situation

Some spatial characteristics are important to mention. To explain these, Diagrams I to IV in Figure 59 and in the graph in Figure 60 will be referred to throughout the text. Firstly, Sectie-C is bordered from Muschberg, Geestenberg as well as from the rural regions. This isolation exists because of the following factors. Firstly, the site is fenced off and can only be accessed through the front entrance (Figure 58 image 4). Additionally, a border of privately owned companies along Urkhovenseweg is oriented away from Sectie-C (Diagram III), however also these companies are highly introverted.

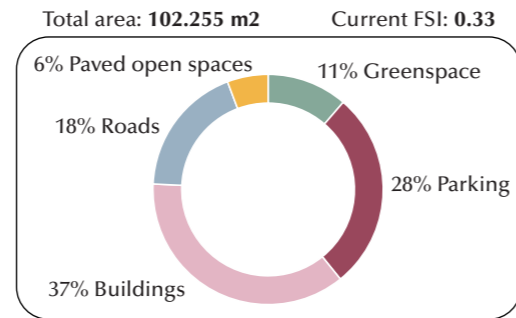
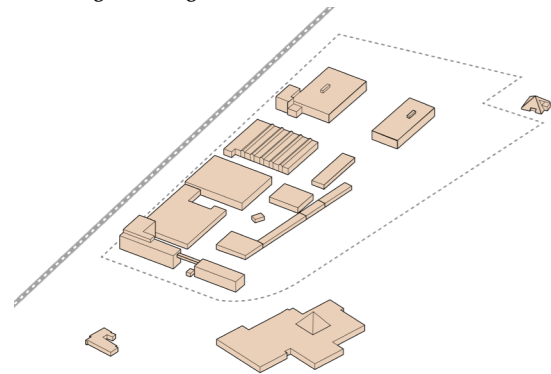
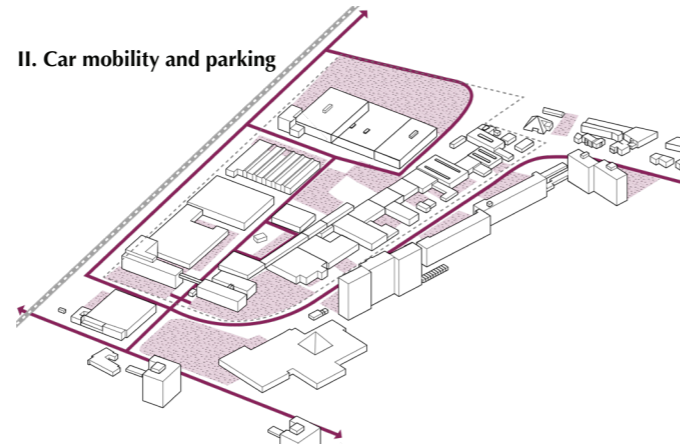


Figure 60 Current floor space division

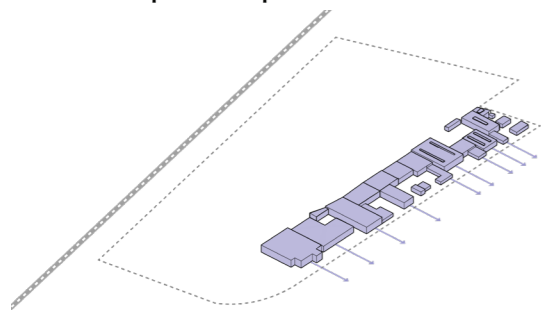
I. Heritage buildings



II. Car mobility and parking



III. Border of private companies



IV. Green structures

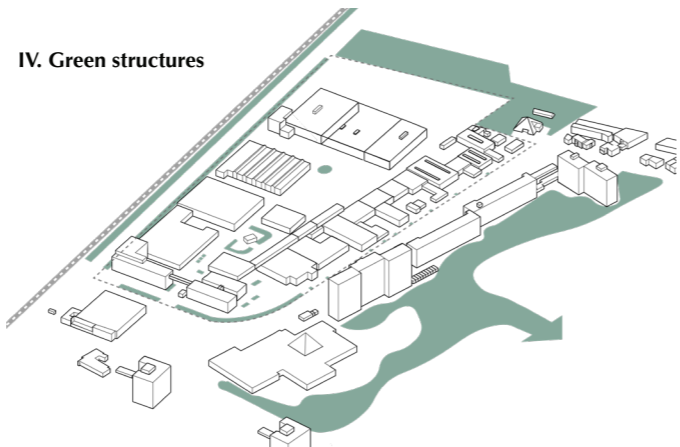


Figure 59 Diagrams Sectie-C characteristics

While some green structures do surround the area, they remain detached (Diagram IV). Within the area, the total greenspace takes up only 11% , however this is only if you count the green structures directly bordering the site. Furthermore, the area is almost completely built-up, with significantly high amounts of floor space taken up by buildings (37%), parking (28%), and unnecessarily wide roads for car infrastructures (18%). Diagram II visualizes the space taken up by car infrastructures.

Within the site, industrial heritage buildings are transformed into ateliers and workshops. A potential for redevelopment exists for many of these buildings, such as the building shown in photograph 5 in Figure 58. These buildings offer opportunities to even better accommodate these creative industries, and to introduce new public

functions within Sectie-C. Furthermore, noteworthy buildings outside the area, such as 't Karregat, community center 'De Orka,' and the facility for 'Scouting Doornakkers' (Figure 61), serve as vital hubs for Muschberg and Geestenberg residents. This is why these buildings are important hubs to connect to the redevelopment area Sectie-C.



Figure 61 Photo impressions (1) 't Karregat (Base Photography, n.d.), (2) Scouting Doornakkers (Lancee, 2012) and (3) Activiteitencentrum De Orka (Orka, n.d.)



creating

Establishing Sectie-C as the vibrant **creative and cultural epicenter** of Eindhoven, fostering and strengthening the existing **community** of artists, while providing space for free and experimental design.



visiting

Opening up Sectie-C by transforming it into an **inviting destination** that captivates its visitors with elements of **excitement and surprise** throughout the year. Enriching visitor's experience by offering a diverse range of facilities, from exhibitions to sports facilities.



living

Creating an **inclusive** living environment that prioritizes the **well-being of a diverse** residential population. Embracing the industrial character and enriching it with a variety of housing typologies.



green

Developing Sectie-C as a **green urban oasis**, in which nature is integrated harmoniously enabling residents to **connect** with green spaces within urban context. A place where a variety of species is **embraced and invited** into the fabric of the neighbourhood.

Figure 62 Vision Sectie-C. Images: creating (Fotopersburo van de Meulenhof BV, 2018), living (Studioninedots, 2014), visiting (Focus Real Estate, n.d.), green (Studioninedots, 2014)

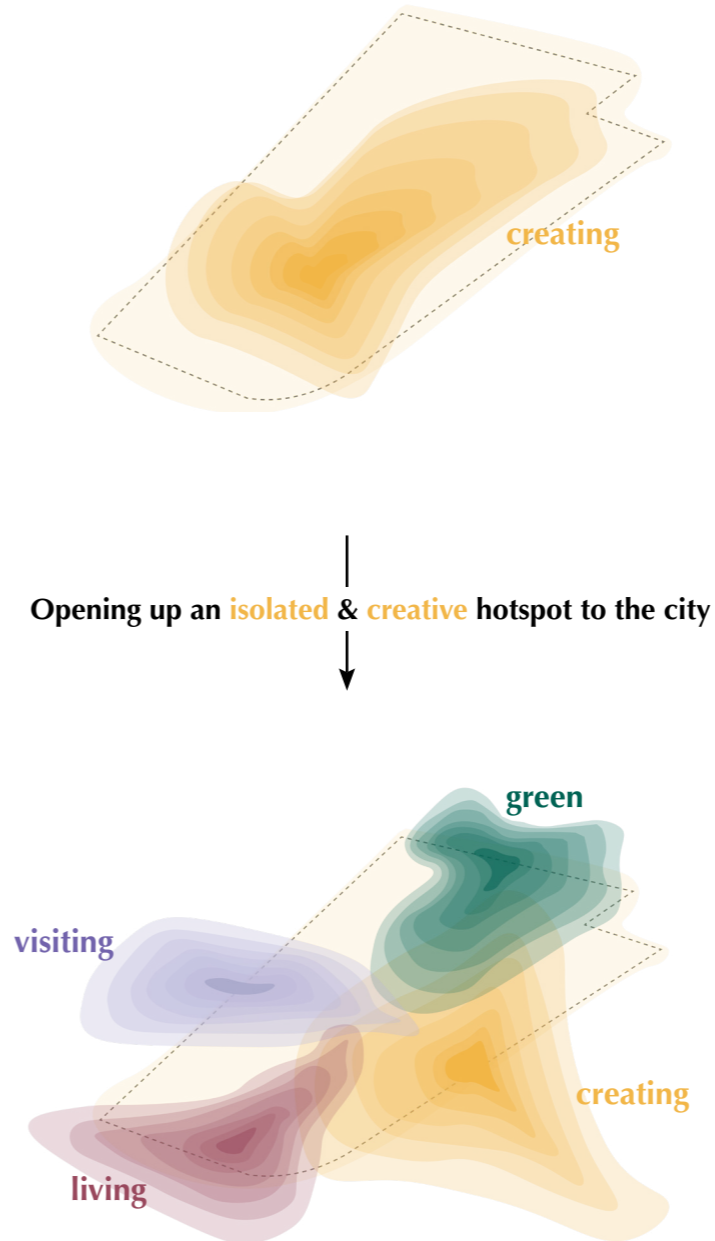


Figure 63 Design concept: Opening up to the city

9.3 Vision and concept

Based on the neighbourhood analysis of Muschberg, Geestenberg and Sectie-C's characteristics, a vision (Figure 62) and main concept (Figure 63) are created for its redevelopment. This vision and concept specifically focuses on improving the state of human well-being and urban ecological resilience in the area by inviting living and green into the area, while fostering the current creative community, and opening up the isolated creative hotspot to Eindhoven.

By the implementation of different facilities and redeveloping the current industrial heritage buildings to house the creative community, Sectie-C will become the creative and cultural epicenter of Eindhoven with space for experimenting and free design. Key in this concept is dismantling the area's isolation by opening its borders and introducing diverse facilities to showcase creative work, complemented by an array of public cultural functions.

Furthermore, housing is welcomed into the area. By introducing an inclusive and diverse range of housing and public space typologies, a diverse residential group is welcomed into the area. The emphasis is on fostering a vibrant environment that prioritizes well-being for this residential community. Crucially, the integration of urban green infrastructure takes center stage and aims at enhancing the well-being of the inhabitants as well as the urban ecological resilience, giving home to a large variety of natural species.

9.4 Principles of 'Reuring, Rust, Ruis

To translate the vision into a tailored framework for public space at Sectie-C, the 'Reuring, Ruis, Rust' principles by De Zwarte Hond (2019) are applied. This framework organizes the urban environment into three distinct zones: Reuring (activity), Rust (tranquility), and Ruis (noise). Reuring encompasses the dynamic urban life, centered around diverse activities; Ruis fosters an ambient atmosphere, addressing noise challenges; and Rust provides spaces for tranquility. These zones are all strategically organized based on urban qualities rather than strict functional boundaries.

Applying these principles to the Sectie-C (Figure 64), 'Ruis' mainly arises from the railway and car traffic. To mitigate this, buffering from the railway is needed and car traffic is to be kept to the outskirts of the area. 'Reuring' naturally emerges in and around the creative community. To strengthen this, the main activity zone will extend from this cultural center to the newly introduced Station Sectie-C, and outside of the neighbourhood, connecting communal hubs in Muschberg, Geestenberg 't Karregat and community center 'De Orka' through shared cultural programs. Furthermore, the building visible in image 5 (Figure 58) with its central location in Sectie-C is envisioned as main exposition building, enhancing opportunities for artists to present their works. Additionally, an existing square will be transformed into a cultural event garden.

Creating tranquil green spaces ensures 'Rust' in Sectie-C, connecting it to Muschberg, Geestenberg and to the rural areas. The multifunctional greenspace Spoorpark will function as buffer from the railway and provide a pleasant walking and cycling environment. To create an ecologically valuable connection from Sectie-C to the rural landscape, a wetland park is introduced in accommodating the characteristic green-blue structures of the surrounding environment. Additionally, an activity park provides a green setting for sports participation and art exhibitions. Finally, the Connect park establishes a green link between the green zones and the neighborhood park, encouraging connectivity among green structures and active transport modes.

Collectively, these Reuring, Rust and Ruis create a diverse urban patchwork welcoming creative industries, visitors, inhabitants and natural species alike (Figure 65).

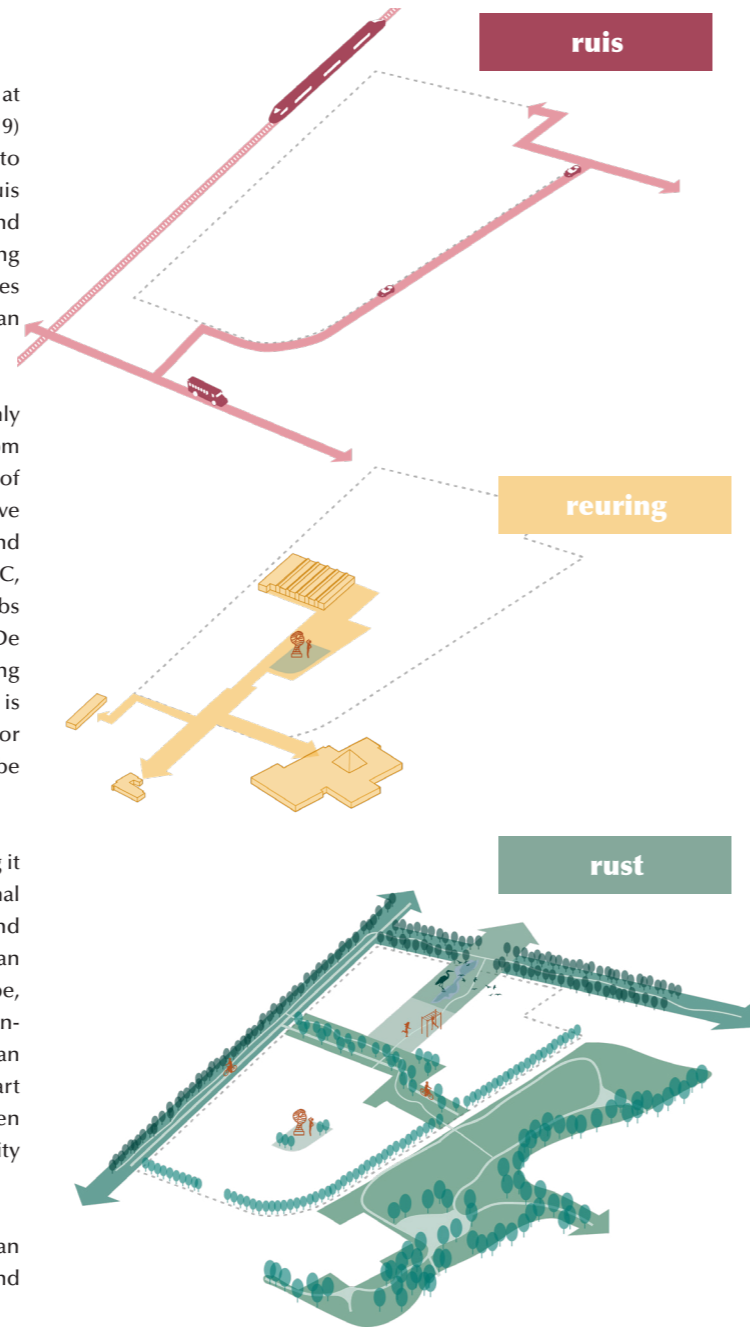


Figure 64 Application of principles for 'Reuring, Rust, Ruis' Sectie-C

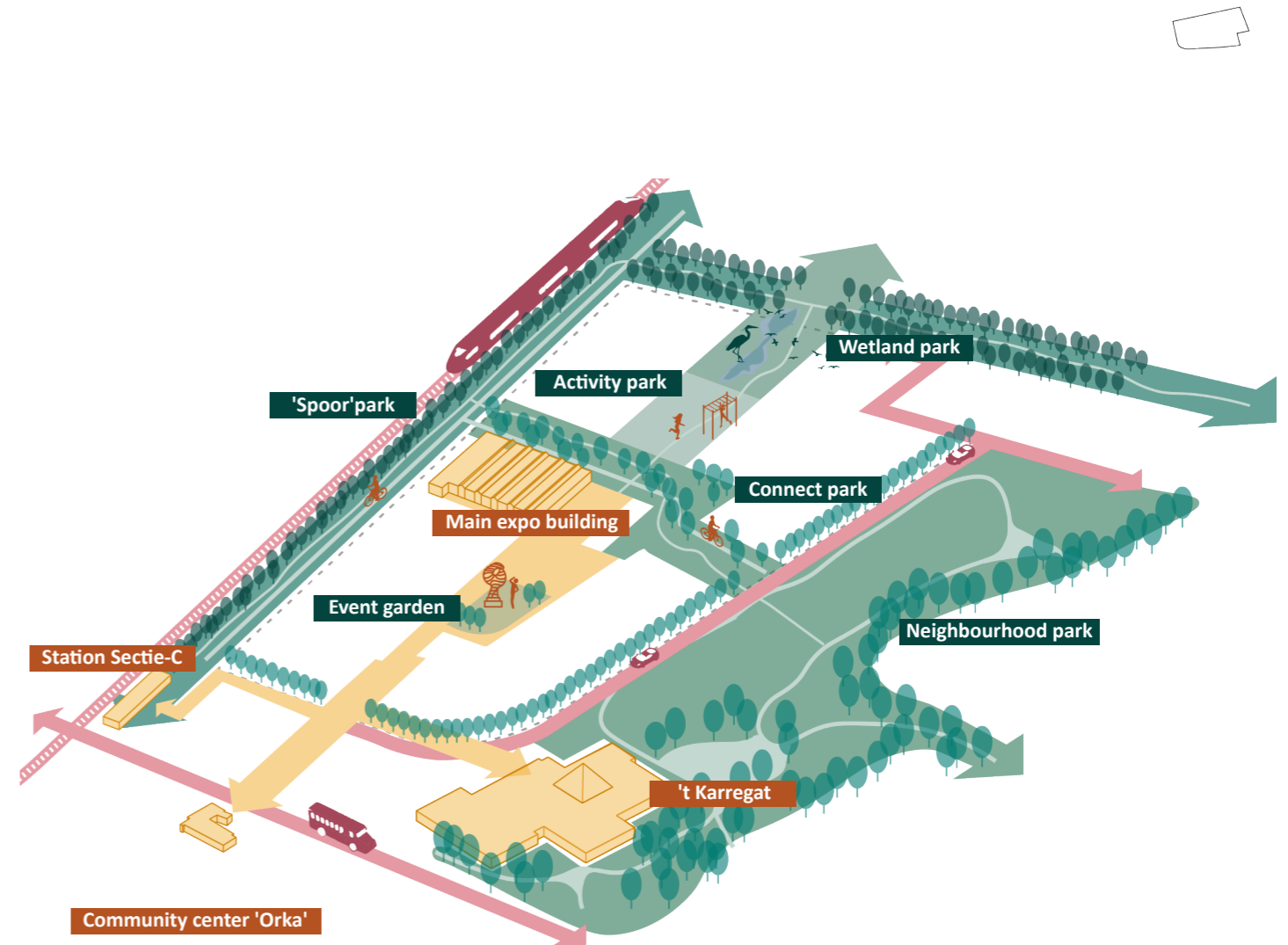


Figure 65 Public space framework based on principles for 'Reuring, Rust, Ruis'

9.5 Target groups

To cultivate an inclusive living environment that caters to a diverse residential population, Sectie-C's housing strategy encompasses a range of typologies tailored to specific target groups. Notably, 10% of the residences will be reserved for artists seeking to immerse themselves in the creative hub, with apartments featuring an additional room designed as an atelier. **Timon (30)**, an audio-visual artist, finds the Sectie-C community appealing for its shared workshop and the inspirational atmosphere created by fellow artists.

25% of the dwellings will consist of single apartments, offering individuals like **Dana (27)**, who recently returned from a yearlong travel, a private living space within an exciting and surprising urban environment. Furthermore, recognizing the growing popularity of shared living, 15% of the housing will take the form of friend apartments, catering to friend groups like **Sarah, Bregje, and Britt (20s)**,

recent TU/e graduates looking to upgrade their living space from their current student houses. Another 25% will target couples and starters, providing diverse housing options for starters couples to somewhat larger couples housing, to accommodate different generational and income groups. **Marit and Hessel (30s)** have lived together with their cat Bloom in a small apartment downtown, but are missing the proximity of greenspace and a safe environment for their cat to go outside. Sectie-C will offer them a well-balanced mix of natural surroundings and vibrant urban life.

For families of 3-4, comprising 20% of the housing, Sectie-C offers residences suited to the desires of couples like **Karlijn and Noel (35)**, who prioritize a safe environment for their two children, that is rich in arts and nature. Finally, 10% of the housing allocation is dedicated to senior living, meeting the needs of couples like **Anneke and Leen (80s)**,

who have lived a house in which they raised their three children for a very long time, but are looking to move to a smaller-scale apartment. Having visited numerous museums over the years, they find appeal in the convenience of having cultural amenities in close proximity to their home.

Bringing this wide variety of housing typologies into the area, Sectie-C can house a diverse and intergenerational community.

Single apartments



Dana (27)

Friends apartments



Sarah, Bregje & Britt (20s)

Couple/ starters housing



Marit & Hessel (30s)

Family housing



Karlijn & Noel (35), Lio (5) & Miles (3)

Senior housing



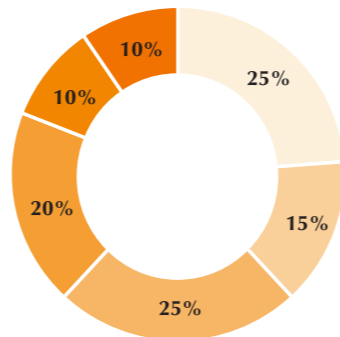
Anneke & Leen (80s)

Artist residences



Timon (30s)

Figure 66 Housing target groups



9.6 Densification and mobility strategy

Reflecting on the current state of Sectie-C as presented on page 108, together roads and parking take up 46 percent of the total land coverage. In the proposed mobility plan (Figure 67), these car-centric spaces are removed from the area all together. Instead, two mobility hubs are strategically positioned at the outskirts of the area. With the introduction of a new train station, a nearby bus station and enhanced cycling connections, the role of car mobility will diminish from the area. This measure will give precedence to public transportation and active mobility forms as the primary future modes of mobility in the area.

In addressing the integration of new functions, the redevelopment plan adopts two densification strategies (Figure 68). Heritage buildings within Sectie-C are repurposed for cultural activities, employing the 'Topping up' strategy for proper preservation, particularly along the railway. These buildings serve a dual purpose as buffers, shielding Sectie-C from railway noise. To cater to a diverse target group, the remaining plots earmarked for development are allocated to mixed typology blocks, aligned with the Cityplot Concept by Studioninedots (2014), as detailed in the upcoming section.

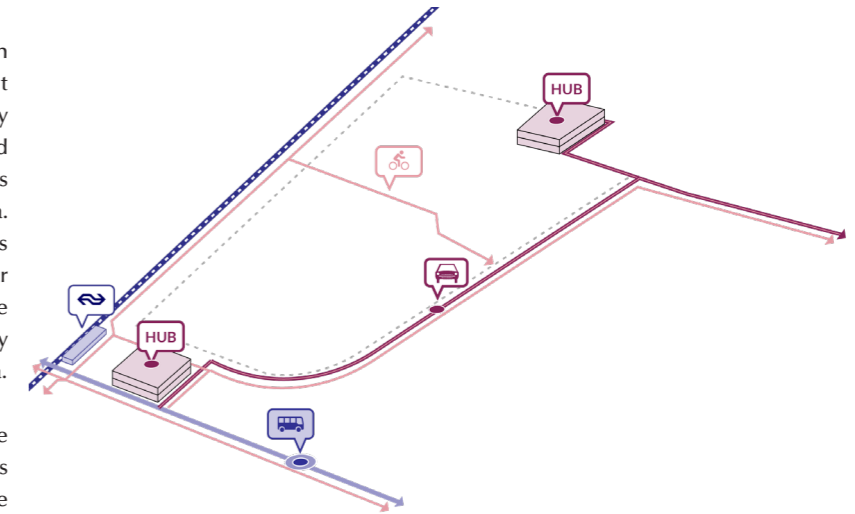


Figure 67 Proposed mobility strategy

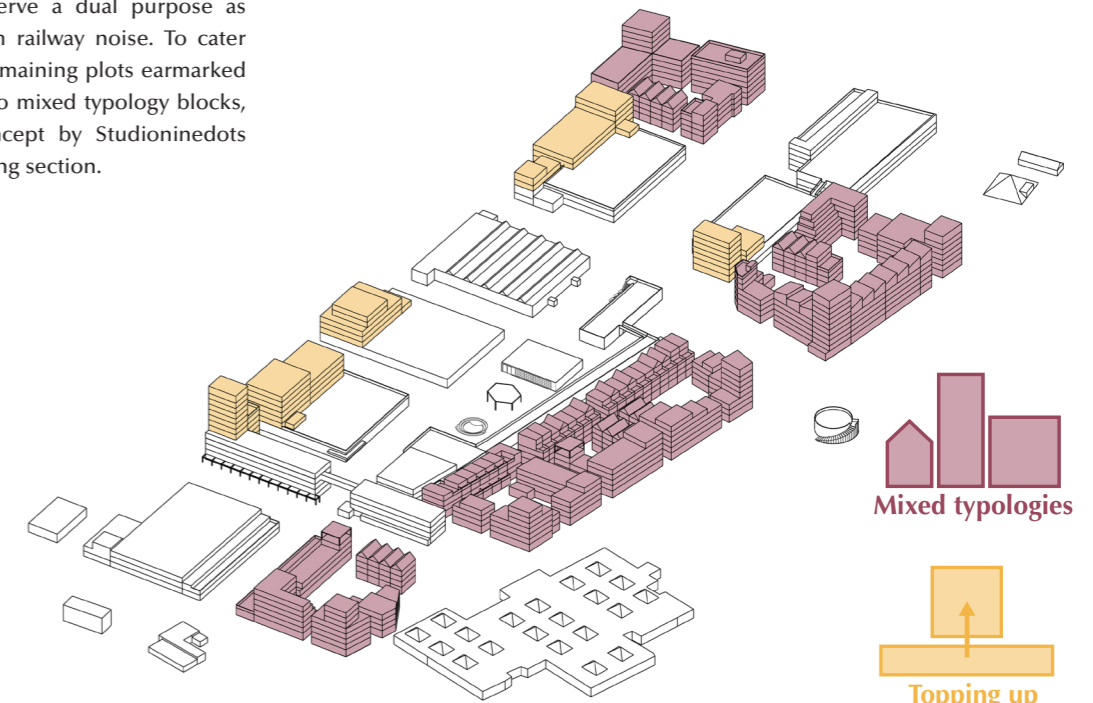


Figure 68 Densification strategies

9.7 City Plot Concept

The Cityplot Concept is created by Studioninedots (2014) and it reimagines urban planning by proposing compact, flexible city blocks that integrate diverse, small-scale, mixed-use developments. Designed around a 100x100 meter ideal plot size, this concept facilitates a dynamic layering of building typologies, accommodating self-build projects, social housing, work/home units, and social hubs. This inclusive approach engages residents, individuals, collectives, investors, and small-scale developers, fostering a sense of community participation and allowing for gradual, economically viable regeneration over time while retaining individuality within the masterplan.

Along the Urkhovenseweg, a row of privately owned companies is situated. With the redevelopment of Sectie-C, these companies will have to make way for the mixed-use developments. By applying this concept, the cityplots will be able to be developed over a longer period of time, while the companies are phasing out. With this process, it is important to assess which companies might be suited to remain within the cityplots as mixed-use functions. Additionally, this concept is applied to an empty plot bordering the Spoorpark and in front of the Karregat. These cityplots will be able to be developed at once.

These cityplots are developed based on the steps visualized in Figure 69. Firstly, (I) the plot envelopes are determined based on the existing neighbourhood framework. Secondly, (II) a flexible grid is determined, creating different building plots with a variety of programmes and housing types. Following, (III) a diversity in building blocks, formats and scales is introduced, and collectively (IV) these diverse blocks housing a variety of programmes and housing types create the urban ensemble of the city plot.

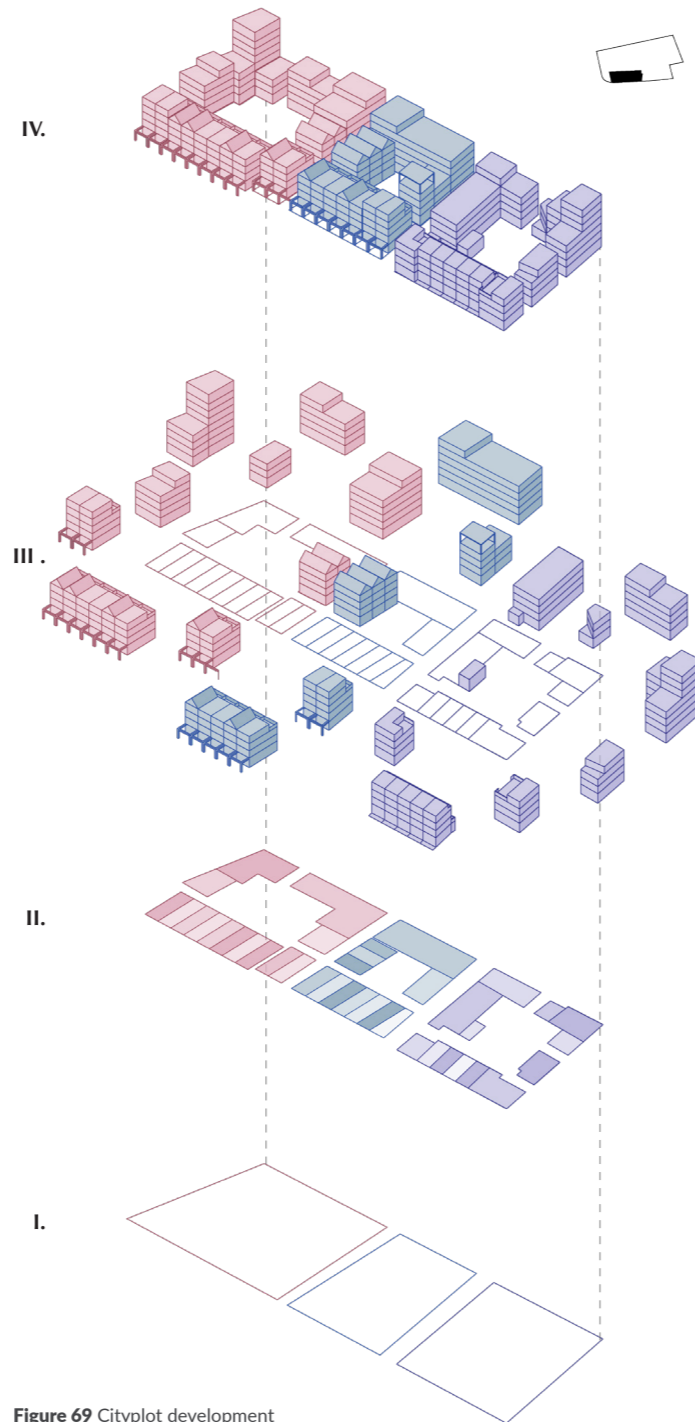


Figure 69 Cityplot development

9.8 Sectie-C development phases

Based on existing structures and planned interventions, the following sequence of development is best suited. Firstly, the mobility hubs and station can be introduced to replace the parking demand in the neighbourhood. Within this phase, Cityplots can be developed on the currently open locations. Besides, the existing atelier and workshop buildings can be redeveloped.

Within phase B focuses on the further implementation of the park areas and redevelopment of the other heritage buildings. Finally, phase C, the Cityplots can be fully developed along the Urkhovenseweg. As the border of privately owned companies needs to be phased out, this phase will start when possible and redevelop from there.

- Phase A
- Phase B
- Phase C

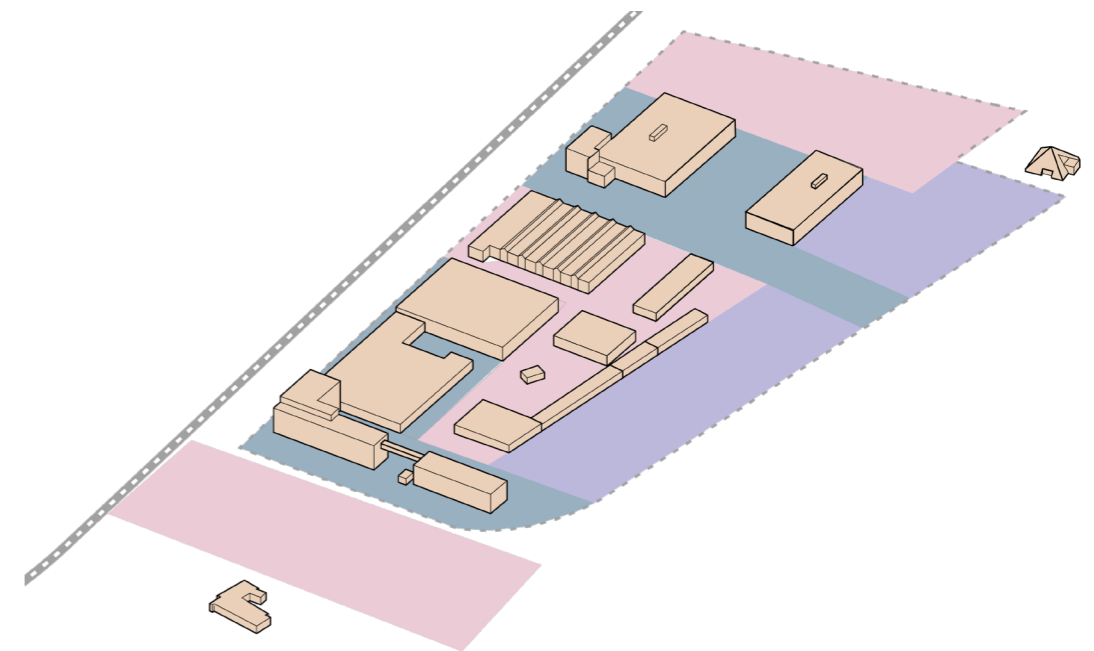


Figure 70 Sectie-C development phases

9.9 Masterplan

Figure 71 shows the proposed masterplan. This masterplan combines the public space plan created based on the principles of Reuring, Rust, Ruis.

The main activity zone connects the newly introduced train station to the creative center of Sectie-C. This zone extends along the park boulevard on the South side of the C-Park. Furthermore, this activity zone extends outside of Sectie-C, linking the Karregat and the Orka to the cultural programmes. Along the streets extending to these areas, ateliers are placed to make the building plinths more active.

Through the removal of one of the out-dated apartment buildings, the Muschberg, Geestenberg park and the green structures in Sectie-C are connected through the Connector Park. Additionally, this park connects the green structures in Sectie-C to the Spoorpark and to the region in the East.

When looking into the application of the strategies for human well-being and urban ecological resilience, this can be explained by highlighting them through the numbers in the masterplan.









The integration of the strategy (1) Multi-scaled UGI networks is applied through a sequence of different green spaces on different scale levels, ranging from green courtyards, to green pockets like the event garden, to the linear park along the railway, to the central park, and so on. Besides, the (2) introduction of UGBI becomes clear through the implementation of an infiltration strip along the railway, as well as the introduction of a new wetland park in the area. Finally, within the design and carefully deciding the nature of the newly introduced ecosystems, such as the wetland park, (3) local conditions are leading in this masterplan.

Furthermore, the linear green park and the introduction of many pathways and improved cycling infrastructure symbolize (4) UGI to encourage active lifestyles. Because of the reduction of car mobility, space is created for the implementation of green active routes. Besides, (5) greenspace equity is accounted for through the implementation of accessible green courtyards and roofs, bringing greenspace closer to home and thus minimizing the greenspace proximity. Lastly, (6) UGI

for human-nature contact is, for example, created by the introduction of zones in which activities can happen within a green environment, such as in the event garden. Where arts go hand-in-hand with a green surrounding.

Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 6
Multi-scaled UGI networks	Introduce and enhance UGBI	Local conditions leading	UGI to encourage active lifestyles	UGI for (greenspace) equity	UGI for human-nature interaction

Masterplan Sectie-C 🕒 1:3000

-  Proposed Connector park
-  Main activity zone (permeable paving)
-  Proposed Activity park
-  Proposed Wetland park
-  Proposed neighbourhood pavillion
-  Proposed elevated green rooftop walk
-  Proposed Cityplot courtyard
-  Proposed Spoorpark
-  Neighbourhood park
-  Proposed natural playground
-  Proposed mobility hub with active roof
-  Proposed residential
-  Proposed mixed-use
-  Proposed green corridor streets
-  Main road with proposed seperated bike lanes
-  Proposed seperated bike lanes

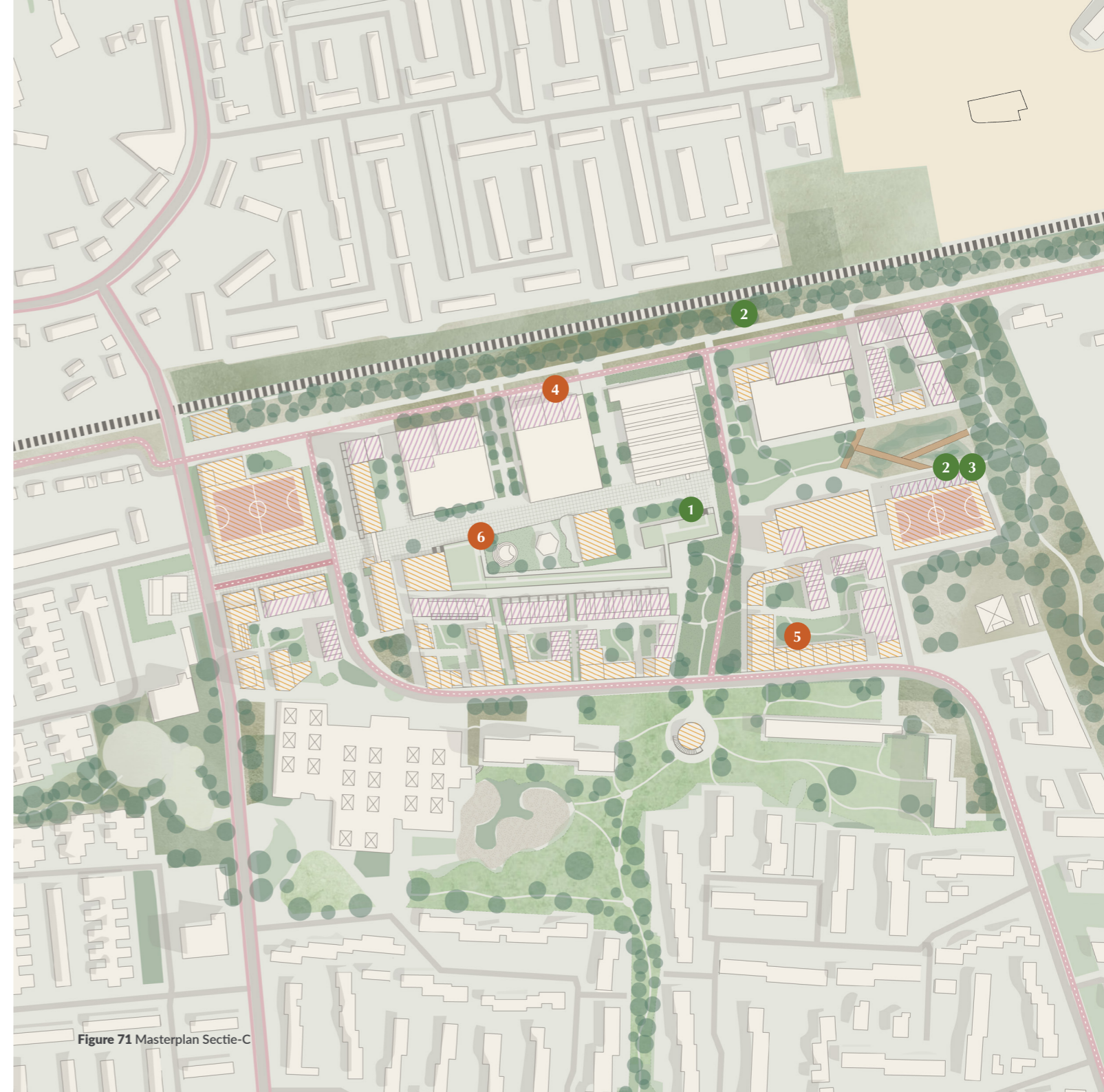


Figure 71 Masterplan Sectie-C

9.10 Cityplot

Figure 72 shows an impression section of how this sequence of three Cityplots can eventually look like, however as the layout and infill is based on a flexible grid, the actual application might differ.

The section clearly shows how each Cityplot is built around its own courtyard, in which greenspace with a communal feel is provided for the inhabitants of the building blocks. Within these courtyards there is space for relaxation, gardening, playing and creating. Along the plinths most buildings host a different function than housing, to create a mixed-use environment. Through this, space is created for functions such as the cultural industries and healthcare facilities to settle in these blocks. Through the application of the Cityplot concept, the plots are quite a private community, that are connected to the adjacent plots through intimate green streets. On the eastern side of the plots a connection is made to the park.

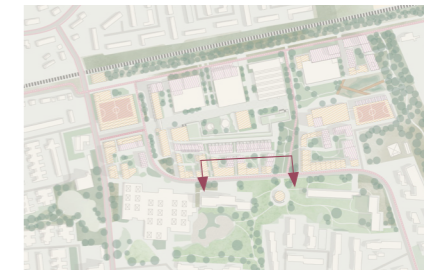
Figure 72 Cityplot impression, scale 1:400

Furthermore, an active rooftop programme is introduced on most buildings. This programme ranges from the introduction of habitat roofs, to buffering roofs, to roof gardens.

When looking into the application of the strategies for human well-being and urban ecological resilience in these Cityplots, this is explained by highlighting them through the numbers in the section below.

Firstly, (1) Multi-scaled UGI networks are introduced by creating greenspace on different implementation levels. Ranging from green rooftops, to green courtyards, which are interconnected through greened streets, connecting the plots to the larger green structures of the area. Secondly, the (2) introduction of UGBI can be seen in the application of green roofs with a buffering function. Lastly, (3) local conditions are leading in the design of the courtyards, by for example introducing communal gardens with native species.

The application of the strategies for human well-being are done as follows. Firstly, (4) UGI to encourage active lifestyles is introduced through the integration of active cycling and walking routes within green environments. Besides, (5) greenspace equity is accounted for by creating safe green environments with active social control from the plinths and street lights along the active routes. Finally, (6) human-nature contact is provided through the introduction of interactive facilities within the communal gardens, such as a small vegetable garden, but also by providing spaces for passive enjoyment.



Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 6
Multi-scaled UGI networks	Introduce and enhance UGBI	Local conditions leading	UGI to encourage active lifestyles	UGI for (greenspace) equity	UGI for human-nature interaction



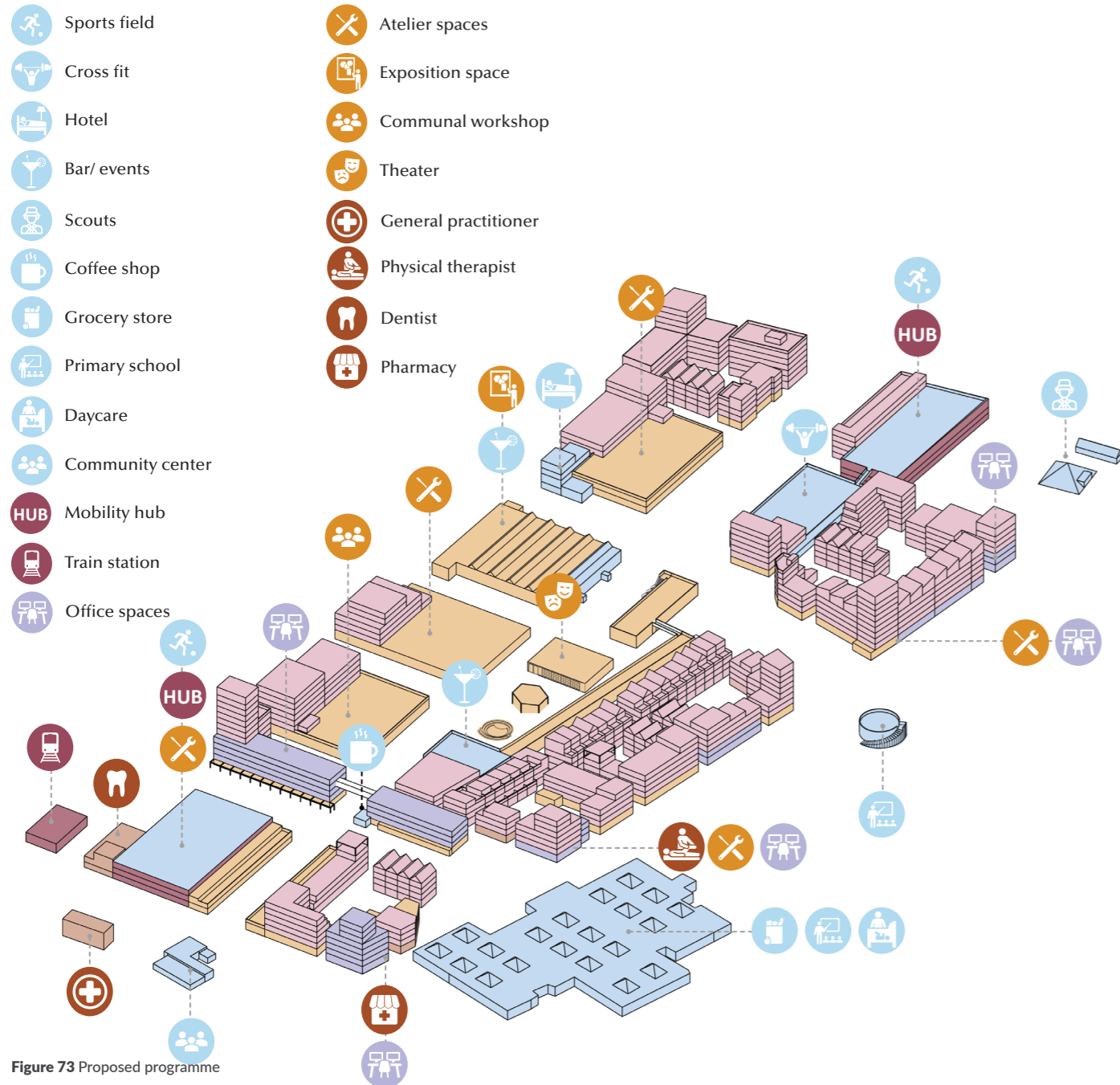


Figure 73 Proposed programme

9.11 Programme

The proposed programme (Figure 73) brings a mixed-use programme to the site in which the creative industries play a very important role. Additional atelier spaces are introduced as plinth functions in buildings throughout the entire area, with large windows to create a lively and diverse street scape. Also, more public functions complementing the creative community are introduced, such as the theater, main exposition building and communal workshop. Altogether, the amount of floorspace dedicated to the creative industries is almost doubled from 12.705 to 10.685 square meters (Figure 75).

The main programme that is introduced is a residential programme. Ranging from more metropolitan apartments along the railway to more community focused Cityplot developments, housing is provided for diverse socio-demographical and intergenerational groups. Out of the total added programme, 57% is residential (Figure 75).

Furthermore, to invite more visitors, the social and recreational facilities are boosted by introducing functions such as a coffee shop, sports facilities and a hotel. In total, 13% of the added floorspace is dedicated to this typology. Additionally, another 13% of the added floorspace is dedicated to office and work spaces. Inviting different smaller companies into the area.

To facilitate a mobility transition away from the car, mobility hubs and Station Sectie-C are introduced.

Existing creative industries:	12705 m ²
Total area:	89.255 m ²
Total added programme:	168.029 m ²
Residential	95.875 m ²
Social and recreational	31.310 m ²
Creative industries	10.685 m ²
Office space	21.129 m ²
Healthcare	4.680 m ²
Mobility	14.350 m ²

Figure 75 Total added floorspace per programme

Finally, to accommodate the growing population residing in the area, additional healthcare facilities are added: a general practitioner, a dentist, a physical therapist and a pharmacy. This pharmacy is strategically positioned across the grocery store.

With the proposed redevelopment plan, the current greenspace will be quadrupled (Figure 74).

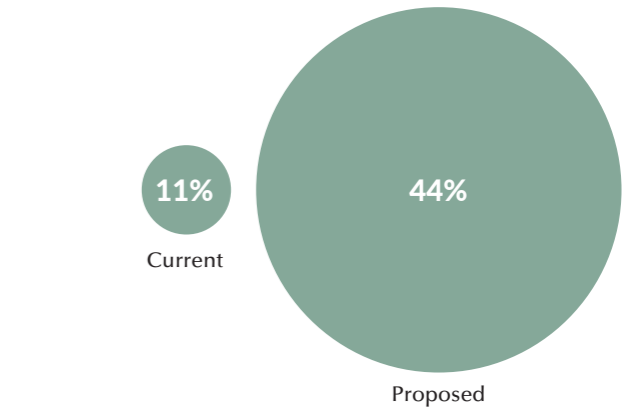
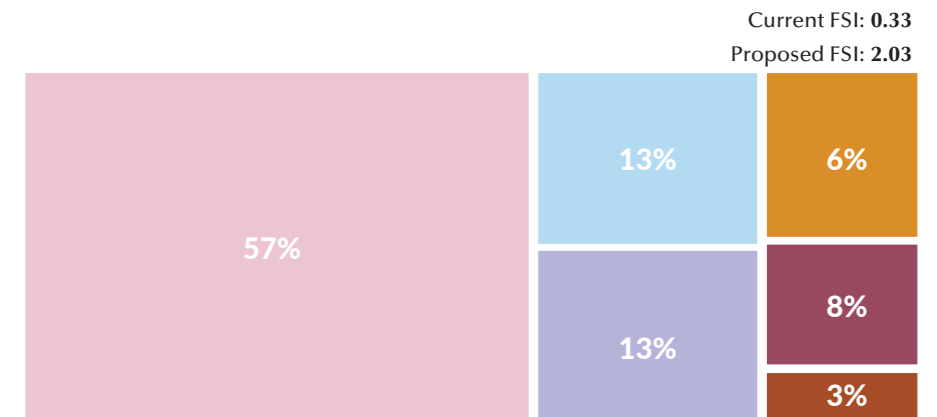


Figure 74 Total added green on groundlevel



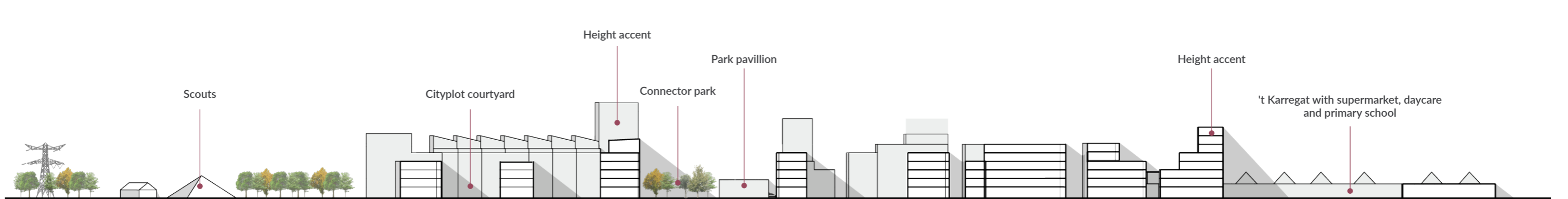
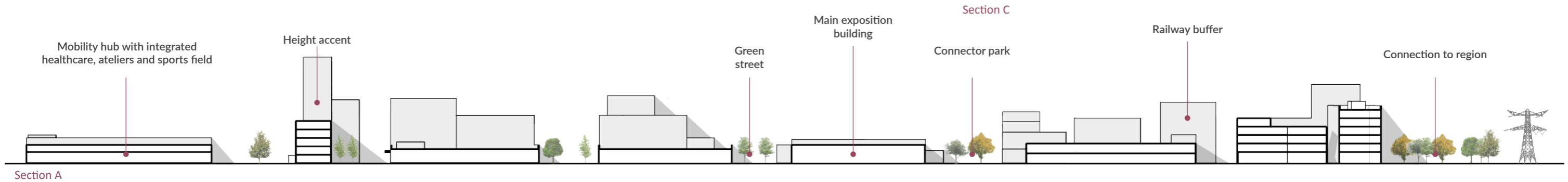
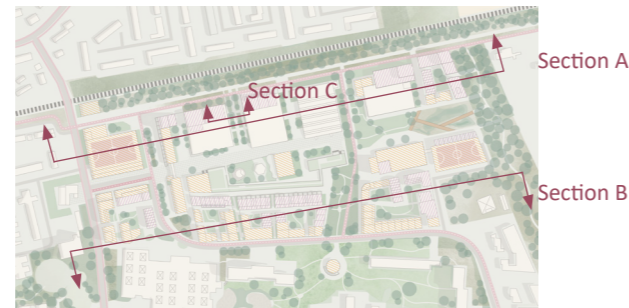
Current FSI: 0.33
Proposed FSI: 2.03

9.12 Urban sections

Section A and B in Figure 76 show longitudinal sections through the proposed Sectie-C development. Section A shows the large to be redeveloped buildings in which ateliers, the communal workshop and the main exposition building are situated. Furthermore, it shows how these existing buildings are topped up by residential towers, providing buffer from the railway. At the most western side, the mobility hub in front of the station is visualized and the entrance to Sectie-C is marked with a height accent. The most eastern side shows the connection to the region.

Section B shows the section through the line of Cityplots, showcasing a more diverse and mixed typology. On the most eastern edge, the scouts have remained their activity garden, which connects to the courtyard of the adjacent Cityplot. Along the Connector park, a height accent is placed, marking the edge of the site. Within the neighbourhood park, a park pavillion is introduced. Finally, another height accent is placed at the edge of the Cityplot along the road and 't Karregat.

Section C shows a green corridor street from the main activity zone to the Spoorpark.



Section A
Section B
Figure 76 Longitudinal urban Section A and B Sectie-C, scale 1:3000, and green corridor street section, scale 1:300

9.13 Event garden

The event garden (Figure 78) will serve a variety of purposes. On regular days, it provides a green outdoor setting for visitors to observe artists at work through the open windows along their ateliers, or working outside in the garden. Local artists have the opportunity to showcase their creations, turning the garden into an open-air art gallery. The garden features special meeting spots such as the garden pavilion and the garden amphitheater. During warmer days, these can be used to have barbecues and outdoor movie screenings.

The rooftop above OST (event location) and the existing ateliers will be repurposed into a green rooftop walkway, offering an elevated view of Sectie-C, the parks, and the event garden.

By highlighting several parts of the park, examples of the application of the main strategies for UGI are visualized.

The integration of (1) multi-scaled UGI networks is visible on a smaller scale through interventions like the insect hotel in the garden and integrated nesting stones for bats, and on a larger scale by the introduction of the elevated green rooftop walkway. Additionally, (2) UGBI is embodied in the garden amphitheater, which serves as a water retention zone during periods of heavy rainfall. (3) Local conditions are leading when creating the habitat roof above the theater space, incorporating elements specifically to support local bird and insect species.

(4) The incorporation of UGI to promote active lifestyles becomes clear through the introduction of the green walkway, encouraging walking as an active leisure. Additionally, (5) greenspace equity is achieved by integrating seating options within the garden. Finally, (6) UGI for human-nature contact is fostered through the introduction of a series of stepping stones, inviting active engagement with nature.

Altogether, the integration of these UGI interventions help steering towards achieving the six strategies and promote both human well-being and urban ecological resilience. At the same time, the green setting supports the creative community of Sectie-C.



Figure 77 Reference image: Hotel Hofbogen (AtelierRuimDenkers, n.d.)

Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 6
Multi-scaled UGI networks	Introduce and enhance UGBI	Local conditions leading	UGI to encourage active lifestyles	UGI for (greenspace) equity	UGI for human-nature interaction



Figure 78 Axonometric impression of the Event Garden

9.14 C-PARK

The new park in Sectie-C is named 'C-PARK' after its location, and is visualised in Figure 80. Within this park, an ecologically valuable connection is established to the rural landscape through the wetland park by applying characteristic green-blue structures of the surrounding environment. The focus of this wetland park lies in creating a tranquil, relaxing, and beautiful surrounding for the inhabitants as well as high-quality habitat for species.

The activity park accommodates a green setting for sports and allows the CrossFit club to conduct sessions outdoors. Furthermore, sports equipment is applied so people can have workouts with a nice view and in a cool environment. Additionally, small paved podiums throughout the activity park allow for public displays of art creations. Zooming in on several parts of the park, examples of the application of the main strategies for UGI are visualized (Figure 79).

Image I shows how in and around the park a (1) multi-scaled network of UGI is integrated, ranging from an integration on the building scale in which a brown roof, integrated nesting, and facade gardens are applied, to a larger scale on which a wetland park creates a connection to the region. Furthermore, this image shows how (3) UGBI is introduced in the area. This is done by anticipating the (3) local conditions of the green-blue surrounding region (Urkhovense Zegge, Kleine Dommel valley).

Image II shows that possibilities are included for the (4) promotion of active lifestyles within the green surroundings of the park. Furthermore, (5) greenspace inclusivity and equity are ensured by, for example, the integration of wheelchair-accessible pathways in and around the park.

Image III shows the integration of native species into the design of the green spaces for which (3) local conditions are leading. Additionally, it shows the integration of elements such as furniture into the park, corresponding to the creation of (5) greenspace inclusivity and equity by making it more accessible for all different types of age groups. Finally, (6) it shows how the park promotes contact between humans and nature.

Collectively, these applications of the six strategies through different UGI interventions boost the state of human well-being and urban ecological resilience in Sectie-C.

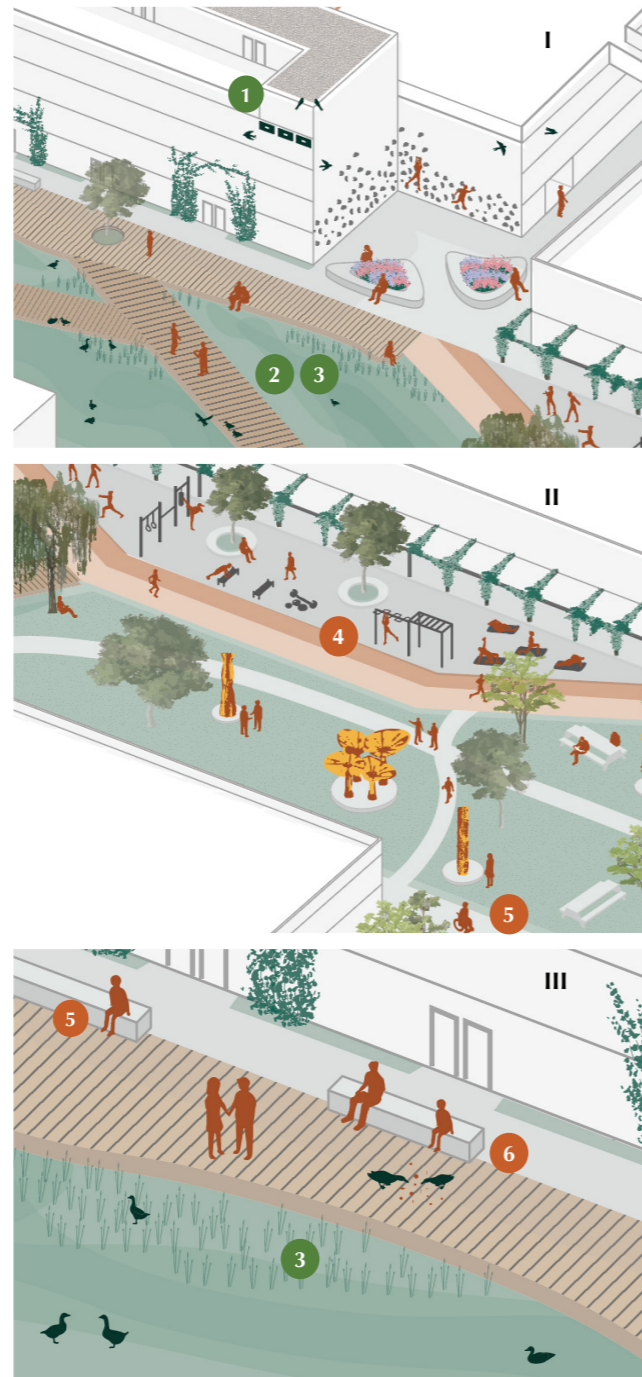


Figure 79 Zoom-ins C-park

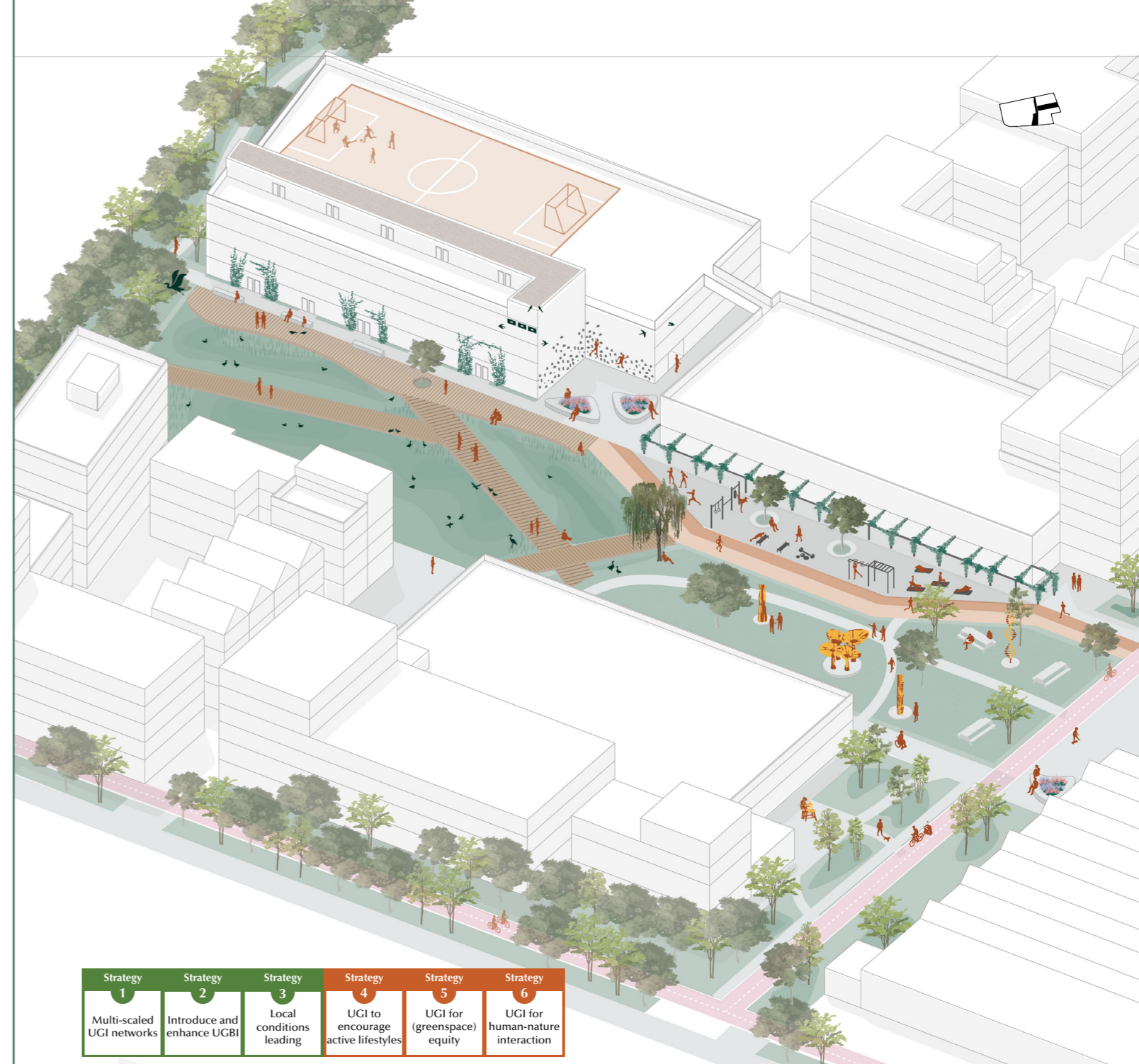


Figure 80 Axonometric impression C-park

9.15 Spoorpark

Figure 81 shows the section from the railway to the main activity zone, showing the plans for the redevelopment of 'building 8' into the main exposition building, including a museum café with a view over the parks. If you look closely, you can see that there is an exposition on bio-art happening...

By highlighting the following UGI in the section, the integration of the six strategies can be explained.

The integration of (1) multi-scaled UGI networks can be found on different scale levels in this section. Integrated on the building level is a green roof, and the Spoorpark exemplifies a green-blue connecting corridor along the linear railway. The strategy of (2) introducing and enhancing UGBI is applied through the introduction of an infiltration zone along the railway, attracting a variety of species such as the heron.

Figure 81 Spoorpark section, scale 1:300

Within the design of the Spoorpark (3) local conditions are leading in the choice of native flora species that complement and enrich the existing ecosystems.

Furthermore, (4) active lifestyles are encouraged by the introduction of a wide path, suitable for walking and running. In summer this pathway will be nice and cool. Within the Spoorpark, (5) inclusivity and greenspace equity is ensured by implementing street lighting, making it a safer space for different users. Finally, human-nature contact is encouraged by providing slow active mobility modes. Going for a stroll along this pathway will ensure different encounters with the ecosystems of the Spoorpark.

9.16 Entrance

Figure 82 on the next page shows how the entrance of Sectie-C will be transformed into the impression visible on the following page (Figure 82). This figure shows the characteristic entrance to Sectie-C with its blue bridge and the 'Portiershuisje', which is transformed into a coffee shop as a welcome to the area. The plinths of the two office buildings are transformed into atelier spaces with a small outdoor threshold area.

An active cycling and walking route brings you from the entrance of the area into the neighbourhood, to the city center or right into the region. When looking into the area, the elevated green walkway is

revealed, the parks are visible in the background and surprising art pieces are scattered around.

To highlight how the strategies for the implementation of UGI are implemented, interventions are highlighted in the image. Firstly, (1) multi-scaled UGI networks range from integrated nesting facilities, to a green street corridor connecting to the Spoorpark. Furthermore, (2) UGBI is integrated by the addition of permeable paving, buffering roofscapes and by improving infiltration possibilities at ground level. Lastly, (3) local conditions are leading when supplementing the space with habitat elements for native plant and tree species.

Additionally, (4) active lifestyles are encouraged by introducing green active routes. (5) UGI for greenspace equity is realized by introducing different types of elements to the public spaces, such as benches. Finally, (6) human-nature contact is facilitated by creating an environment enriched with different types of elements for humans and species, allowing for them to meet.

Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 6
Multi-scaled UGI networks	Introduce and enhance UGBI	Local conditions leading	UGI to encourage active lifestyles	UGI for (greenspace) equity	UGI for human-nature interaction





Figure 82 Sectie-C entrance



10. Critical reflection design

The objective of this thesis was to develop a strategy to enhance both human well-being and urban ecological resilience in densifying areas, through the integration of UGI. A final overview showing which UGI interventions have been implemented in the design area can be found in Appendix B.2. This overview visualizes the studied UGI interventions per scale level and their potential connectivity, as outlined in the Urban Green Guide. Besides, Figure 83 shows this overview of integrated UGI and their corresponding scores. This shows, when only counting each intervention once, that the total increased score for human well-being is 115 and for urban ecological resilience 114. This shows that the implementations of UGI interventions benefit human well-being and urban ecological resilience almost equally.

Within the city scale analysis phase of this study, the current states of human well-being and urban ecological resilience are analyzed on the city scale, comparing the overall state of the neighbourhoods. Within this process, a selection of datasets has been used to base the conclusions on, however if other datasets had been used, different outcomes of the current state of human well-being and urban ecological resilience could have come about.

Furthermore, in the city strategy for densification, the projected densification aim was to achieve an FSI of 3-4 in Sectie-C, however the FSI proposed in the design phase comes at 2.03. Within future re-alterations of the redevelopment of the building masses along the Spoorpark, the FSI could be increased by adding additional height and masses to the topped up buildings. Besides, due to the flexibility of the Cityplots, the density of these housing blocks could also be increased. Building on the elaborate neighbourhood analysis, a masterplan framework for Muschberg, Geestenberg is proposed. Within this study only a clear masterplan is worked out for the Sectie-C area in this plan, however a masterplan encompassing the entire neighbourhood would be a great addition.

Within the design, the most attention has been paid to the development of Cityplot housing and the layout of the greenspaces. However, further attention could be given to the specific design of the main activity zone as well as to the development of the introduced buildings according to the strategy topping-up.

Finally, a more specific idea of how the different target groups and corresponding housing typologies are applied in the area would clarify the integration of the diverse target groups.

Additionally, attention should be paid to the financial feasibility of the large cultural community residing in a redeveloped area. As a neighbourhood improves, prices go up. This could be problematic for the artists renting spaces. One of the powers of Sectie-C is the young community that is excited to develop themselves to become professionals. For this reason, research into a working system for feasibility is needed. An example of this could be that to live within the area inhabitants should be prepared to pay a little extra to collectively subsidize the artists partly for their workspaces. Another option could be making it the responsibility of the building owners to keep the prices for the ateliers and workspaces low.

This brings up the topic of gentrification and urban greening, which often go hand in hand. This is a problematic relationship, because as main strategy 5 also states: 'UGI to create environmental justice and greenspace equity'. Urban green has the potential to make living environments a lot more pleasant for its inhabitants. Usually it is the people from lower socio-demographic groups that need the benefits that urban green brings the most. This is a topic of high importance for future research and redevelopment projects.

Let's make urban greening a given.

Table Overview of implemented UGI with corresponding total score

Applied UGI interventions	Scoring human well-being	Scoring urban ecological resilience
Green roofscapes: green, brown, water roofs, sky garden, roof garden [SS]	5	5
Green gardens: green courtyards, green residential yards, private gardens, front gardens [SS]	5	5
Vertical greenery: façade gardens, green walls and façades [SS]	4	4
Balcony greenery and window boxes [SS]	3	2
Integrated nesting facilities, insect hotels [SS]	3	5
Small-scale green-blue spaces, e.g. ponds [SS]	3	5
NBS: e.g. permeable paving, raingardens, bioswales [SS]	5	5
Vegetated tree discs and spontaneous vegetation[SS]	3	5
Ornamental plantings (e.g. planters, grasses, pergola's or scaffoldings) [SS]	3	3
Centralize parking and converting on-street parking into UGI [SS]	3	3
Dense, diverse and layered patches of native flora species: e.g. hedges, bushes, shrubs, grass, flowers [SS]	5	5
Maximizing street furniture and amenities in UGI (e.g. benches, water fountains, bike parking, street lights) [SS]	5	0
Green fine-grain basis network for slow traffic [SC]	5	5
Layered green space through accessible greenways on rooftops [SC]	3	4
Diverse canopy of street trees [SC]	2	3
Greening of streets and alleyways [SC]	5	5
small urban parks (SUPs), pocket parks, green squares, urban gardens, playgrounds [NS]	5	5
Communal gardens, allotments, communal farms, communal orchards [NS]	5	5
Greening blue corridors, e.g. canals [CC]	5	5
Main green network for slow traffic, maximizing width (walking, cycling, jogging) [CC]	5	5
Greening along linear elements, e.g. boulevards, canals, railways [CC]	3	3
Public city parks, waterfront parks, gardens, green squares and plazas, etc. [CS]	5	5
Urban wetlands, urban wetland parks [CS]	5	5
Green urban sporting locations, e.g. golf courses [CS]	5	2
Green-blue corridors at region scale: e.g. rivers, canals [RC]	5	5
Green belts, green wedges, connecting to the region [RC]	5	5
Designing for region-wide green fast cycling routes [RC]	5	5
Total score	115	114

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Appendix

- A** Reference sources and DID classification
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- A** Reference sources and DID classification
- A.1 References systematic literature review

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A Reference sources and DID classification

A.2 References handbook review

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A.3 References policy review

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B Relation matrices

B.1 Relation matrix layout

The UGI interventions found in the literature and handbook review, and the sources in which they occur, have been placed in rows. To show the quality of the relationship of these interventions with the key concepts, the main pillars of these key concepts (Table B.1.1) have been placed in columns.

To provide an overview of the scale levels at which the interventions operate in a city, a column has been dedicated to linking the interventions to UGI-network scale levels. These scale levels are based on the UGI-network layers as presented in Table 3 on page 19. Additionally, another column specifies the nature of the interventions, distinguishing between spatial and non-spatial.

The qualitative data is presented in the cells of the matrices shows explains the relation between the interventions and the pillars of the key concepts. If no relation is identified within literature and handbooks, the cells are left blank. The nature of the relations is classified based on the data presented in the cells, based on the classification in Table B.1.2.

Table B.1.1 Pillars for human well-being and urban ecological resilience

Human well-being	Urban ecological resilience
<ul style="list-style-type: none"> • Health • Social development • Belonging 	<ul style="list-style-type: none"> • Biodiversity • Connectivity • (a)Biotic fitness

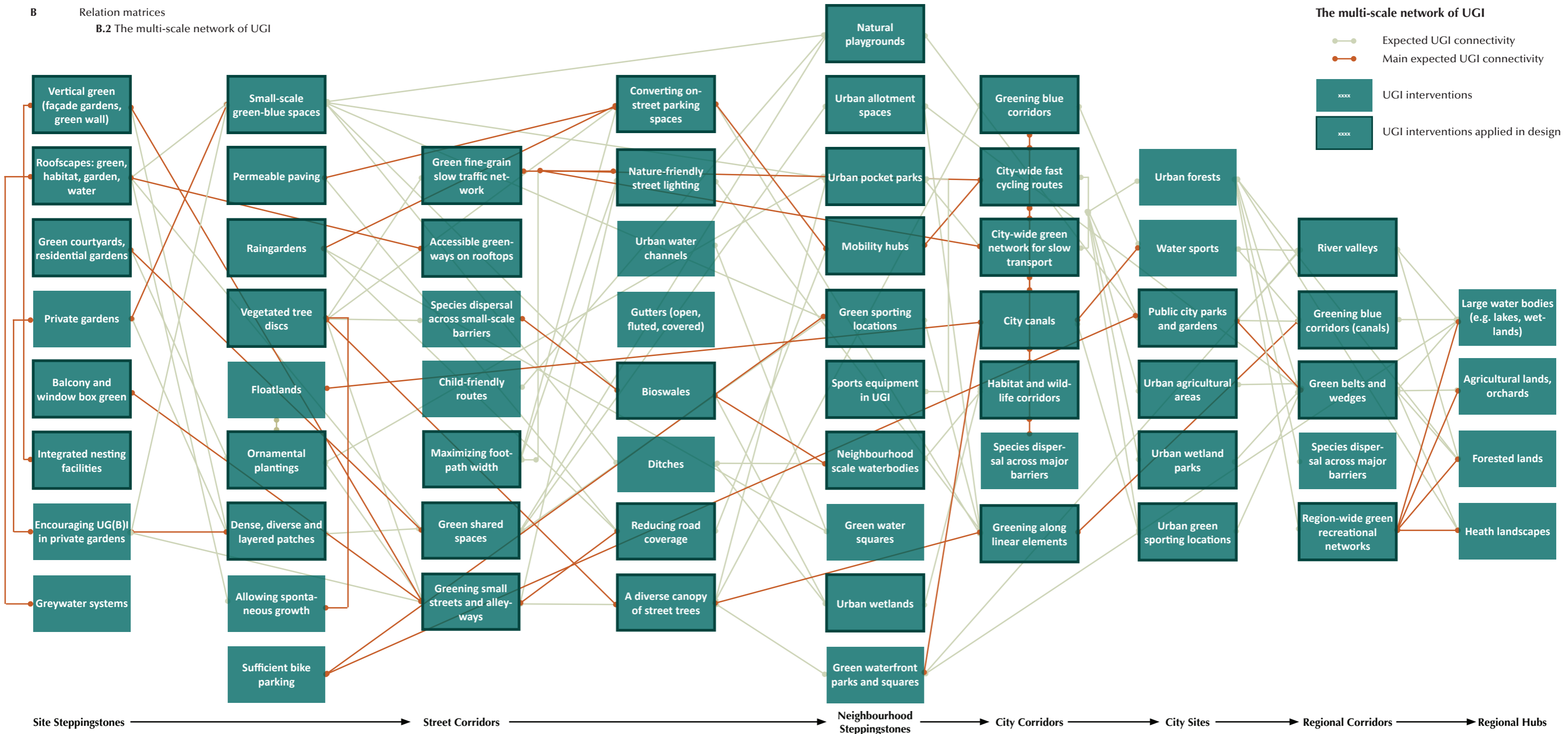
Table B.1.2 Pillars for human well-being and urban ecological resilience

Nature of relation	Explanation
	Positive relation found in data
	Neutral relation or both positive and negative relation found in data
	Negative relation found in data
	No relation found in data

B Relation matrices

B.2 The multi-scale network of UGI

The multi-scale network of UGI



B Relation matrices

B.3 Relation matrix strategy 1

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[1], [2], [3], [9], [13], [16], [20], [21], [24], [26], [27], [28], [33]	Green roof (extensive, intensive, nature roof)	Spatial	SS	Enriches health benefits from urban green, green roof approach more efficient than surface vegetation in high-density context [20], cooling and water buffering [21]	Safe and accessible spaces for vulnerable groups, capture fine particles, provide green scenery for relaxation [21]	Can serve as places for community [21]	Increase species habitat, increase species foraging. Beneficial for: butterflies, bees, birds, bats, plants, people [27]	Additional site steppingstones for flora and fauna [27]	Provides food sources for species, helps with run-off water, mitigates heating, [22]
[27]	Brown roof	Spatial	SS	Water retention, cooling and buffering [27]			Beneficial for: insects and birds nesting in sandy environments [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[27], [33]	Water roof, blue roof	Spatial	SS	Water retention, cooling and buffering. Also: greywater possibilities [27]			Beneficial for: insects, birds, fish and bats. Providing habitat, drinking water, cooling [27]	Additional site steppingstones for flora and fauna [27]	
[1], [2], [20], [26], [27]	Sky garden, roof garden, communal roof garden	Spatial	SS	Water retention, cooling and buffering [27]	Safe and accessible spaces for vulnerable groups, capture fine particles, provide green scenery for relaxation [21]	Can serve as places for community [21]	Increase species habitat, increase species foraging	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[21], [27]	Greenways on rooftops	Spatial	SS	Water retention, cooling and buffering [27] Stimulate active mobility	Safe and accessible spaces for vulnerable groups, capture fine particles, provide green scenery for relaxation [21]	Can serve as places for community [21]	Increase species habitat, increase species foraging	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[13], [20], [21], [24], [26], [27], [28], [33]	Green facades, green walls, vertical gardening	Spatial	SS	improve resilience and quality of life in cities as well as prevent food insecurity [17] Water retention, cooling, buffering, isolation in winter, noise isolation [27]	Green facades and roofscapes provide excellent locations for urban agriculture [21]	Capturing of fine particles, and provide green scenery for relaxation, heat mitigation [21]	Beneficial for: butterflies, bees, birds, bats, plants. By also implementing specific climbing plants biodiversity can reach its maximum [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[2], [10], [15], [27], [28], [31]	Facade gardens	Spatial	SS	Water retention, cooling, buffering, isolation in winter, noise isolation [27]	Green facades and roofscapes provide excellent locations for urban agriculture [21]	Capturing of fine particles, and provide green scenery for relaxation, heat mitigation [21]	Increase species habitat, increase species foraging. Beneficial for: butterflies, bees, birds, bats, plants, small mammals such as hedgehogs [27]	Increase species mobility [27]	Provides habitat by offering food sources [22]
[20], [26], [27], [28]	Window, balcony boxes with greenery	Spatial	SS	Water retention, buffering, cooling [27]		Improve restorative quality of streetscapes [20]	Beneficial for: butterflies, bees, birds, bats, plants [27]	Additional steppingstone [27], mainly for insects and birds	Water retention, buffering, cooling [27]

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[17], [21], [24]	Vertical forests, gardens (tall and middle sized buildings covered in green vegetation, trees, etc.)	Spatial	SS	Water retention, buffering, cooling [27]	provide green scenery for relaxation [21]		promotes biodiversity in cities since buildings are designed to be inhabited not only by humans but also by birds and insects [17]	Additional steppingstone [27], mainly for insects and birds	Water retention, buffering, cooling [27]
[27]	Features for species, e.g. Integrated nesting facilities (birds, bats, insects)	Spatial	SS	Bees and butterflies contribute to 60% of the cross-contamination of our fruits and vegetables [27]			Local biodiversity can be greatly improved with relatively cheap solutions [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[2], [10], [12], [20], [33]	Hotels and stones for insects	Spatial	SS	Bees and butterflies contribute to 60% of the cross-contamination of our fruits and vegetables [27]			Local biodiversity can be greatly improved with relatively cheap solutions [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[1], [2]	Private garden, domestic garden	Spatial	SS	Opportunities for positive interactions with nature [26]	A means of healthy leisure and recreation [27]		Contribute to a healthy bees and butterfly population in cities [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[1], [6], [13], [17], [23], [25]	Green courtyards, residential yards	Spatial	SS	Opportunities for positive interactions with nature [26]	A means of healthy leisure and recreation [27]	Can serve as places for community [21]	Contribute to a healthy bees and butterfly population in cities [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[2], [10]	Community gardens	Spatial	SS	Opportunities for positive interactions with nature [26]	A means of healthy leisure and recreation [27]	Can serve as places for community [21]	Contribute to a healthy bees and butterfly population in cities [27]	Additional site steppingstones for flora and fauna [27]	Provides habitat by offering food sources [22]
[26], [27]	Encouraging wildlife and native species gardening in residential gardens, balconies and rooftops	Spatial	SS	Opportunities for positive interactions with nature [26] Contribute to bee population, which contribute to 60% of cross-contamination of fruits and vegetables [27]	A means of healthy leisure and recreation [27]	Supports natural ecological processes by providing resources for species beyond traditional UGI [26]	Contribute to a healthy bees and butterfly population in cities [27]	Buildings and gardens become additional steppingstones [27]	Improves soil quality [27]
[27]	Hedges	Spatial	SS			Provide ecological property partitioning [27]	Beneficial for: birds and small mammals such as hedgehogs [27]	Provide shelter for birds and animals [27]	Provides habitat by offering food sources [22]

B Relation matrices

B.4 Relation matrix strategy 2

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[32]	Gutters: regular, fluted, open, covered	Spatial	SS	Controlled run-off water and can help with aesthetics [32]	Educational value of run-off water on the streets [32] Attention needs to be payed to a safe design [32]				Controlled run-off water [32]
[32]	Hollow roads	Spatial	SC, SS	Controlled run-off water and can help with aesthetics [32] Water can splash up against road-users, which can be annoying [32]	Educational value of run-off water on the streets [32] Attention needs to be payed to a safe design [32]				Controlled run-off water [32]
[32]	Ditches	Spatial	SC, SS	Controlled run-off water and can help with aesthetics [32]	Educational value of run-off water on the streets [32] Attention needs to be payed to a safe design [32]	Cooling effect [32]	Planted ditches influence biodiversity in a positive manner [32]	Planted ditches influence connectivity in a positive manner [32]	Controlled run-off water [32]
[32]	Urban water channels	Spatial	SC, SS	Controlled run-off water and can help with aesthetics [32]	Educational value of run-off water on the streets [32] Attention needs to be payed to a safe design [32]	Cooling effect [32]	Planted ditches influence biodiversity in a positive manner [32]	Planted ditches influence connectivity in a positive manner [32]	Controlled run-off water [32]
[13], [30]	Water fountains and other water elements	Spatial	SS	Cooling effect, aesthetic effect [30]	Objectively identifiable features (e.g. water features) more important for mental health than subjective features, e.g. safety [13]	Can help with place-making [30]			Cooling effect [30]
[2], [9], [21], [22], [24], [32]	Reducing road coverage, 'soil unsealing', permeable pavings	Spatial	SC, SS	Improves ES of soils + positive effects on QoL & health of urban population. [22] Unsealing brings cooling + rainwater infiltration [32]	Unsealed soils bring positive consequences for society, economy, and QoL in context of climate change [22]		Removing paving provides more habitat for plants, animals, plants and soil life + more food becomes available for insects, birds and other animals [32]		Increased presence of roots makes soil porous, leading to more infiltration to supplement groundwater levels + protects the soil from drying out [32]
[1], [6], [7], [15], [17], [24], [26], [27], [32], [33]	Introducing new and improving existing waterbodies, blue spaces: ponds (detention, retention, wildlife), lakes, wetlands	Spatial	SS	Rainwater buffering and purification [32] Cooling [17] Impacts range of issues: e.g. community involvement & empowerment, safety, inclusion, equality, health, [17]	UGBS can contribute to social inclusion and social justice + provide cultural links and opportunities for social events and outdoor activities [17] Improves education, recreation [17]	Can help with place-making [17]	Create habitat for a range of species [26]	Improves when surrounded by varied grassy areas to allow movement between ponds and have rocks and logs available for shelter [26]	Reducing of urban heat island effect [17] Increasing the green cover and rejuvenating the water bodies improve the heat dissipation and water recharge [24]
[1], [2], [3], [7], [8], [9], [13], [10], [16], [17], [20], [21], [24], [26], [27], [31], [32], [33]	Introducing new and improving existing NBS: permeable paving, rain gardens, swales, reservoirs, green-/ brown-/ water-vegetated tree discs	Spatial	SS	Maximize flood mitigation [8] NBS can enrich UGI health benefits, e.g. air filtration, cooling, aesthetics, health [9]	Capturing of fine particles, and provide green scenery and green recreational (sitting and playing) environments [21]	Can bring the opportunity to create places for community [1]	Beneficial for amphibians, fish, birds, small mammals, plants and insects [27] [26]	Species mobility can be provided by creating vegetated corridors between sites, making use of NBS, e.g. drains or swales [26]	Best when designed dependent on local nature [7] Maximize ground water infiltration or flood mitigation [8]

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[8], [19], [21], [25], [27], [32], [33]	Natural playgrounds (including water playing elements)	Spatial	CS, NS	Benefits for: development, health + well-being [27, 33] + for cooling [27] + exposure to soil microbes benefits immune system [33]	Playing and discovering nature [21] Playing builds strength, stamina and helps with social interaction [33]	Helps develop interest in nature [33] Should be combined with child-friendly design of the public realm [21]	Beneficial for: butterflies, bees, birds, small mammals, plants [27]	Increases species mobility [27]	Improves water infiltration and soil health [27]
[32]	Green water squares/ plazas	Spatial	SC, SS	Aesthetical value + possibilities for physical activity added to water storage + heat stress reduction [32]	Educational value: making dynamics of water visible for inhabitants [32] Can be combined with other public functions [32]	Relatively high in maintenance, should be cleaned immediately after water storage [32]	Combination of watersquare and vegetation leads to higher biodiversity [32]		Water storage, controlled run-off [32]
[8], [17], [26], [27], [32], [33]	Bioswales	Spatial	SC, SS	No overflow possible + green-blue veins in neighbourhoods: cooling, aesthetic, air quality [32]	Educational value of run-off water on the streets [32]	Like other NBS, can bring the opportunity to create places for community [1]	Create habitat for a range of species [26] Usage of varied, native species can create a nature-friendly wadi system [32]	Drains and swales as vegetated corridors between sites [26] Wadi can play an important role in species and ecological connectivity [27]	Maximize infiltration & flood mitigation [8] Vegetation makes soil highly porous [32] Their soil diversity allows them to host high plant diversity [33]
[32]	Urban infiltration strips	Spatial	SS	Controlled run-off water + help with aesthetics + little space needed [32]	Educational value of run-off water on the streets [32]	Can help with place-making [30]	Increased amount of space for plants, insects and other animals [32]	Connectivity can be improved by creating vegetated corridors between sites [26]	Increased roots, increase permeability and help supplement groundwater levels [32]
[27], [32]	Water roof	Spatial	SS	Water retention, cooling, buffering, greywater [27]			Beneficial for: insects, birds, fish and bats. Providing habitat, drinking water, cooling [27]	Additional site steppingstones for flora and fauna [27]	Water retention, cooling and buffering [27]
[1], [2], [3], [9], [13], [16], [20], [21], [24], [26], [27], [28], [32], [33]	Green roof (extensive roof gardens, intensive sedum roofs, nature roof for habitat)	Spatial	SS	NBS can enrich UGI health benefits, e.g. air filtration, cooling, aesthetics, health [9] Efficient cooling approach in high-density areas [20]	Accessible and safe UGBS for vulnerable groups [1] air filtration, scenery, green recreational environments, cooling) and buffering [21]	Provides opportunities for solar panels and water storage [21]	Provides habitat for many species by offering food sources for species, increase species foraging [2] [27]	Additional site steppingstones for flora and fauna [27]	Helps with water runoff & cooling [2] [21] Good measure for cooling in high-density contexts [20]
[16], [26], [31], [32], [33]	Urban wetlands, wetland parks	Spatial	RH, CS	Water quality/ carbon storage: balancing emissions, removing pollutants, regulating climate [16]	Provide space for recreation [32]	forests and wetland parks in cities provide services that significantly improve water quality and carbon storage [16]	Highly important for different species of plants, birds, amphibians and insects [32]	Provides an important hub in the network of UGI [31]	Carbon storage: balancing carbon emissions, removing air pollutants, and regulating microclimate [16]
[1], [6], [7], [15], [17], [24], [26]	Greening blue corridors or introducing green-blue corridors: creeks, canals, rivers	Spatial	RC, CC, SC	Exposure to both UGBS results in highest association with daily walking time in Barcelona [12]	Social qualities, through e.g. recreational use [17], inclusion, cultural links opportunities for events [17]	Benefits not equitably distributed across cities and populations [17], this measure can help counter that	Create habitat for a range of species [26]	Provides important corridors in the network of UGI [31] Improves when surrounded by varied grassy areas, rocks and logs [26]	Cooling [17] Increasing the green cover and rejuvenating the water bodies improve the heat dissipation + water recharge [24]
[2], [10], [12], [20]	Green-blue structures in private garden, domestic garden	Spatial	SS	Cooling + local run-off [27]	Opportunity for interactions with nature [26]		Important for urban bird species, diversity and distribution [2]	They improve connectivity across urban landscapes [2]	Provides habitat by offering food sources for species [2]

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[1], [3], [6], [8], [19], [20], [21], [22], [23], [24], [25], [30], [32]	Waterfront parks	Spatial	CS, NS	Give space for: playing, moving, cooling, shading, relaxation, etc. [30]	Increase opportunities for recreation (e.g. soccer, skateboarding, jogging) and leisure (e.g. boardgames, picnicking, hanging-out) [30]	Provides social opportunities [30]	Allows for green areas, improving the biodiversity [30]	Connect green spaces in neighbourhoods to the wider region through the green-blue corridors [30]	Additional green and rooted soils improve the soil condition [32]
[21], [26], [27], [31]	Implementing more soft, green, ecological quays/banks	Spatial	CC, SC	Provides cooling + beneficial for aesthetics [27]	Increased safety along quays compared to high hard quays [27] Safer for children [31]		provides shelter, nesting, soft border for animals [27] Beneficial for: plants, birds, small mammals, amphibians, fish, insects [27]	An ecological bank also works well as a fauna exit point; animals can easily exit the water there. [27] Gradual transition from shore to water [31]	Controlled run-off water [32] + Increased roots, increase permeability and help supplement groundwater levels [32]
[27], [28], [31]	Placing of floatlands in canals	Spatial	NS	Provision of human-nature contact [30]		Can help with place-making [30]	Local biodiversity can be greatly improved with relatively cheap solutions [27]	Transforming buildings into additional steppingstones [27] works well as a fauna exit/ resting point [27]	
[27]	Green quay walls	Spatial	CC, SC	Provides a cooling effect, and is beneficial for aesthetics [27]	Can provide a more pleasant environment for e.g. recreational activities [27]		Wall flora beneficial for: wall plants, ferns, bees, butterflies [27]	Additional steppingstones in the UGI network [27]	
[8], [17], [21], [26], [32], [33]	Rain gardens	Spatial	NS	Maximizes ground water infiltration & flood mitigation [8] Rainwater buffering and purification [32] Cooling [17]	Capturing fine particles, green scenery and green recreational environment [21]		Habitat for a range of species [26] Opportunity to increase native biodiversity [33]		Maximize ground water infiltration or flood mitigation as may be appropriate [8]
[8], [9], [10], [27], [33]	Tree pits (not always vegetated), tree discs (vegetated)	Spatial	SS	Can bring: healthier trees, air filtration, cooling, aesthetics, infiltration, health benefits [9] carbon capture [33]	Can provide a more pleasant environment for e.g. recreational activities [27]		Beneficial for many species [27] designed > 4m ² to reduce crowding effect + allow colonization of species, this will bring >10 species per patch [9]	Useful connectors of other green spaces [9] [27]	Soil health will benefit the survival of trees in the warmer and drier climate [9] Highly contributes to healthy soil life [27]
[32]	Rainwater tanks in private gardens	Spatial	SS	Help with capturing runoff water [32]	Saves costs for water + helps with taking care of garden [32]	Allow for a connection to natural resources [32]			Help with capturing runoff water [32]
[32]	Systems for using precipitation in homes/buildings	Spatial	SS	Help with capturing runoff water [32]	Saves costs for water [32]	Allow for a connection to natural resources [32]			Help with capturing runoff water [32]

B Relation matrices

B.5 Relation matrix strategy 3

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[2], [6], [13], [20], [23], [28], [33]	Applying suited approaches based on local and native conditions	Spatial	All		The character of places helps people to recognise & form connections with their environment [33]	Local approaches can be developed by learning from other cities, however must be grounded on the local factors [20]	By applying local/native vegetation, diverse species communities on a local scale can be maintained. [2]		Because of the dynamic differences between UGI, more consideration should be given to local conditions for improvement [6]
[2], [9], [21], [22], [24]	Improving the urban soil quality by "unsealing"	Spatial	SC, SS	Noise reduction [2] Can significantly improve the living standard and health condition of urban population [22]	Positive consequences for society + economy + living conditions of urban populations in the context of climate change processes [22]		Can lead to an increase in species due to increased habitat, especially around green spaces [2] Soil health benefits the species survival [9]		Soil conditions can significantly improve absorption of water into the soils [22] Sealed surfaces are the main cause of the UHI [22]
[1], [2], [3], [7], [8], [9], [13], [10], [16], [17], [20], [21], [24], [26], [27], [28]	Implementing nature-based solutions (NBS), based on local characteristics, and native species (e.g. bioswales)	Spatial	SS	Maximizes flood mitigation [8] Brings health benefits through e.g. air purification, cooling, aesthetics, infiltration [9]	Capturing of fine particles, and provide green scenery and green recreational (sitting and playing) environments [21]	Can bring the opportunity to create places for community [1]	Beneficial for: Amphibians, fish, birds, small mammals and insects [27] Lead to an increased value of local species [26]	Species mobility can be provided by creating vegetated corridors between sites, making use of NBS, e.g. drains or swales [26]	Functions best when designed dependent on local nature [7] Provide appropriate ways to maximize ground water infiltration [8]
[2], [6], [7], [8], [9], [10], [15], [17], [18], [19], [20], [21], [22], [23], [26], [28]	Ensuring a diverse native vegetation variety (e.g. wildflower patches), and ensuring a native urban tree variety (first, second and third size)	Spatial	SS, SC	More effective in addressing health issues [18] The supply of ES depends highly on the local vegetation type and variety [20]		Planting diverse vegetation helps with benefitting local communities in the face of cooling, stormwater runoff, giving shelter and improving carbon sequestration [25]	Native vegetation diversity can increase species richness and diversity [2] + Bring food for butterflies and bees & shelter for other species [27]	Local vegetation helps with facilitating native species dispersal [26]	Provides habitat by for native species [2] new habitat can be created by adding complex and diverse native flowering vegetation, water sources, wood and stone refugia [26]
[2], [6], [8], [9], [13], [15], [23]	Maintain and increase vegetation coverage in the urban areas (quantity and quality)	Spatial	All	High quantity of vegetation coverage can bring climatic comfort throughout the seasons [8]			Increases biodiversity [6]. Dense vegetation has important value as a habitat [9]	UGS quantity helps enhance network connectivity, benefiting UGS quality [6]	Dense vegetation has important value as a habitat [9]
[6], [9]	Allowing spontaneous vegetation growth in some locations	Spatial	SC, SS	Increases air filtration, aesthetics, infiltration, health + reduces heat [9]		The benefits of spontaneous vegetation are especially true for lower socio-eco groups [9]	Increases biodiversity [6]. Dense vegetation coverage important as habitat many species [9]	This helps enhance network connectivity, benefiting UGS quality [6]	Spontaneous vegetation reverses the effects of compacted soils [9]
[5], [6], [8], [26]	Introducing habitat corridors to connect green spaces	Spatial	RC, CC, SC		Improving green networks can increase human and urban animal mobility [6].		Habitat corridors connecting green spaces are known to provide high value for biodiversity and intact ecosystems, especially in compact cities. [5]	Increases urban animal mobility [6], maximize vegetation connectivity connecting urban spaces to the region [8], facilitate species dispersal [26]	
[1], [6], [7], [8], [9], [13], [17], [19], [26]	Retrofitting and improving existing UGI (e.g. near existing canals, roads and railway lines)	Spatial	All	Provides air/water purification, wind/ noise reduction, cooling, psychological benefits [17, 19], reduce stress [10]	Provides ability to relax faster [19], improves property value, reduces energy consumption [26]	Helps with place-making [1], ensures places people want to stay [8], attracts highly educated people and boosts economy [6]	Improved UGI can help to mitigate effects of urbanization on biodiversity, such as habitat loss and fragmentation [9]	Facilitation of species dispersal [26]	Positive effects on climate issues [17], provides habitat by offering more food sources for species, reduces flooding and heating [1]

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[9], [31]	Integrate periodic maintenance, e.g. periodic mowing	Spatial	CS, NS, SS	Brings improved air filtration, temperature reduction, aesthetics, stormwater management and overall health [9]	Saves money [9]	This type of maintenance can bring lower socio-eco groups more access to green and biodiverse spaces [9]	Can help to increase the species richness that a network of urban patches can support. [9]	PCan help to increase the species richness that a network of urban patches can support. [9]	Helps resistance against localized disturbances (e.g. trampling, soil compaction, and pollution) and can help to ensure their quality [9]
[8], [17], [20], [21], [29]	Ensuring multifunctionality of UGI (hybrid, flexible and adaptable UGI)	Spatial	CS, NS, SS		Allow for easy adaptation to current and future needs [21]	Allows for opportunities for inhabitants to appropriate to their preferences [21]			
[33]	Respect heritage features	Spatial	CS, NS, SS	Local character of places helps people to recognise + form connections with their environment, positively influencing mental health [33]	Local character of places helps people to recognise + form connections with their environment [33]	Often the basis of communities' sense of identity + many mature native and non-native flora species [33]	Historic buildings and sites often provide valuable and scarce habitat for wildlife (e.g. nesting sites for swifts, old masonry for wall flora and insects) [33]	Often many hedges, shrubs, lakes and ponds are located at these sites: improve the connectivity of the UGI [33]	Historic buildings and green spaces represent investment by past generations and significant embodied carbon > age matters [33]
[13], [15], [20], [30]	Providing furniture and amenities in streets and green spaces, depending on local typology	Spatial	SS	Can enhance opportunities for physical activity [15] + important for mental health [13]	Furniture and amenities help with enhancement of social cohesion [15]	Furniture and amenities help with the inclusion of different groups + makes it easier for vulnerable groups to visit green spaces [13, 20]			
[2], [8], [20], [21]	Implementing vertical densification near large green spaces, where possible and wished for	Spatial	NS	Vertical densification would be the best scenario for cooling, due to increased shading, compared to horizontal densification [20]	densification around this green space can reduce its perceived recreational quality due to the higher crowding perception among users [20]	The increase in UHI-effects in the inner city is compensated by adding urban green and shadow cast of high building blocks [21]	Increasing building density, can lead to a decrease in species sensitive to landscape changes, but increase in urban-dweller species [2]	Depending on the existence of functional connections, a dense city can provide suitable habitat for specific breeding birds [20]	The increase in UHI-effects in the inner city is compensated by adding urban green and shadow cast of high building blocks [21]
[5], [8], [11], [16], [23]	Stimulation of participatory processes, civic engagement and feedback loops	Non-spatial	All	Participatory processes can help encourage healthy lifestyles [5]	Inclusion of a wide-range of stakeholders offers environmental educational value, + allows to integrate social and cultural approaches [5].	Opportunities for residents to experience nature and participate in environmental stewardship, capturing benefits of ES [16]	e.g. scientific outreach, in situ explanations citizen science projects may contribute to public appreciation and assist long term successes. [9]		

B Relation matrices

B.6 Relation matrix strategy 4

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[30], [32], [33]	Main green network for slowtraffic (walking and cycling)	Spatial	RC, CC	Facilitation of active movement instead of other mobility options [30]	Increased slowtraffic safety, especially when separated or very broad + facilitates active recreation [30]	Green increases the enjoyment + experience of slowtraffic mobility [30]	Allows for linear green spaces throughout the city, improving biodiversity [30]	Can be used to connect urban green spaces to the wider region through corridors [30]	Additional green and rooted soils improve the soil condition [32]
[30], [32], [33]	Green fast cycling routes	Spatial	RC, CC	Facilitation of active movement instead of other mobility options [30]	Increased slowtraffic safety, especially when separated or very broad + facilitates active recreation + can be used as link between living, working and recreation-zones [30]	Green increases the enjoyment and experience of slowtraffic mobility [30]	Allows for green areas, improving the biodiversity [30]	Can be used to connect urban green spaces to the wider region with corridors [30]	Additional green and rooted soils improve the soil condition [32]
[30]	Green, fine-grain basis network for slowtraffic	Spatial	CC, SC	Encourages more inhabitants to become active: walking, jogging, walking meetings, etc. [30]	Ensures short and safe connections to and from travel destinations [30]	Brings green closer to home [30]	Allows for green in neighbourhoods, improving the local biodiversity [30]	Network that brings urban green into neighbourhoods [30]	Additional green and rooted soils improve the soil condition [32]
[30]	Mobility hubs	Spatial	NS	Encourages slowtraffic and public transportation options [30]	Ensures better connections + Allows for integration of other functions (e.g. package service) and for a central place: social cohesion, place for sports, etc. [30]	Allows for inhabitants to pick their own preferred mode of travel [30]			
[30]	Building density, functional mix, variation of buildings and public plinths	Spatial	NS, SC	Invites inhabitants to take shorter trips by foot or by bike [30]	Brings more life into neighbourhoods, along with an increased level of social security [30]	Improves social cohesion, by creating more liveliness and events in the street [30]		Improved green space proximity, leads to improved connectivity [30]	
[1], [3], [4], [8], [12], [14], [15], [17], [18], [19], [20], [21], [23], [29]	Striving for a proximity of UGS near living and working (3-30-300 rule)	Non-spatial	All	Brings mental and physical health benefits [15, 18] + invites inhabitants to take trips by foot or by bike [30]	Increased social activity + security [29] + social interaction amongst neighbours [19] + provides leisure space and extended living space [14] + makes parents more likely to let their children play outdoors [29]	Increased groups using UGI > "cosy crowdedness" and "more eyes on the street" (Jane Jacobs). The presence of people attracts people [21]			
[3], [4], [8], [13], [15], [20], [21], [30]	Child friendly design and school zones	Spatial	NS, SC, SS	Encourages children to play outside, whilst also creating more space for them [30]	Increased safety for children outdoors, and allowing them to be more independent [30]	Stimulate social interactions for children and parents [30]		Safer animal crossing [30]	
[30]	Shared green spaces, with a priority for slowtraffic	Spatial	SC	Encourages active mobility and other activities, whilst demotivating car usage [30]	Increases safety for walking, cycling, playing and sporting people on the streets [30]	Can be tough for (visually) impaired users [30]		Safer animal crossing [30]	

B Relation matrices
B.7 Relation matrix strategy 5

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[30]	Nature-friendly street lighting to maximize safety	Spatial	SS	Encourages active mobility, even in the dark [30]	Improves safety, as well as the feeling of safety on the streets at night and in the early morning [30]	Improves safety, as well as the feeling of safety on the streets at night and in the early morning [30]	Lighting does not disturb animals, which is positive for biodiversity [30]	Lighting does not disturb animals, which is positive for connectivity [30]	
[8], [30]	Shift on-street parking to clustered parking facilities	Spatial	NS, SC, SS	More space available for slowtraffic mobility, and making car usage less attractive, because the car is further away [30]	Increased safety on the streets with less car movement [30]	Free space for meeting neighbours, increasing social cohesion [30] + increased inconvenience for e.g. physically impaired and vulnerable groups	More space free for other functions than parking (green space), which improves the biodiversity [30]	More space free for other functions than parking (green space), which improves the connectivity [30]	
[21], [27]	Greenways on rooftops: accessible from the street	Spatial	SC	Water retention, cooling and buffering [27]	Additional space for leisure and other activities [27]		Increased green space, leading to higher biodiversity [27]	Improving human and animal mobility [27]	Water retention, cooling and buffering [27]
[14], [15], [17], [20], [23], [26]	Planting of a diverse canopy	Spatial	SC, SS	Provides shading and cooling [17]			Important for quality of UGBS: tree canopy cover [17]		In terms of the ecological quality of UGBS, one of the natural attributes of green space is tree canopy cover [17]
[8], [19]	Maximize footpath width	Spatial	SC	Improves pedestrian infrastructure [8]	Striving for 'access for all' [8]	Striving for 'access for all' [8] Insufficient recreational infrastructure one of the most often indicated limitation for all types UGI [19]			
[30]	Ensure enough bike parking	Spatial	SS	Encourages healthy behaviour [30]	Increases bike safety [30]				
[30], [32], [33]	Main green-blue active recreation network (walking, cycling, mountain-biking, jogging)	Spatial	RC, CC	Active recreation + active movement + green-blue structure offers cooling, air purification [30]	Allows for possibilities to play, exercise and meet [30]	Green increases enjoyment + experience of slowtraffic mobility [30]	Allows for green areas, improving the biodiversity [30]	Connect green spaces in neighbourhoods to the wider region through the green-blue corridors [30]	Additional green and rooted soils improve the soil condition [32]
[30], [32]	Fine-grain network of green-blue pathways	Spatial	CC, SC	Encourages active behaviour: walking, jogging, etc. + Countering the UHI [30]	Ensures short and safe connections to and from travel destinations [30]	Green increases enjoyment + experience of slowtraffic mobility [30]	Allows for green areas, improving the biodiversity [30]	Connect green spaces in neighbourhoods to the wider region through the green-blue corridors [30]	Additional green and rooted soils improve the soil condition [32]
[1] [3] [6] [8] [9] [10] [11] [12] [13] [15] [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] [30] [32]	Public parks and gardens	Spatial	CS, NS	Park walking routes, have the highest association with daily walking time [12] Give space for: playing, moving, cooling, shading, relaxation, ... [30]	Increase opportunities for recreation (e.g. socces, skateboarding, jogging) and leisure (e.g. boardgames, picnicking, hanging-out) [30]	'formal greenspaces' (e.g., parks) may not be sufficient to meet some residents' needs, especially in denser environments [17]	Allows for green areas, improving the biodiversity [30]	Connect green spaces in neighbourhoods to the wider region through the green-blue corridors [30]	Additional green and rooted soils improve the soil condition [32]
[30]	Sports equipment in public spaces	Spatial	NS, SS	Stimulation of physical activity [30]	Inclusion for those who cannot afford a gym membership [30]	Multifunctionality enlargens the group of users [30]			

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[1], [3], [4], [8], [12], [14], [15], [17], [18], [19], [20], [21], [23], [29]	Striving for a proximity of UGS near living and working (3-30-300 rule)	Non-spatial	All	Brings mental and physical health benefits [15, 18] + Invites inhabitants to take trips by foot or by bike [30]	Increased social activity + security [29] + social interaction amongst neighbours [19] + provides leisure space and extended living space [14] + makes parents more likely to let their children play outdoors [29]	Increased groups using UGI > "cosy crowdedness" and "more eyes on the street" (Jane Jacobs). The presence of people attracts people [21]		Improved green space proximity, leads to improved connectivity [30]	
[2], [8], [20]	Increasing building density near UGS		CS, NS, SS	Min. threshold of density is necessary for UGS to have effect on health [2]	Increases the proximity of UGS [2]	This research showed that densifying around an UGS reduced its perceived recreational quality due crowding perception [20]	Can decrease species sensitive to landscape changes, but increase in urban-dweller species [2] This research showed density has a significant impact on the functionality of UGI, but dense areas can also provide suitable habitat for specific breeding birds [20]	Mobility of species between green spaces to meet their basic requirements is reduced when building density is increased, with the existence of functional connections, dense areas can provide suitable habitat for specific breeding birds [20]	All studies included in this review investigating the relationships between urban form, green coverage and ecosystem services found that, generally, ecosystem performance declined with increasing urban density [20]
[4], [18]	Closing the health gap (increasing UGI health benefits for tackling inequalities brought by socio-economic factors)	Non-spatial	All	Lowering risks of poverty-related stress + health issues [4] higher socioeconomic status often correlated with better health: closing the health gap is a priority for healthy cities [18]	UGI-related health benefits are effective in tackling health inequalities + have larger positive effects on populations from lower socioeconomic groups [18]				
[13], [15], [30], [32]	UGI implementation equally distributed across cities	Spatial	NS	Inequity in UGBS distribution has negative health implications [13] access to UGI promotes health [23]	Wealthy areas have access to more amenity-rich UGS than lower socioeconomic areas [13] Environmental justice is pivotal in supporting healthy communities [23]	One cannot presume that UGS provides benefits for everyone equally [13]	Allows for green in neighbourhoods, improving the local biodiversity [30]	Network that brings urban green into neighbourhoods [30]	Additional green and rooted soils improve the soil condition [32]
[23], [33]	Reducing of 'riskscapes' (areas with high exposure to environmental stressors)	Spatial	All	Tackling these would be highly beneficial for the health of communities [23]	Low income + minority communities reside more in riskscapes, and are more likely to be exposed to pollutants [23]	Makes places welcoming, safe, healthy and secure [33]			Tackling these would be highly beneficial for the health of ecological systems [23]

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[3], [4], [8], [13], [15], [20], [21], [33]	UGI design for varying age, gender, cultures, and other socio-demographics	Non-spatial	All	UGI linked to positive mental health outcomes + better self-perceived health across socioeconomic statuses + genders [15]	Lower socio-economic areas have less accessible UGS/ fewer amenities to make them more appealing [13] Child-friendly design measures have positive effect on safety + well-being	Increases sense of belonging for different groups [3, 4] + more likely to use UGBS [17] considering them in the design will help makes a place welcoming, safe, healthy and secure [33]			
[8], [17], [20], [21], [29]	Ensuring multifunctionality of UGI (hybrid, flexible and adaptable UGI)	Spatial	CS, NS, SS		Allow for easy adaptation to current and future needs [21]	Allows for opportunities for inhabitants to appropriate to their preferences [21]			
[8], [19], [21], [25], [27], [32], [33]	Natural playgrounds (including water playing elements)	Spatial	CS, NS	Benefits for: development, health + well-being [27, 33] + for cooling [27] + exposure to soil microbes benefits immune system [33]	Playing and discovering nature [21] Playing builds strength, stamina and helps with social interaction [33]	Helps develop interest in nature [33] Should be combined with child-friendly design of the public realm [21]	Beneficial for: butterflies, bees, birds, small mammals, plants [27]	Increases species mobility [27]	Improves water infiltration and soil health [27]
[33]	Accessible greenspaces must be high quality and well maintained	Spatial	All	Makes a place welcoming, safe, healthy and secure [33]	Makes a place welcoming, safe, healthy and secure [33]	Makes a place welcoming, safe, healthy and secure [33]			
[13], [15], [20], [30]	Providing furniture and amenities in streets and green spaces, depending on typology	Spatial	SS	Can enhance opportunities for physical activity [15] + important for mental health [13]	Furniture and amenities help with enhancement of social cohesion [15]	Furniture and amenities help with the inclusion of different groups + makes it easier for vulnerable groups to visit green spaces [13, 20]			
[30], [32], [33]	Facilitation of green-blue active routes, all through-out the city (walking, cycling, mountainbiking, jogging)	Spatial	RC, CC	Allows for active recreation, active movement and exercise + The green-blue structure offers cooling, air purification [30]	Allows for possibilities to play, exercise and meet for all [30]	Green increases the enjoyment and experience of slowtraffic mobility [30]	Allows for green areas, improving the biodiversity [30]	Connect green spaces in neighbourhoods to the wider region through the green-blue corridors [30]	Additional green and rooted soils improve the soil condition [32]
[11], [20], [23], [33]	Planning from the perspective of ES and EDS, e.g. anti-allergenic species	Spatial and non-spatial	All	Provision of ES creates sustainable development socioeconomic + ecological systems [11]	Provision of ES creates sustainable development socioeconomic + ecological systems [11]	Provision of ES will include more vulnerable groups in UGS [11]	Factors such as tree species, allergenic index, tree condition, and length of in-leaf season impact the services that trees provide. [23]	Stakeholders have argued that areas of urban ES need to be treated as connected networks [11]	Generally, ecosystem performance declines with increasing urban density [20]

B Relation matrices

B.8 Relation matrix strategy 6

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[3], [4], [5], [8], [9], [13], [14], [15], [16], [19], [26]	The provision of 'human nature contact', 'human-nature connection'	Spatial	All	UGS contribute to supporting physical and psychological health benefits + cooling effects [13]	UGI is often the only source of nature within any reasonable distance [17]	Spiritual experiences sense of place + extends the living space into nature [14] Provides opportunities to restore interactions between human city-dwellers and nature [26]			
[27]	Designing for activities to bring people in contact with nature (green routes, playgrounds, sports, gardening)	Spatial	All	Allows for active recreation, exercise + The green-blue structure offers cooling, air purification [30]	Allows for possibilities to play, exercise and meet [30]	Green increases the enjoyment and experience of slowtraffic mobility [30]	Allows for green areas, improving the biodiversity [30]	Connect green spaces in neighbourhoods to the wider region through the green-blue corridors [30]	Additional green and rooted soils improve the soil condition [32]
[5], [8], [11], [16], [23]	Stimulation of participatory processes, civic engagement and feedback loops	Non-spatial	All	Participatory processes can help encourage healthy lifestyles [5]	Inclusion of a wide-range of stakeholders offers environmental educational value, + allows to integrate social and cultural approaches [5].	Opportunities for residents to experience nature and participate in environmental stewardship, capturing benefits of ES [16]	e.g. scientific outreach, in situ explanations citizen science projects may contribute to public appreciation and assist long term successes. [9]		
[8], [19], [21], [25], [27], [32], [33]	Natural playgrounds (including water playing elements)	Spatial	CS, NS	Benefits for: development, health + well-being [27, 33] + for cooling [27] + exposure to soil microbes benefits immune system [33]	Playing and discovering nature [21] Playing builds strength, stamina and helps with social interaction [33]	Helps develop interest in nature [33] Should be combined with child-friendly design of the public realm [21]	Beneficial for: butterflies, bees, birds, small mammals, plants [27]	Increases species mobility [27]	Improves water infiltration and soil health [27]
[26], [27]	Encouraging wildlife and native species gardening in residential gardens, balconies and rooftops	Spatial	SS	Opportunities for positive interactions with nature [26] Contribute to bee population, which contribute to 60% of cross-contamination of fruits and vegetables [27]	A means of healthy leisure and recreation [27]	Supports natural ecological processes by providing resources for species beyond traditional UGI [26]	Contribute to a healthy bees and butterfly population in cities [27]	Buildings and gardens become additional steppingstones [27]	Improves soil quality [27]
[8], [17], [20], [21], [29]	Ensuring multifunctionality of UGI (hybrid, flexible and adaptable UGI)	Spatial	CS, NS, SS		Allow for easy adaptation to current and future needs [21]	Allows for opportunities for inhabitants to appropriate to their preferences [21]			
[13], [15], [26], [32], [33]	Designing for passive activities bringing people in contact with nature (e.g. view from window, furniture)	Spatial	SC, SS	Features e.g. walking paths, water features, seating, are more important for mental health than subjective features [13]	Complementing UGI with a diversity of urban elements can enhance social cohesion [15]	Furniture and amenities helps with the inclusion of different groups (e.g. children and elderly) [13, 20]	Promote connectivity by transforming buildings into an additional steppingstones [27]		
[6], [9]	Allowing spontaneous vegetation growth in some locations	Spatial	SC, SS	Increases air filtration, aesthetics, infiltration, health + reduces heat [9]		The benefits of spontaneous vegetation are especially true for lower socio-eco groups [9]	Increases biodiversity [6]. Dense vegetation coverage important as habitat many species [9]	This helps enhance network connectivity, benefiting UGS quality [6]	Spontaneous vegetation reverses the effects of compacted soils [9]

DID	UGI interventions	Spatial/non-spatial	UGI scale level	Health	Social development	Belonging	Biodiversity	Connectivity	(a)Biotic fitness
[6], [17], [20], [25], [29], [33]	Urban allotment garden space (The recommended area of an individual plot is 300-500 m2 each)	Spatial	CS, NS	Resource of health: active recreation, therapeutic value [25] can considerably help to promote 'healthy life style' [25]	Educational: opportunities, low cost, encourages to eat more fresh produce, highlights respect for nature, reverence for social and spiritual needs, family values [25]	Creates community links, contact, sharing knowledge, recreational activity [25] Elderly: place for overcoming loneliness + for self-fulfillment during retirement [25]	Varied habitat, variety of plants, opportunities species to thrive + When mostly planted with native species, positive impact on local biodiversity [25]	allotments often located on the outskirts of housing estates make often important links in eco-corridors and green chains [25]	Inflow of fresh air from the peripheries to city area: cooling, reducing pollution + improving air quality[25]
[27], [28], [31], [33]	Integrating green on the building scale (e.g. green balcony, façade gardens, integrated nesting, edible green infrastructure)	Spatial	SS	Water retention, buffering, cooling, etc. [27]	Creating opportunities for positive interactions with nature, and addressing conflicts between biodiversity and safety objectives [26]		Local biodiversity can be greatly improved with relatively cheap solutions: should be placed on the North-East-West-side, not above windows [27]		
[11], [20], [23], [33]	Planning from the perspective of ES and EDS, e.g. anti-allergenic species	Spatial and non-spatial	All	Provision of ES creates sustainable development socioeconomic + ecological systems [11]	Provision of ES creates sustainable development socioeconomic + ecological systems [11]	Provision of ES will include more vulnerable groups in UGS [11]	Factors such as tree species, allergenic index, tree condition, and length of in-leaf season impact the services that trees provide. [23]	Stakeholders have argued that areas of urban ES need to be treated as connected networks [11]	Generally, ecosystem performance declines with increasing urban density [20]
[27], [28], [31]	Designing for human-wildlife interactions (e.g. floatlands, integrated nesting facilities)	Spatial	SS	Provision of human-nature contact [30]		Can help with place-making [30]	Local biodiversity can be greatly improved with relatively cheap solutions [27]	Transforms buildings into additional steppingstones [27] works well as a fauna exit/ resting point; easy water access [27]	
[2], [10], [12], [20], [25], [26]	Designing of private green facilities (e.g. private garden, façade garden, front garden, green balcony)	Spatial	SS		Ownership encourages to take care of nature [20]	Public/ private UGS have different meanings and are not substitutes [20] Densification reduces private tree cover, affecting disadvantaged communities [20]	Important habitat for bird species in cities, they influence bird diversity and distribution + provide breeding sites, shelter, food [2]	They improve connectivity across urban landscapes [2]	Provides habitat by offering food sources for species [2] AND provide breeding sites, shelter, food sources, wintering stopover sites for bird species [2]
[1], [6], [13], [17], [23], [25]	Designing of shared green facilities (e.g. gardens, farms, residential yards, roof gardens, allotments)	Spatial	SS	Active recreation [25]	Recreational activity [25]	Co-operation, local community links, bringing people together, sharing knowledge [25]	When planted with native plant species will have a positive impact on local biodiversity [25]	Natural habitats for flora and fauna in urban space, providing potential eco-corridors [25]	Improves water infiltration and soil health [27]
[2], [3], [6], [9], [10], [11], [12], [13], [15], [16], [19], [20], [21], [24], [26], [31]	Designing of public green (parks, SUPPs, green squares)	Spatial	NS, SS	The increase in the number of small, medium and large UGS patches strengthened climate mitigation	Highly important for recreation [31]	These are the most encountered green spaces in cities by locals [9]	Habitat for species [9] small UGS can help to mitigate, e.g. habitat loss, fragmentation [9]	They improve connectivity across urban landscapes, Strengthening of UGI connections [9]	Food sources for species + increases cooling/ infiltration [9]



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