Norwegian
University of
Life Sciences

Master's Thesis 2023 30 ECTS
The Faculty of Landscape and Society (LANDSAM)

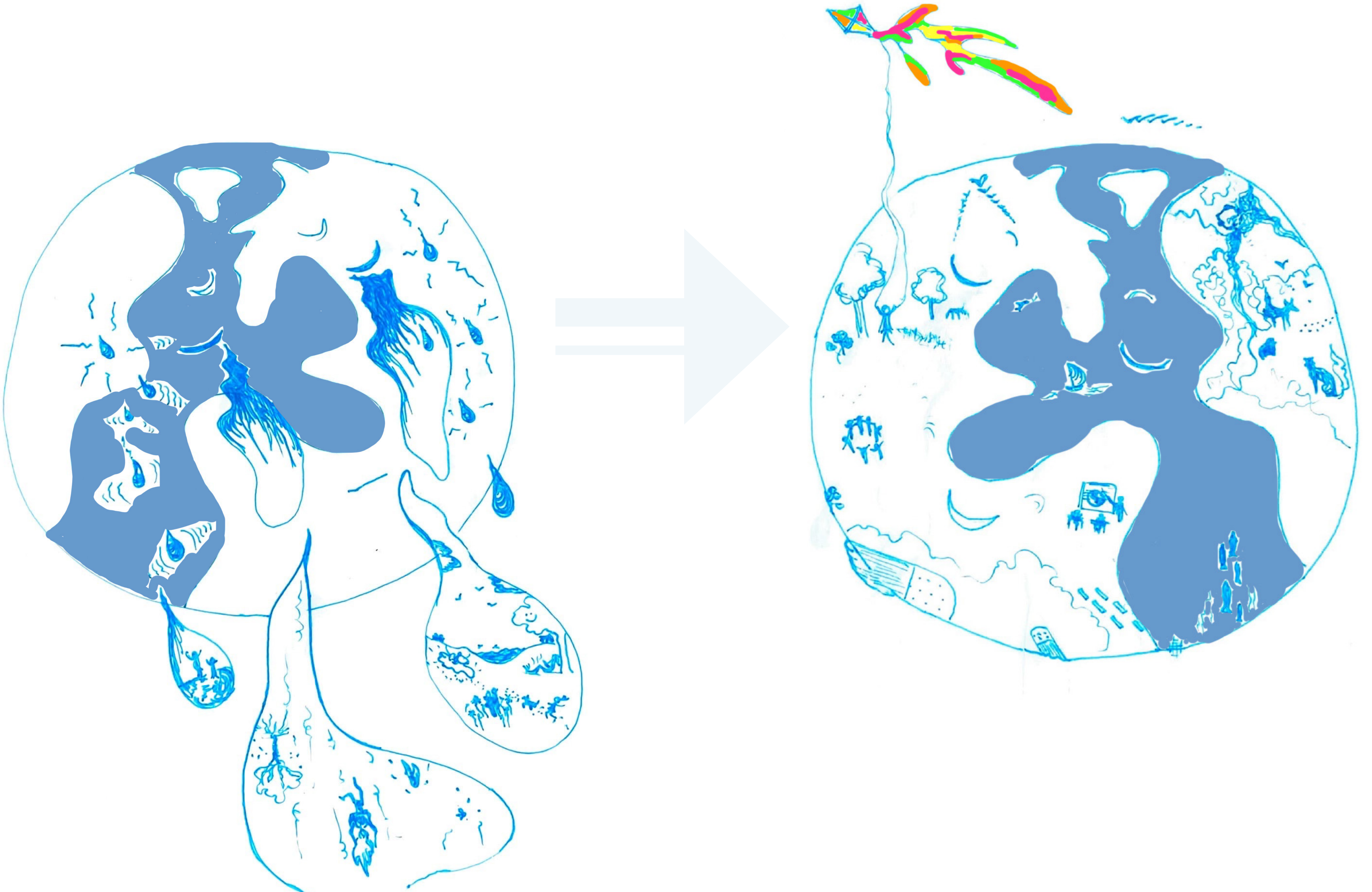
Ecosystem health: what, why, how?

What potential does an ecosystem health approach have for landscape architects to achieve sustainable land-use development?

Lovisa Emilia Mokrosinski-Hoel
Landscape Architecture

Ecosystem health: what, why, how?

What potential does an ecosystem health approach have for landscape architects to achieve sustainable land-use development?



This work is dedicated to you.
For letting me into your world of nature,
for showing me all the wonders around us,
for making me see the deer who tries to pass us by unnoticed and be observant, always.
For teaching me to trust the night and see the small glimpses of stars in the sky above the canopies,
rather than the dark that consumes us.
For showing me your great affirmation of the small things,
the last green leaf hanging in November,
the tempting first straws of grass in Spring,
the warmth of the sun,
the sound of excited birds harmonizing the symphony called joy,
the stunning sunset diving towards the ocean.
For reminding me of how little I am,
swirling and dancing like a leaf in the wind
and of how persistent nature is,
welcoming us with open arms,
come what may.

And for giving me limitless,
unconditional love
every moment of every day
like a container full of it,
constant like gravity itself.
My life therapist and wisest friend.
I am sure you would have written a much cleverer thesis if you had hands instead of hooves.
But I sure am happy you don't,
for all the other reasons.

Library page

Title:
Ecosystem health: what, why, how?
What potential does an ecosystem health approach have for landscape architects to achieve sustainable land-use development?

Author:
Lovisa Mokrosinski-Hoel

Supervisors:
Sally O'Halloran
Wenche Dramstad

Pages:
150

Format:
Landscape A3 (29.7 x 42.0 cm)

Figures:
Figures are referenced to by figure number in text with reference, and complete references in reference list. All figures, drawings and photographs without references are produced by the author.

Keywords:
Ecosystem health, sustainability, sustainable land-use development, landscape architecture.

Acknowledgements

Sally, your sharp mind, ability to see the missing links and keeping me on track has been priceless.
Wenche, your optimism, engagement and creativity for problem solving has been a real life saver. I could not have been luckier with my supervisors. You have inspired and motivated me to new extents. Thank you.

Thank you to my wonderful family and friends, two- and four legged, for your everlasting support. Thank you Kristian, for saving me from my water damage emergency, and all other emergencies. Thank you Juditte, for the quality moments of dear coffee-breaks, deep talks and encouraging words. I will miss seeing you in the library every day.
And to all ambitious students who inspired me in the library to work just as hard as you do. *Heia!*

Abstract

One of the main challenges in today's society is sustainable development of our land and landscapes for people, nature and the planet. This thesis will explore healthy ecosystems, what they are and why they need to be addressed (i.e. the potential they hold) and finally how we can achieve them. It will explore how landscape architects can utilise landscape ecological theory to improve the ecosystem health in their work, as one approach from one scientific field. Rather than a transformation in the planning field this thesis urges the need for a systematic transformation of how we see all systems on Earth as one with sub-systems alternating its dynamic. The thesis aims at becoming a useful tool across disciplines to provide a new understanding of planet Earth and us. The objective is further to give a brief understanding of some important landscape ecological theories and principles (i.e. connectivity, corridors, barriers, heterogeneity, fragmentation) and make a deeper exploration of the sources and sinks for ecosystem health in our built landscapes.

Ecosystem health was in the thesis mainly oriented on people, nature and due to the scope of landscape architecture. The innovative approach of using landscape ecological theory enabled analyses of the function of different elements as sources and sinks (i.e. how they impact the ecosystem health dynamics). This was done for different scales (regional, landscape and site-scale) and contexts (land-use types in different matrixes: urban and sub-urban, residential and industrial). To see the potential of such an approach for landscape architects a system was developed to grade and map the functioning of elements as sources and sinks, and the system was tested on four Norwegian case-study sites as a joint assessment to map their ecosystem health. Further, final suggestions were demonstrated on how the dynamics of sources and sinks could be altered by simple interventions.

The system proved to be effective in mapping sources and sinks in sites on multiple scales and within the three systems. The joint assessment provided a holistic synergy (scales and systems) and resulted in a possible prioritization of the ultimate good and bad solutions as in common sources and sinks across the systems. Trade-offs like missing out detail when mapping and limiting the study sites to built structures were addressed in the discussion. In the thesis a new understanding of ecosystem health was proposed, the potential of ecosystem health as a more applicable approach for landscape architects in the strive towards sustainability was identified and landscape ecology proved valuable as a tool to achieve healthy ecosystems. More research and testing is required but I conclude that ecosystem health is a concept that holds great potential for achieving social and environmental sustainability for the future.

Table of contents

Glossary

There are multiple definitions for the terms used in this thesis, this glossary lists the definitions most suitable to how they were interpreted in this thesis.

Novel ecosystem
Derives from the word "novelty" that describes something new, original or in this case human made (Hobbs et al., 2006). Novel ecosystems are the result of unintended or intended human actions and some key characteristics are new species combinations or the potential to influence ecosystem functioning (Hobbs et al., 2006). Novel ecosystems are the opposite of natural ecosystems and in this thesis they are used to describe the non-natural or non-naturally emerging ecosystems in the surroundings.

Ecosystem integrity
"The ability of an ecological system to support and maintain a community of organisms that has species composition, diversity, and functional organization comparable to those of natural habitats within a region. An ecological system has integrity when its dominant ecological characteristics (e.g., elements of composition, structure, function, and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions." (p.852, Parrish et al., 2003). It is a holistic concept and framework that focuses on native biodiversity, the natural range of variations as reference points and promoting resilience (p.447, Wurtzebach & Schultz, 2016).

Biotic
Used to describe living or once-living organisms, and biotic factors are living organisms that impact their environment (National Geographic, n.d.-b). Examples of biotic factors are vegetation, animals and humans.

Abiotic
Used to describe non-living parts of an ecosystem, with an absence of life or living organisms. An abiotic factor nevertheless shapes its environment, and climate, temperatures, water are examples of abiotic factors (National Geographic, n.d.-a). Unique ecosystems comprise of biotic and abiotic factors that work together (National Geographic, n.d.-a).

Biosphere
"The biosphere is a global ecosystem composed of living organisms (biota) and the abiotic (nonliving) factors from which they derive energy and nutrients» (Gates et al., 2023).

Homeostasis
A state of equilibrium, of maintaining and achieving a stable balance in a system (Ernest, 2008).

Heterogeneity
Environmental heterogeneity is spatial or temporal variability in resources and factors. Some distinguish between biotic and abiotic heterogeneity of abiotic origins such as variations in topography, slope, aspect, micro-climate, substrate particle sizes. Biogenic heterogeneity is caused by organisms (Wilson, 2000).

Homogeneity
Absence of variation (Kolasa & Rollo, 1991).

0 Introduction

Setting the scene and presenting a problem statement and research questions.

0.1 Setting the scene

The world is in a tumultuous state in the 21st century. Status quo is increasing global warming and decreasing global biodiversity while global sustainability goals target a transition scenario with limited global warming, optimally to 1.5 degrees and an increase in global biodiversity (p.71,WWF, 2022). This chapter will look at the greatest challenges facing the Earth at the moment.

The global temperatures are increasing at a faster pace than expected, biodiversity is decreasing rapidly, nature is degraded globally due to land-use changes, the oceans are becoming more acid, global freshwater resources are decreasing, the geochemical fluxes (e.g. nitrogen and phosphorus) are changing with polluting effects harming nature and society and there is an increase in chemical pollution in the atmosphere (IPCC, 2023; Rockström et al., 2009). All of these effects further accelerate the greenhouse balance and damage terrestrial and aquatic ecosystems (Rockström et al., 2009; Sutton et al., 2011). According to Rockström et al., a group of world-leading ecologists, humanity is pushing the natural system on Earth beyond what they call its "safe operating conditions" (2009). They identified 9 planetary boundaries, see figure 0.1, that humanity need to safe guard for a sustainable and sustained development of the natural systems on Earth (2009). Climate change and biosphere integrity, also known as the nature crisis are two of the boundaries that already are exceeded to various extents.

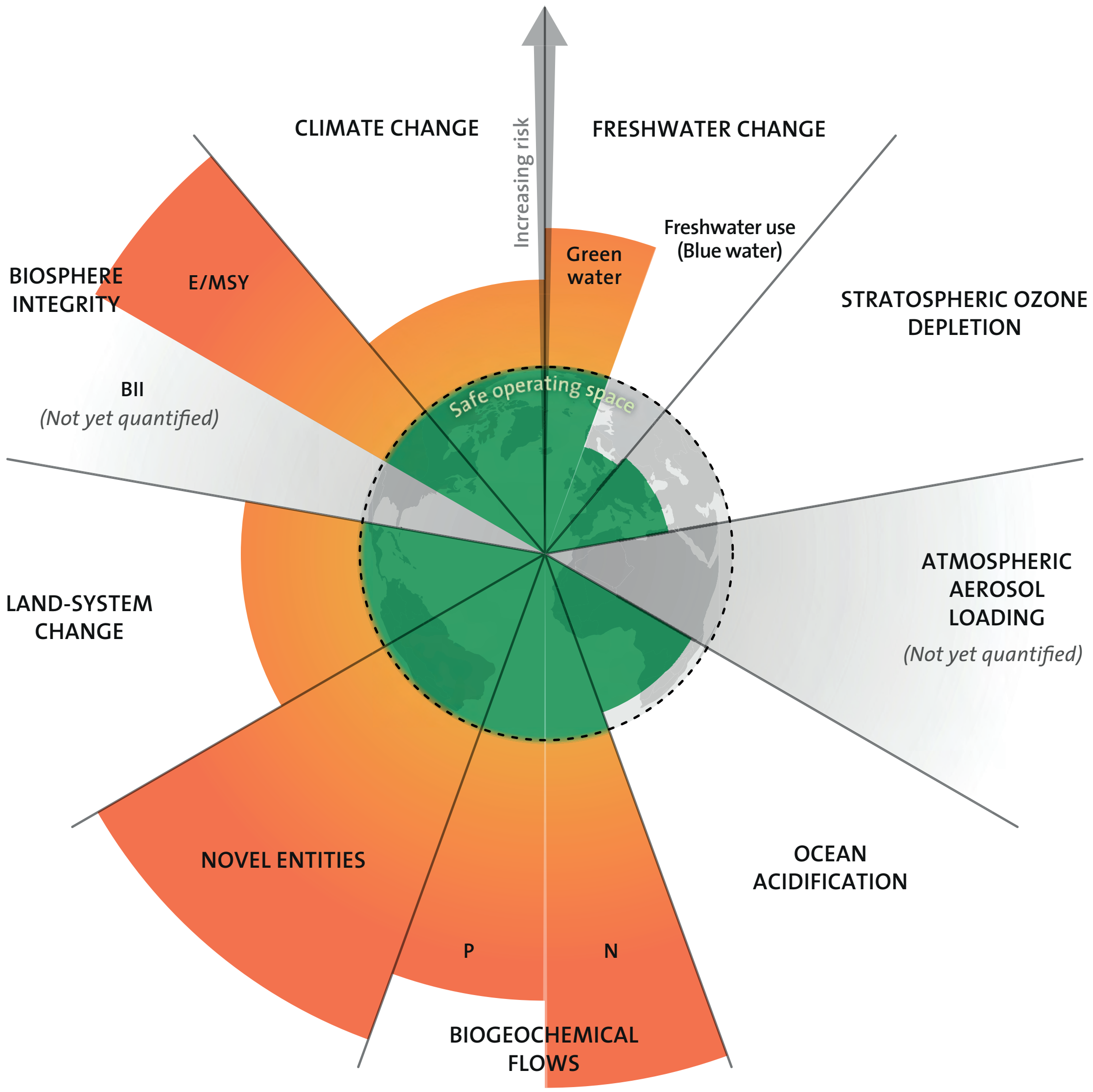


Figure 0.1 illustrating the nine planetary boundaries with their current status of exceedance in 2022. Novel entities (like plastics, pesticides and pollutants), biogeochemical flows, biosphere integrity and climate change are some of the boundaries that already are exceeded beyond their safe-operating space. Stockholm Resilience Centre.

The climate crisis

The UN intergovernmental panel on climate change (IPCC) are calling for urgent action in 2023 to limit global warming to 1.5 degrees within 2030 as the effects of climate change already are transforming societies and natural systems around the globe (Åsnes et al., 2023; IPCC, 2023; Senel et al., 2023; Ulvin et al., 2023). The window of opportunity to limit global warming to 1.5 degrees is narrowing and thereby enabling climate resilient and friendly development as seen in figure 0.2 (IPCC, 2023). Earth's biodiversity is on a trajectory towards a critical threshold that can lead to the sixth mass extinction of the worlds species, mainly driven by human activity of unsustainable use of land, water and energy (World Wildlife Fund, n.d.; WWF, 2022).

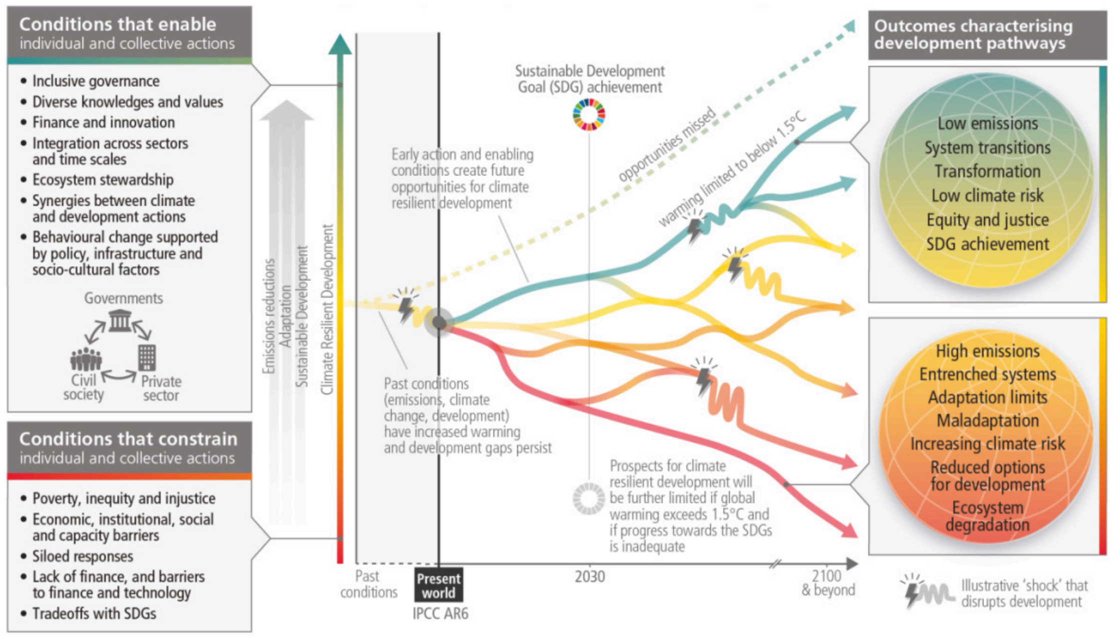


Figure 0.2 illustrating the development pathways for Earth depending on the degrees of global warming presented by IPCC (2023) with the conditions that can either enable or restrain a better or worse case scenario of different outcomes. IPCC 2023.

The nature crisis

In the Living Planet Report, WWF called it "code red for the planet and humanity" (p.6: WWF, 2022). According to the report land-use is the biggest, current threat to nature by fragmenting natural habitats for plant- and animal species on land, in the sea and in freshwaters. However, climate change is also causing biodiversity loss and is expected to become the dominant driver of biodiversity loss if efforts to limit temperature increase are not successful (WWF, 2022). The report shows an average 69 % decline of wildlife populations from 1970 to 2018 around the world due to key threats like agriculture, hunting, logging, pollution, invasive species and climate change (WWF, 2022). See figure 0.3. The report urges a nature-positive transformation in how humanity produce, govern, consume the Earth and what is financed (WWF, 2022). They called for nature- or net nature positivity (net-positive biodiversity within 2030) of having more nature by the end of this decade than at its start, with countless benefits to society, climate, nature, human well-being, food and water security (WWF, 2022).

The global Living Planet Index

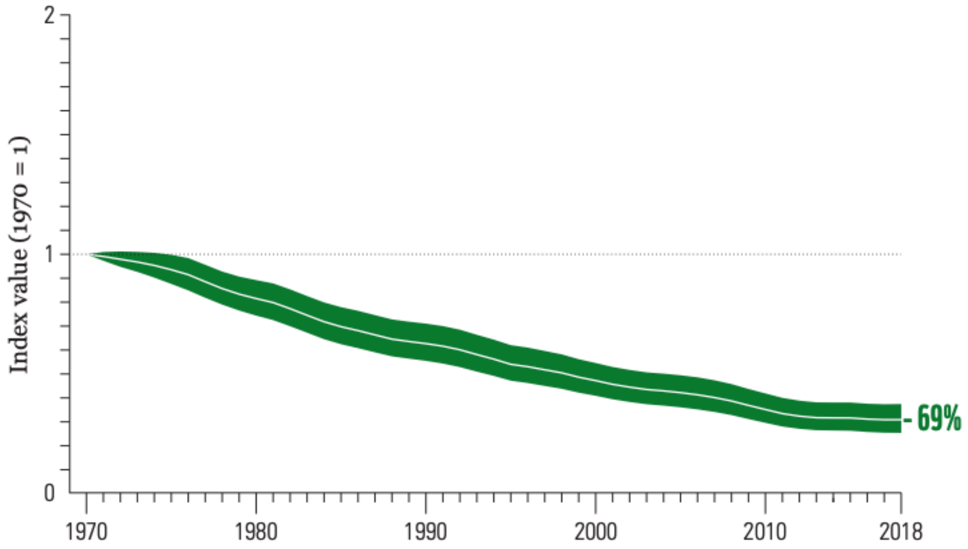


Figure 0.3 showing the 69 % decrease in relative abundance of 5 230 species across the globe of 31 821 populations. 95 % statistical certainty for the trend. WWF, 2022.

Historic nature deal

During the last UN Biodiversity Conference in December 2022 (COP 15) in Montreal a historic nature-deal was signed. As Inger Andersen, the UN Under-Secretary-General and UNEP Executive Director stressed "the conference of the Parties must secure the future of our planetary life support system" (UNEP, n.d.-b). During the opening remarks the UN Secretary-General António Guterres stressed the emergent threat "business as usual" poses to the world, causing and driving two interlinked crises of nature and climate (UN News, 2022). He called humanity "a weapon of mass extinction" that has led the world into a "cacophony of chaos" where humanity is "committing suicide by proxy" to the only planet we have (UN News, 2022b).

Some of the resulting targets of the Kunming-Montreal biodiversity agreement (CBD, 2022) were to:

- Restore 30 % of degraded ecosystems on land and sea by 2030
- Conserve and manage 30 % areas by 2030
- Reduce pollution risks and negative impacts of pollution from all sources by 2030
- Tackle climate change through nature-based solutions
- Prevent introduction and spreading of invasive alien species
- Green up urban spaces

Two interlinked crises, globally and nationally

Before the COP15 the "champions of the Paris Agreement", four of the key architects of the agreement wrote a statement in where they urged world leaders to understand that the climate and nature crises are entwined and interconnected, and that climate action will be undermined without equal measures to conserve nature (Fabius et al., 2022; UN News, 2022a). They emphasized that only by protecting biodiversity can the Paris Agreement with the target of 1.5 degrees warming be protected, and only by protecting the Paris Agreement can biodiversity be protected (Fabius et al., 2022). Net-zero emissions within 2050 is possible only through actions of delivering a nature-positive society (Fabius et al., 2022). The global panel of biodiversity of the UN called for equal action for the nature crisis and the new Nature Deal from Montreal in 2022 set ambitious goals for the world's nations to limit species extinction, sustain ecosystems and protect, restore and preserve more nature globally with cascading benefits to the climate crisis (IPBES, 2022a).

Already, bigger development projects in Norway have been put on halt due to the new targets of the nature-deal and their implications (Nyhus, 2023). The "climate law" that was legalized in 2018 in Norway is a legislation to help reach the national climate goals for 2050 however few links have, up until the latest Nature Deal been drawn between climate and nature (Klima- og miljødepartementet, 2018). What is heavily emphasized by world leaders and scientific experts is the need to stop treating these two crises as separate ones and see them as two sides of the same coin, with cascading effects of crises or benefits (Klenske, 2021).

Public health challenges

The geological epoch of today is called Anthropocene due to the dominating influence humans have had on Earth-system processes (Leichenko & O´Brien, 2019; Steffen et al., 2015). "Business as usual" has pushed forward fundamental changes to the systems on Earth that have been stable for centuries (Steffen et al., 2015). However, humanity is also in a tumultuous phase with increasing pressures to solve the crises they have caused and an increasing global population (United Nations, n.d.-b). The global population passed 8 billion people in 2022 which was considered a historic milestone in human development (United Nations, n.d.-b). The population is expected to continue to increase even more rapidly, and reach more than 9.7 billion within 2050 (United Nations, n.d.-b). This means increasing demands and pressures on Earths systems to sustain global societies with detrimental support like food, human habitat and possibility for societal development.

Despite a global population increase there are other types of public health challenges that dominate in the 21st century than those of communicable diseases and viruses. Some of the pressing challenges are climate change to cause extreme weather conditions and climate anxiety, people spending more time indoors and on screens, insufficient physical activity levels, especially for young people, a mental health crisis of increasing mental health issues around the globe and more people feeling less connected to nature and society (Clayton, 2020; Gibson et al., 2020; Guthold et al., 2020; Hansen, 2021; Lucero-Prisno III et al., 2023; Ogunbode et al., 2022; White et al., 2021; WHO, 2015; WHO, 2022; Wilson, 1984)

Urbanisation

A growing part of the global population are moving to cities and currently more than 50 % of the global population resides in cities (The World Bank, 2023). The urban population is expected to increase 1.5 times within 2045, to 6 billion (The World Bank, 2023). This put increasing pressures on cities to fulfil the requirements and needs for people to live healthy, happy lives (The World Bank, 2023). In addition it urges sustainable development and economic growth as more than 80 % of the global GDP is generated in cities (The World Bank, 2023). Urbanisation challenges land-use planners as growing cities require sustainable sprawl rather than the opposite that can have detrimental effects to land and natural resources in providing essential services and benefits to humanity like food production and publicly available recreational areas (The World Bank, 2023). Currently the expansion of urban land outpaces population growth of 50 % (The World Bank, 2023). As with Oslo, the surrounding areas might be at stake when the city will expand, figure 0.4 and 0.5.

Figure 0.4 Map of Oslo, showing the city edges bordering to the Oslofjord and the Oslo forest (Oslomarka). Typically developed areas are previous agricultural- or natural areas. For the scenario of urban sprawl of Oslo thoughtful planning is required to leave the forests untouched. Maps from Applemaps.

Figure 0.5 of Oslo from its front by the fjord. Water and forest seems to embrace the city.

Land-use change

Human activity has significantly altered 75 % of the land surface on Earth and 66 % of ocean areas like from fisheries and pollution (UNEP, n.d.-a). Land degradation affects 40 % of the global population and 25 % of global greenhouse gas emissions are generated by land use changes like fertilization, crop production and land clearings (UNEP, n.d.-a). Global food production is the primary driver of biodiversity loss and 70 % of the projected loss of terrestrial biodiversity is said to be caused by agricultural expansion (UNEP, n.d.-a).

The amount of novel versus natural ecosystems is increasing, evident as one of the main drivers of climate change and one of the planetary boundaries is land-use change (Steffen et al., 2015). Currently the expansion of urban land outpaces population growth with 50 % and it is expected that new urban built-up land will take up 1.2 million km2 in 2030 (The World Bank, 2023). That is an area the size of Norway four times, of existing land that will be developed, subject to land-use change and urbanization (NationMaster, 2008; Worldometer, n.d.). In Norway the type of area that is most built down is forests and agricultural land for the land-uses of buildings and roads (Søgaard et al., 2021), see figure 0.6.

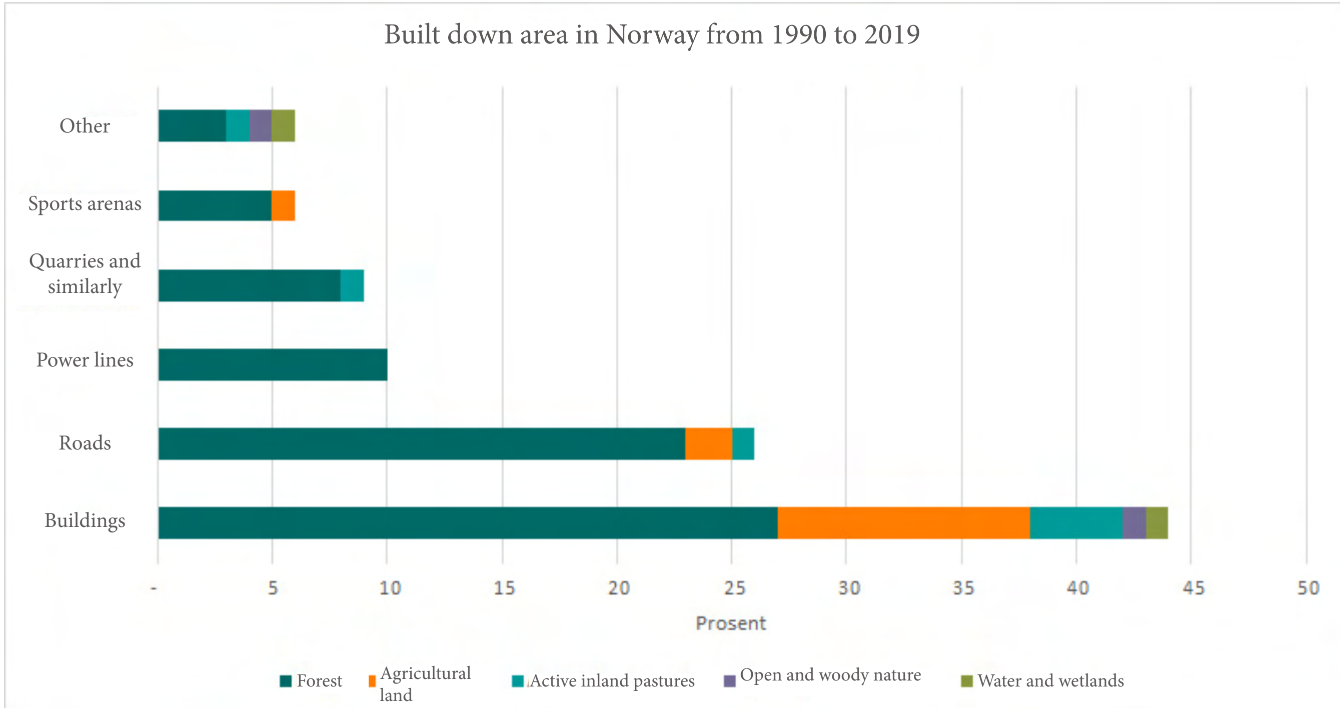


Figure 0.6 showing the development of built down area in Norway from 1990 and 2019. Land types that are most built down are forests and agricultural land, while it is buildings and roads that are the most built land-use types. Miljødirektoratet 2023, based on statistics from Søgaard et al. (2021). Translate to English by me.

Landscape architecture in a tumultuous world

There are challenges both in the natural and social systems of Earth and there is a call for action in a number of fields. These challenges are in the hands of landscape architects and land-use planners. There is a need to build green, resilient and inclusive cities that can be sustainable and at the same time be adapted to and mitigate climate change (The World Bank, 2023). The IPCC urged planning of urban systems that could reduce emissions and advance in climate resilience (2023). At the same time urban systems should promote public health by facilitating active mobility, well-being of ecosystem services by green and blue structures, climate regulation like urban cooling and reduced vulnerability to changes (2023).

Landscape architects work with a number of elements in the Earth system, see figure 0.7, but mainly focus on the natural system with ecological and environmental matters like geological, climatic and botanical, and the social system with matters of promoting public health, facilitating social inclusion and public availability, coherence, recreation and community spaces (Dramstad et al., 1996).

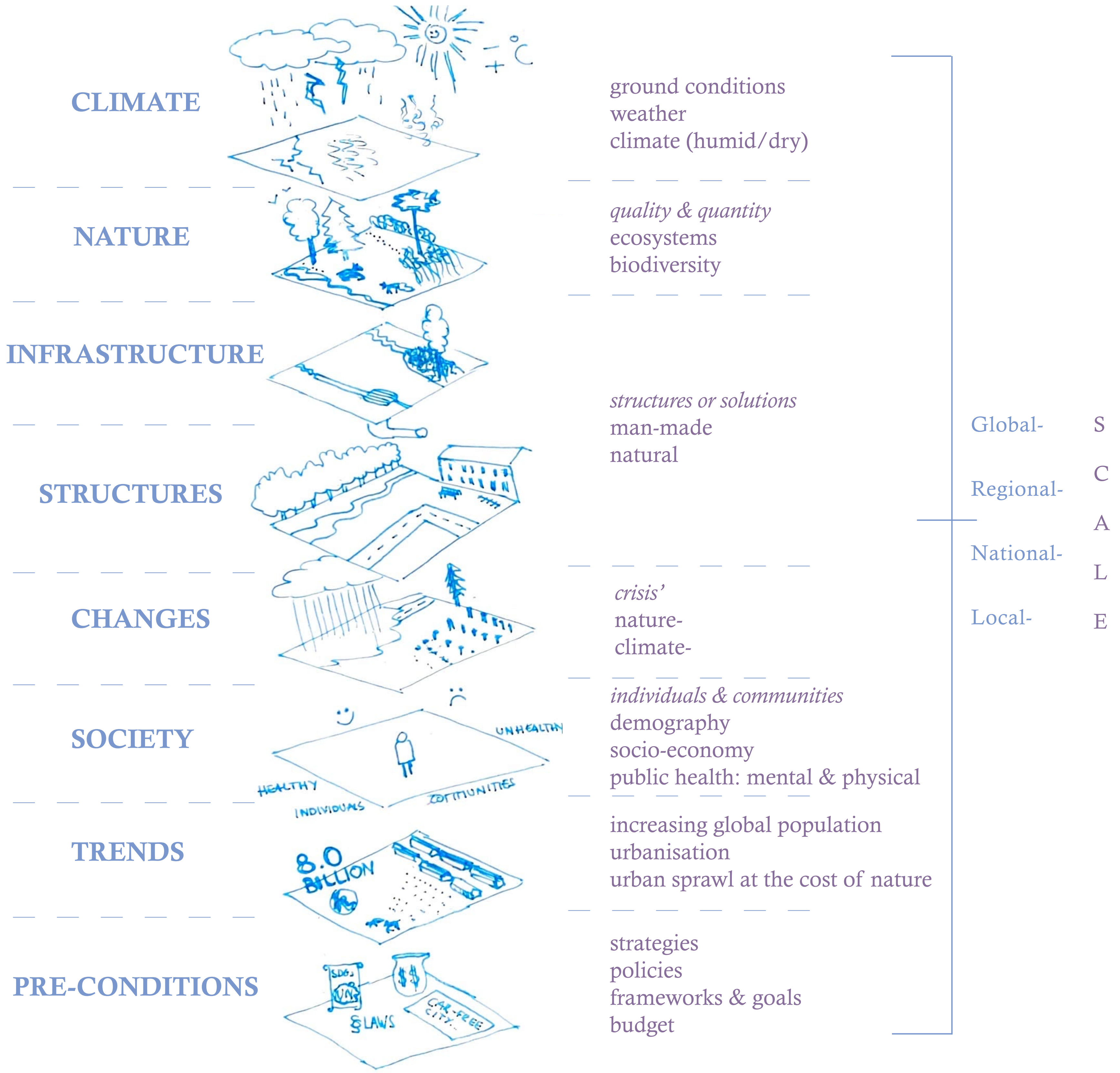


Figure 0.7 with illustrations of some of the elements landscape architects have to consider and deal with during landscaping like climate and nature, structures, changes, society, trends and pre-conditions like laws, frameworks, conflicting interests, politics and budgets. These are considerations on a global, regional, national and local scale.

Conflicting interests and land-uses

The significant role of land-use change in the climate- and nature crisis calls for landscape architects to find solutions that can mitigate these negative impacts, boost nature while at the same time enable as healthy and happy societies as possible. As the Living Planet Report (2022) emphasized, all land users contribute to landscape changes or influences through individual, collective and collaborative actions (WWF). There are often conflicting interests and competing land-uses simultaneously in different landscapes, as visualised in the thematic maps below, figure 0.8. These lead to constant compromises and prioritizations in planning processes.

Figure 0.8 A
showing a thematic map of untouched nature areas graded from dark to light green in a descending order of distance between landscape interventions and untouched nature.

Figure 0.8 B
showing a thematic map of nationally preserved recreational areas.

Figure 0.8 C
showing a thematic map of living areas for wild reindeer.

Figure 0.8 D
showing a thematic map of nature reserves.

Figure 0.8 E
showing a thematic map of valueable cultural landscapes.

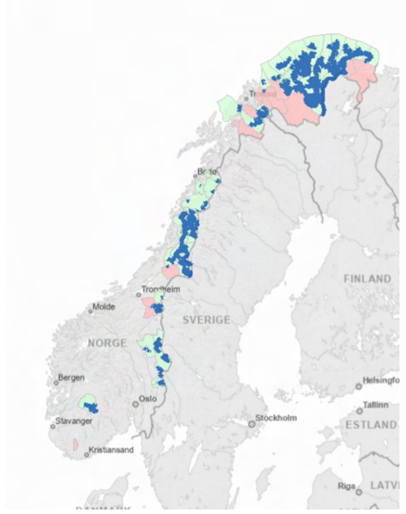


Figure 0.8 F
showing a thematic map of snow scooter trails.

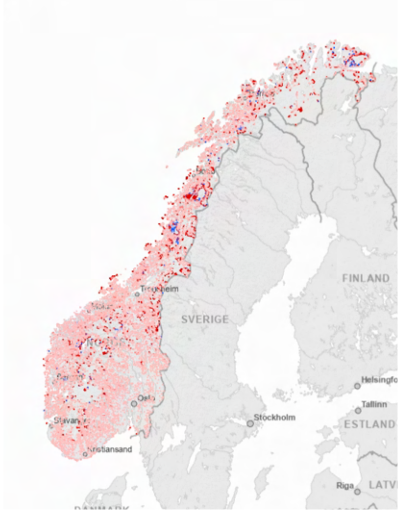


Figure 0.8 G
showing a thematic map of developed areas from 1988 to 2018.

Figure 0.8 H
showing a thematic map of hotspots for threathened species.

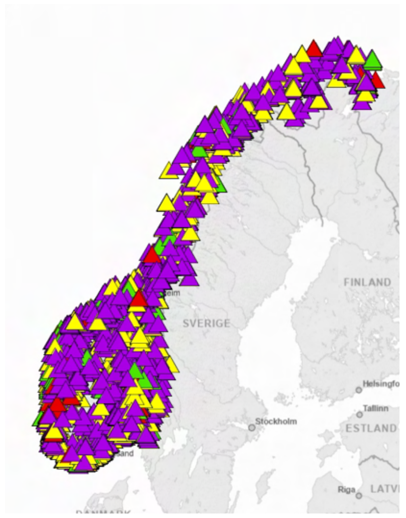


Figure 0.8 I
showing a thematic map of polluted ground.

0.2 Problem statement

Landscape architects are one of the lead actors in sustainable land-use development, however the aim of sustainability might not be the most applicable for actual projects and designs. Achieving social, environmental and economic development simultaneously can be challenging, and way too often prioritizations are given to certain elements at the expense of other. I want to explore another approach to sustainability for landscape architects in where people, nature and the climate is prioritized and social, ecological and environmental sustainability is achieved. With my thesis I want to discover the potential of an ecosystem health approach for landscape architects to achieve sustainable development.

Landscape architects have to deal with a multitude of factors and use different approaches when designing. Landscape ecology is a science field that through a simple language logically explains the effects of land-use and human activity for ecosystems and biodiversity on multiple scales. The understanding a landscape ecological approach provides of what a landscape is and how it works has been priceless for me as a landscape architect student.

I want to test the potential of landscape ecology as a tool for landscape architects in the attempt of achieving sustainability with healthy ecosystems. I want to illustrate the links between what we design and the impact it makes to the ecosystem health and provide inspiration of alternative ways to do things. As Special Representative Aboulgmagd stressed during the COP27, there is a dire need for progress, not in words but in actions and implementation (UN News, 2022a). With this thesis I hope to make sustainability more applicable by showing how the strive towards healthy ecosystems can be implemented in planning and landscape designing through illustrative examples of implementation. My compassion for nature and the Earth' systems makes saving the world imperial and that is what I am hoping I can contribute with as a landscape architect.

Research question:
What potential does an ecosystem health approach have for landscape architects to achieve sustainable land-use development?

To answer this, the research question is broken down into three sub-questions. They are:

1. **What is ecosystem health?**
2. **Why is ecosystem health relevant for a sustainable land-use development?**
3. **How can landscape architects create healthy ecosystems?**

These will constitute the three main parts of the thesis. Within the three questions related elements will be addressed and studied in a logical order. For further details, see the table of contents or outline.

0.3 Method

In order to answer the research question these methods were used:

I Literature review

To answer the first sub-question a literature review was conducted on the existing literature on ecosystem health to get a grip of the concept and its role in society. The aim was to achieve an understanding of the concept as it is today with its definitions, implications and suggestions to explain its limited use. As the concept is not much used in landscape architecture, additional theories from other science fields (philosophy, social science, public health, economy) were analysed to see if they could add to a broader understanding of the concept that could make it more applicable to landscape architects.

To answer the second sub-question empirical data was collected to create a scientific evidence base of the challenges present in the world to argue for the unhealthy state of the world. A literature search was conducted to search for theory and methodology used by landscape architects and to support the conception that there is a lack in these for the profession.

To answer the third sub-question a literature review was conducted on landscape ecology to present the history of the profession, the foundation of the theory and main principles. A literature search was done to see if ecosystem health had previously been linked to landscape ecology. Literature was also reviewed to understand the scale and context dependence within landscape ecology that was relevant to ecosystem health.

II Developing a system

A system was developed to test if the landscape ecological principles of sources and sinks could be used to determine the function typical elements could have in outdoor rooms for the ecosystem health. Empirical data was collected on the evidential negative and positive effects of elements, and the data was summarized in a table (”table on source and sink elements”). The data can be found in appendix 1.
From this, a gradient was developed with criteria for achieving different scores (”source and sink gradient).

III Case study

To test the developed system a joint assessment of four Norwegian case study sites was conducted. The sites were chosen based on their representative characteristics for typical land-uses. Landscape ecological theory was used for conducting the case study analyses to identify the function of the present landscape metrics. For a final, joint assessment of source- and sink function in the sites, common functions within the three systems assessed were identified, inspired by McHarg spatial overlaps or layer cake model.

Development of thesis idea

IV Field trip

18.-25.02.23
In february a field trip to Berlin, Germany was done to study green structures in a city known for its high biodiversity. The aim was to see as many solutions as possible for typical grey and green structures relevant to landscape architects like fences, parks, vegetation and planting regimes, mixed plantings, nature conservation efforts and biodiversity protection in public parks, informational signs, use of outdoor lighting in parks, zoning for different types of use in green areas.

The outcome of the field trip was a realisation of the fact that the previous idea for the thesis, a proposal of optimal, better solutions always depend on what the objective was and to whom they were directed. A better solution for a dark and scary park for the social system would be to implement a better light regime, but that would give a negative contribution to the ecological system. This was a significant discovery that made me rethink the thesis as in what the objective and research question should be, and how I could suggest improvements that would take this context dependency into consideration. The field trip and case study sites visited was not used directly in the thesis as much as expected and intended when planning the trip, however the results and discoveries derived from it became so imperative that they changed the course of the thesis.

0.4 Outline

The thesis is divided into three parts to answer the three sub-questions of the research question. These three parts constitute of literature, theory and discussions to answer the sub-questions accordingly. The parts build on each other and the answers of the sub-questions in their respective parts sets the premises for the following so the thesis should be read chronologically.

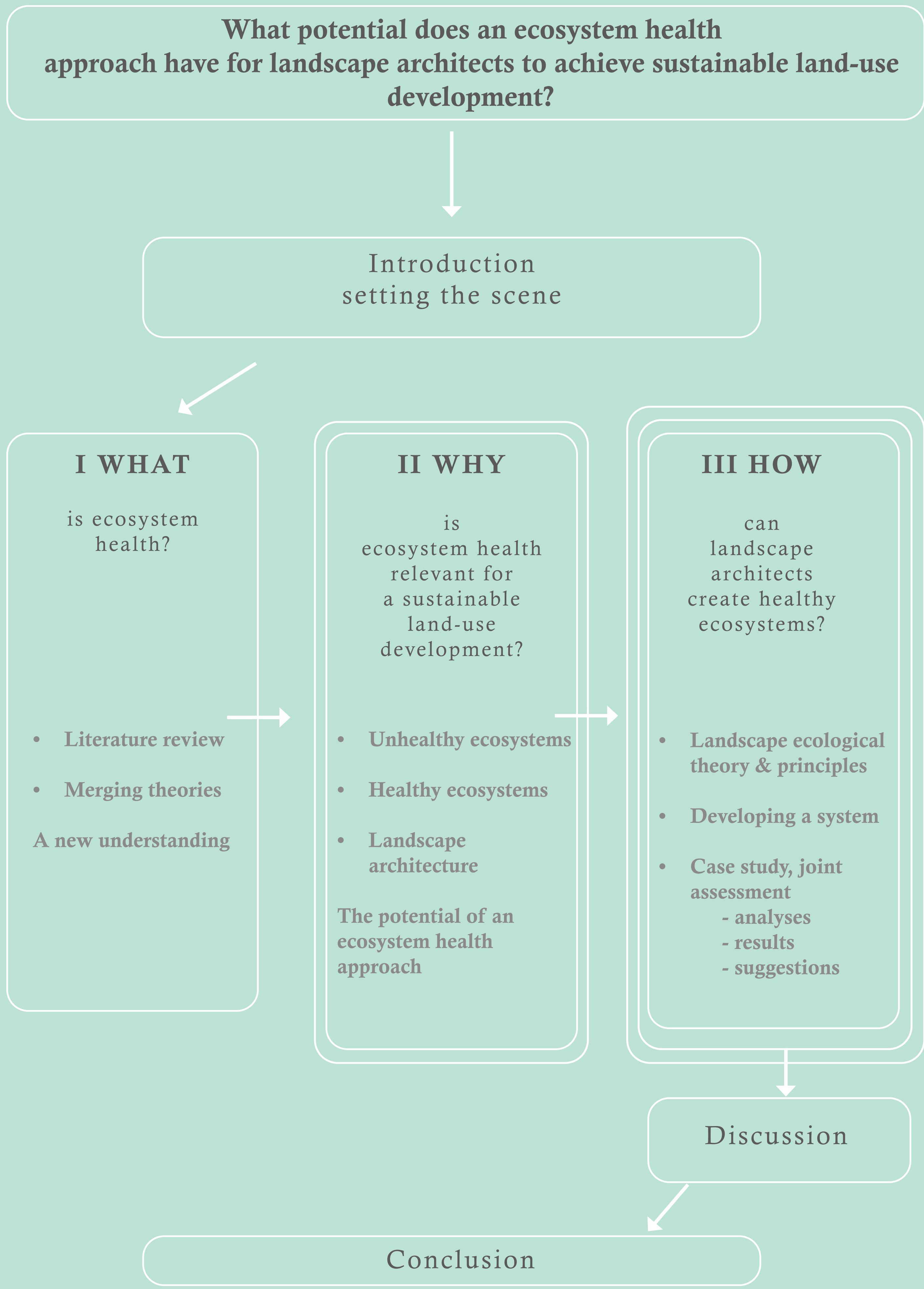
0 - Introduction
By setting the scene, the background and relevance of the thesis is presented. The problem statement and research questions are introduced together with the outline and methods used.

Part I - What is ecosystem health?
Exploration of the concept with its evolution, definitions and use found in a literature review. Additional theories that can evolve the understanding of the concept are presented, leading up to a discussion of a new understanding and its applicability for landscape architects.

Part II – Why ecosystem health for a sustainable land-use development?
Examples of unhealthy ecosystems in the world are presented through three current crises followed by outcomes of healthy ecosystems with the benefits they can provide. Landscape architecture and the lack of theory for solving problems is addressed, followed by ecological theoretical approaches. Finally, landscape ecology is introduced as a theory for landscape architects with ecosystem health as objective.

Part III – How can landscape architects create healthy ecosystems?
Focusing on how healthy ecosystems can be achieved through landscape ecological theory that is introduced, with a reflection of its applicability to ecosystem health. Sources and sinks are chosen as core principles, and context dependency is addressed. A system is developed for testing the function of typical elements in outdoor rooms by scoring them according to their function as source or sink to the ecosystem health. A gradient for the scoring sheet with criteria is developed. To test the developed system, it is applied to 4 Norwegian case study sites where a joint assessment of the whole landscape, landscape metrics and elements' functions are analysed. Finally, suggestions of simple interventions that can change the source-sink dynamics are demonstrated.

Part IV - Discussion and conclusion
The thesis research question and sub-questions are discussed, with the developed system and the developed system for scoring elements. Suggestions for future research are introduced, with a final conclusion.



I **What** is ecosystem health?

Exploration of the concept with its evolution, definitions and use found in a literature review. Additional theories that can evolve the understanding of the concept are presented, leading up to a discussion of a new understanding and its applicability for landscape architects.

Ecosystems

A shopping street in the middle of a city comprises of an artificial environment with hard surfaces, big buildings and materials like glass, concrete, asphalt and stone. The present biodiversity mainly consists of humans, pets, maybe some sea gulls, pigeons and some rats at night. Surface water is led to pipes and climatic factors are regulated to benefit human activity like granite tiles preventing a muddy ground cover. There is a strong presence of infrastructure like outdoor lights, outdoor furniture, vehicles that produce noise pollution and light pollution that can hinder night sky vision. The microclimate in the streetscape is different than for the park across the street with a higher average temperature due to the urban heat island effect caused by the heat-absorbing materials in the streetscape.

In the park hard, artificial surfaces are replaced by vegetation, tree canopies, lawns and permeable ground cover for walking paths. The present biodiversity is higher with additional organisms like pollinating insects, butterflies and more bird species, and at night animals like roedeers or foxes can be spotted. Surface water is absorbed by the vegetated surfaces and there is less controlling of the natural elements. There is still a presence of infrastructure like outdoor lighting, but vehicles are not a regular element in the park, the vegetation can buffer some of the surrounding noise and there is typically less light pollution so the stars can be seen during the night. The microclimatic conditions are significantly different with cleaner and cooler air due to the vegetation. In addition, tree canopies provide comfortable shade to the visitors of the park. These two scenarios might seem contrasting, but both are ecosystems.

Figure 1.1 Illustrations of two types of ecosystems.

Ecosystem

According to Alimov (2000) ecosystems are present where there are interactions between living organisms (humans, pets, wild animals) and their shared, abiotic environment (i.e. buildings, infrastructure, vegetation). Ecosystems are dynamic in that they are unique in time and space (Gillson & Willis, 2004). By most people, ecosystems are considered as something separate from humans (Bormann 1996). But they comprise of a space and time component, various organisms (e.g. humans, pets, pathogens, wild animals) that live together and form communities (e.g. urban settlements, rural, forest biomes, deserts) (Alimov, 2000). In ecosystems there is regularity in the interrelations and -dependence between the organisms, communities and their physical environment (Alimov, 2000). Therefore, ecosystems can be both novel or artificial and natural i.e. cities, neighbourhoods, forests or entire regions can all be considered ecosystems. Novel ecosystems entwine artificial and ecological infrastructures; being water and vegetation in or near built environments (the hinterlands) that interact in delivering ecosystem services at multiple scales (Gómez-Baggethun et al., 2013). Cities have for long been categorized as different types of systems like economic, social or ecological by dominating characteristics such as flow of money (Douglas, 1981). They have also been characterised as "dynamic ecosystems" (Douglas, 1981).

Health

Health is complex as a value-based judgement normally assessed by, and of humans (Rapport, 1989). Health is as Rapport reflected upon unique, relative and a subjective state set in a context of influencing factors (1995; 1999). The human environment can play a significant role for the health of people and there is profound literature and theories (e.g. the Biophilia hypothesis) that support the fact that certain environments (e.g. natural, green, vegetated) are more health stimulating than others (e.g. grey, artificial surfaces), both physically and mentally (Wilson, 1984). Therefore, the way people are affected indirectly or directly by different types of ecosystems can be significantly different both in relation to environmental conditions impacting physical health conditions like air quality and urban heat and in relation to the feeling of well-being, decreased stress levels, lowered blood-pressures and similarly (Jimenez et al., 2021).

1.1 Literature Review

'Ecosystem health' has a surprisingly long history. Ecosystem health comprises of two concepts, 'ecosystem' and 'health'. According to Alimov (2000) an ecosystem is localized in space and dynamic in time. It is set of various organisms that live together and form communities and the conditions of their existence (2000). They are in regular relationships with each other and form a system of interdependent biotic and abiotic processes (2000). Ecosystems are "unique in time and space" (p.995, Gillson & Willis, 2004) and need to be understood not as "disembodied entities" like economic markets but rather as "living, complex, interacting systems" (p.87, Rapport et al., 1999). Health is mostly applied to human and animal sciences and good health is by the World Health Organization (WHO) defined as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." (p.1, United Nations, 1946). An expansion of the concept of 'health' and 'ecosystem' lays in the foundations of 'ecosystem health'. Following comes a chronological review of the evolution and development of the concept based on some key publications.

Evolution of the concept

The first traces of ecosystem health can be found in the writings of the Scottish geologist James Hutton who in 1788 described Earth as one, integrated system (Rapport et al., 1999). Naturalist and acknowledged author Aldo Leopold followed up the idea in his writings of land ethics and land health in 1949, a science that he proclaimed to be science and work for the future (Leopold, 1949; Lo, 2009; Rapport et al., 1999). In his land ethics he associated 'health' with beauty, stability and integrity of the land and emphasized that a thing was right when it tended to preserve this in a biotic community and wrong if it tended otherwise (p.224-225, Leopold, 1949; Lo, 2009). Leopold did not include the abiotic environment as part of the cyclic relationships in ecosystem, something he was criticized for later on (Lawler et al., 2021) (Lo, 2009). These were some of the publications that first introduced 'ecosystem health' as a concept.

In the late 1970s and 80s a number of publications elaborated on the concept of ecosystem health (Rapport et al., 1979; Rapport, 1981; Rapport et al., 1985). David Rapport was one of the key authors with an interdisciplinary background of engineering, business administration, economics and behavioural ecology (Rapport, n.d.). The similar, diagnostic challenges between determining health for individuals and whole ecosystems was emphasized (Rapport et al., 1999). What health for ecosystems should be based on was examined (i.e. ecosystem persistence or resilience) and what the syndromes or symptoms (indicators) of unhealthy ecosystems would be (i.e. primary productivity, species diversity etc.) (Rapport et al., 1979). Symptoms of unhealthy ecosystems were investigated by Rapport et al. (1985) as common responses of dysfunction in both terrestrial and aquatic systems. Changes in productivity, nutrient cycling, species diversity and dynamics within species dominance were considered potential indicators of unhealthy systems (1985). Typical stressors could be harvesting, pollutant discharges, introduction of exotic species, physical restructuring and extreme natural events like storms or volcanic activity (1985). Inability to cope could lead to further dysfunctions or even to irreversible ecosystem breakdown (1985).

Background for concept evolution

According to ecologist Ramade (1995) the Gaia Hypothesis developed by Lovelock (1972) played a determining role in how the scientific environment accepted these two, distinct concepts (health and ecosystems) together. The hypothesis proclaimed that Earths non-living abiotic environment and biotic systems behave as one entity that is self-regulatory through complex interactions (Aoki, 2012; Boston, 2008; Lovelock, 1972). The second explanation Ramade came with for the acceptance of ecosystem health as a concept was the medical perspective in which society saw its total dependence on functioning nature and thus a societal interests to protect the natural environment for the sake of human health emerged (1995).

The relation between society and ecosystems was an emerging concern and landscape architects like Ian McHarg (1969) started addressing the role of humans as stewards of the Earth.

Defining the concept

Costanza et al. (1992) lifted the complexity and cross-disciplinarity within ecosystem health of economic, social and environmental aspects and that it (ecosystem health) had several meanings (i.e. philosophical, societal, medical, biological) (Kuznetsova & Manvelova, 2022; Rapport et al., 1999). Costanza et al. (1992) also gave one of the first and much acknowledged definitions: "An ecological system is healthy and free from "distress syndrome" if it is stable and sustainable – that is, if it is active and maintains its organization, and autonomy over time and is resilient to stress" (p. 9). Mageau et al. (1995) elaborated on this and added operational measures of vigor (productivity), organization and resilience to the definition. The stability prospect from Costanza et al. of 1992 for ecosystem health has become a ground pillar in defining the concept, also referred to as 'homeostasis'. The two fundamental considerations of ecosystem health according to Rapport (1989) to be 1. Ecological integrity to be preserved and 2. Ecosystem sustainability is present in these definitions.

Rapport also elaborated on that these two needed to be addressed in the three-dimensional spheres of ecosystems: the atmosphere, litosphere, hydrosphere and biosphere (Rapport, 1989). In 1995 Rapport added sustained function, self-maintenance and repair as key aspects for healthy ecosystems. Bormann (1996) first touched upon the concept of humans as an integrated part of ecosystems, later elaborated on by Rapport et al. (1999). "Understanding the forces of transformation of the earth's ecosystems calls for a holistic approach in which humans are 'part of' and not 'apart from' the ecosystem" (p. 83). Critics of the definitions argued them to be too vague and that biological, direct measures of ecosystem conditions would be more appropriate (Karr, 1999). How did the use of the concept further evolve in society?

Difficulties with the concept

Even though the concept had been discussed in a number of scientific publications the nature of the health metaphor/analogy in relation to ecosystems was still under discussion in the late 1990's (Rapport, 1995). According to Rapport (1995) the analogy of ecosystems as organisms was debated upon with their non-definable nature of unbounded entities. In addition, the nature of health science to be geared at individuals was argued for by some to not give it (health) validity beyond individuals (1995; Rapport et al., 1999). Critics would also focus on the non-scientific, value-based judgement for defining health in relation to ecosystems that Rapport (1989) early addressed as a relativity concern (Rapport, 1995).

However, as Rapport (1995) accentuated, adoption of ecosystem health as a societal goal and as a recognised objective, almost as a bottom line for sustainable development had already been recognised by national policies and in regional development and environmental concerns in 1995. Following Rapport (1995) the value of the metaphor was both its powerful, underlying holistic model that stressed the human and non-human forces that impacted ecosystem health and the transfer of scientific basis for assessing health (from other scientific fields) that put a focus on curative as well as preventive health practices (Rapport, 1995).

The challenges of 'health'

The 'health' aspect of the concept is complicated. Human health is a relative matter explained with the model of health determinants by Dahlgren & Whitehead from 1991 that still has relevance today, see figure 1.2 (Dahlgren & Whitehead, 2021). A number of socio-economic and individual factors like norms, values and beliefs play a role in defining what is sick and what is healthy, how to treat illness and achieve good health (Dahlgren & Whitehead, 2021). Good health has been defined as a state of surplus to tackle the demands of everyday life (Hjort, 1982) or as the ability to realise goals and challenges set upon one (Nordenfeldt, 1993; Nordenfeldt, 1995; Wacherhausen, 1994). By so, good health has been discussed not only as the absence of sickness but also as a measure of "life-strength", capacity or resilience (Bronfenbrenner 1979).

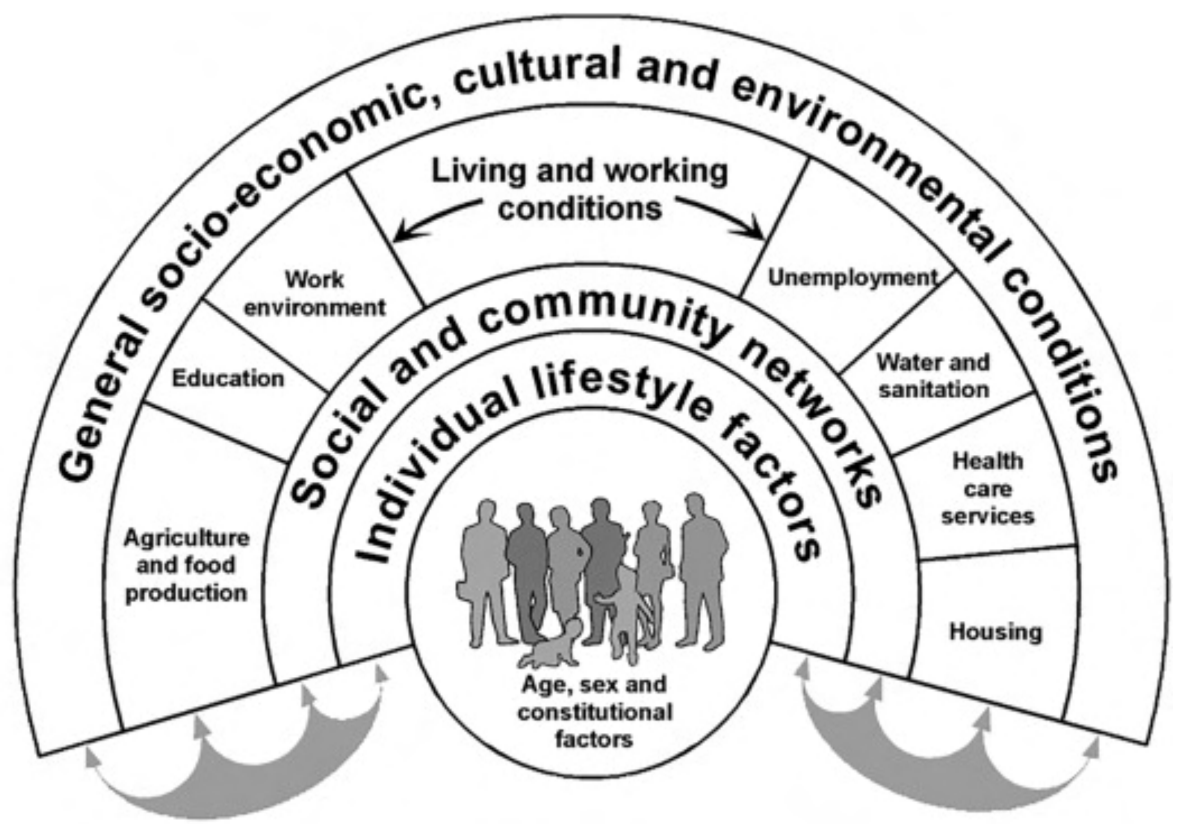


Figure 1.2 The Health Determinants Model by Dahlgren & Whitehead (1991) illustrates a number of health determinants that can affect an individual's perception and relation to health.

Also in means of determining what constitutes health for ecosystems it is a subjective indicator performed by, and on the basis of human values (Rapport, 1995). This emphasizes the need to find objective indicators that do not favour some effects of ecosystem health above others (e.g. ecosystem services from healthy ecosystems cannot be provided at the expense of the system resilience or vigor for its own functioning) (Rapport, 1995).

Scientific establishment of the concept

In 1996 the first international symposium on Ecosystem Health and Medicine was held in Ottawa, USA by the newly founded International Society for Ecosystem Health (ISEH) (Rapport et al., 1999). Transdisciplinary thinkers with backgrounds from economy, ecology, medicine and veterinarian medicine agreed that the discussions on the potential of merging these sciences into ecology needed to be brought to a wider forum and thus ISEH was formed (Rapport et al., 1999). ISEH wanted to engage scholars from a number of scientific fields to bridge or transcend the gap between the natural, social and health sciences (Rapport et al., 1999). “A primary goal was to provide the conceptual and methodological foundations for assessing the condition of the Earth’s ecosystems” (p.82, Rapport et al., 1999). With their first conference more than 800 participants from 33 countries discussed interfaces of ecology, public health, environmental management, ethics, philosophy, ecological economics and more, and the cross-disciplinary potential of the concept gained momentum (Rapport et al., 1999).

What halted further development and use of the concept?

In 1999 Rapport et al. reflected upon the hurdles of the concept to understand why the development of an ecosystem model had been limited so far. They gave two possible explanations: the first was the nature of the concept to be cross- and transdisciplinary, thus falling between disciplines in the scientific world (Rapport et al., 1999). The second was the challenge of defining the concept as “’health’ is one of those elusive properties that is better recognized (observed) by its absence” (p. 84). They addressed the contextual nature of ecosystem health that as with human health, some responses of stress are common whilst others are unique features determined by the ecosystem context (Rapport et al., 1999). They were also the first to lift the matters of scale, and Palmer & Febria (2012) later emphasized the complexity within the interactions that occur in ecosystems and their response as a matter of context dependency. They urged the need for a framework to assess ‘ecosystem health’ as both structure and function (Palmer & Febria, 2012).

Sustainability takeover

The Brundtland commission first presented sustainable development in 1987 as a way of developing the world without it being at the expense of nature, the environment or future generations (The World Commission on Environment and Development). In 2015 the three pillars of sustainability (economic, societal and environmental) were utilized within the UN Sustainable Development Goals (SDGs) as 17 systemic goals covering different factors of society. These were set to be reached within 2030, in line with the Paris Agreement of all membering countries of the UN (United Nations, n.d.-a). As Rapport already proclaimed in 2007, achieving healthy ecosystems should be considered a cornerstone in sustainable development as “healthy ecosystems are the essential precondition for achieving sustainable livelihoods, human health, and many other societal objectives” (p.1). He lifted the potential of an Eco-health approach within sustainability science as unique means to reach the SDGs (2007). As Rapport (2007) suggested, that should be done through restoration of ecosystems and landscapes in accordance with the indicators of ecosystem health: resilience, organization, vitality (productivity) and absence of distress syndrome. Following Rapport (2007), healthy ecosystems were the pre-condition for, but also the objective of sustainable development. Despite their similarities it can seem like sustainability took over for ecosystem health as a leading concept due to the attention it received and the utilisation through the SDGs. Nevertheless, their foundation shares many of the same values and objectives.

Connected health

Connecting human, animal and ecosystem health was in 2008 put in a framework of “One World, One Health” with a shared goal – achieving improved health for all (Harvey, 2010). The strategic framework arose as an initiative by WHO, UNICEF, FAO, the World Bank and UN System Influenza Coordination (Harvey, 2010). It ceased to break down barriers between different interests to set upon improving the health of people, animals, wildlife and ecosystems (Harvey, 2010). This was important as an early, international framework that addressed the unity of the issues as addressed in ecosystem health. During the Covid-19 pandemic, the topic was naturally brought back.

Already in 2010 Harvey elaborated upon the need to build cross disciplinary bridges to protect health and talked about “connected health” with respects to the interdependencies of the three (human – animal – ecosystem). She emphasized the communication between different science fields to often shortfall in addressing “connected health” (i.e. identifying ecosystem services as a pre-condition for human survival and not linking it to the pre-condition sustainable land-use is for ecosystem integrity for provision of ecosystem services). As Harvey (2010) addressed, successful collaborations were the highest leverage points for successful policies, actions and outcomes. This confirmed the value Rapport et al. (1999) put on cross disciplinarity as a core in ecosystem health. To quote senator J. William Fulbright (1989) on the value of cross disciplinarity: “The essence of intercultural education is the acquisition of empathy – the ability to see the world as others see it, and to allow for the possibility that others may see something we have failed to see, or may see it more accurately.” (p.217, Fulbright, 1989).

Transdisciplinary use of the concept

Interestingly the concept of ecosystem health has established in a variety of scientific fields that go beyond the biological domain (Hyrynsalmi & Mäntymäki, 2018). In their publication, Hyrynsalmi & Mäntymäki looked into the different uses of ecosystem health with roots back to 1993 where it was introduced within 'business ecosystems' (Moore, 1993). Today the analogy of ecosystems and ecosystem health is found within 'innovation ecosystems', business ecosystems', 'product ecosystems' etc. and the widespread use implies the value of the analogy (Hyrynsalmi & Mäntymäki, 2018). Within business ecosystem research, ecosystem health is defined as "if the ecosystem is healthy, individual participants will thrive; if the ecosystem is unhealthy, individual participants will suffer" (p.5, Iansiti & Levien, 2004).

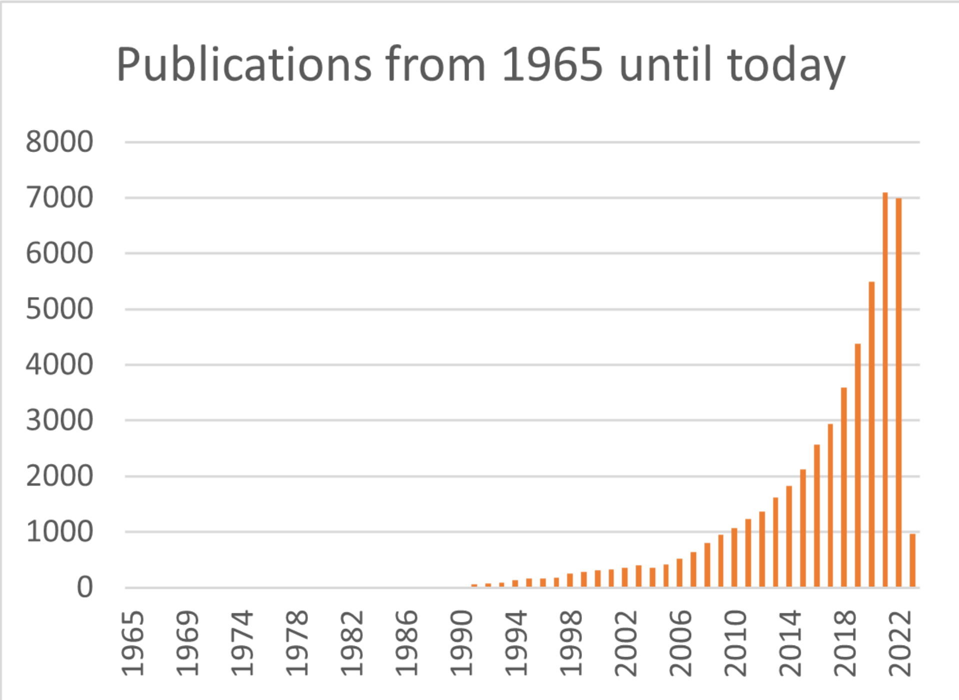


Figure 1.3 showing the history of publications on ecosystem health from 1965 until Today. The first publications came before the once that were included in this literature review but only the ones relating to ecosystem health in the biological "domain" as in this context were considered. Derived from the number of searches in Google Scholar using the search words "ecosystem health".

Today

Within the last years the number of publications on 'ecosystem health' has increased, see figure 1.3, indicating that the concept has become a recognised concern. Numerous publications on planning have used 'ecosystem health' in topics like 'healthy urbanism', 'urban ecology', 'healthy cities' and similarly. Pineo (2022b) promoted a new framework called "THRIVES: Towards Healthy uRbanism: Inclusive, Equitable and Sustainable" illustrated in figure 1.4 (Pineo, 2022a; Pineo, 2022b). She used ecosystem health as an overall objective for urbanism and linked aspects of society like injustice and inequity to the concept.

Still, publications seem to ponder over definitions, what ecosystem health constitutes of and how it can be applicable to different scientific fields. Kuznetsova & Manvelova (2022) studied ecosystem health in relation to aquatic ecosystems. In their publication, they defined ecosystem health as a harmonious unity between the organisms and their environment (p.46, Kuznetsova & Manvelova, 2022). The concept is used in a variety of fields but seems to be a constant object of redefining and subject to different frameworks and methods. One could contemplate over the reasons for why it is like this, if the concept is too abstract (Karr, 1999), if the biological terminology for the indicators are too technical or if the link between health in societal meaning and for ecosystems is too far-fetched. However, what is more relevant to this thesis is the implications of ecosystem health in relation to landscape architects who develop, plan and design land and land-use. As far as this literature review knows, there are few implications on how to achieve healthy ecosystems. My next question is therefore if any additional theory can fill the gaps i.e., evolve the understanding of ecosystem health to become an applicable objective for landscape architects in the strive towards sustainable land-use development.

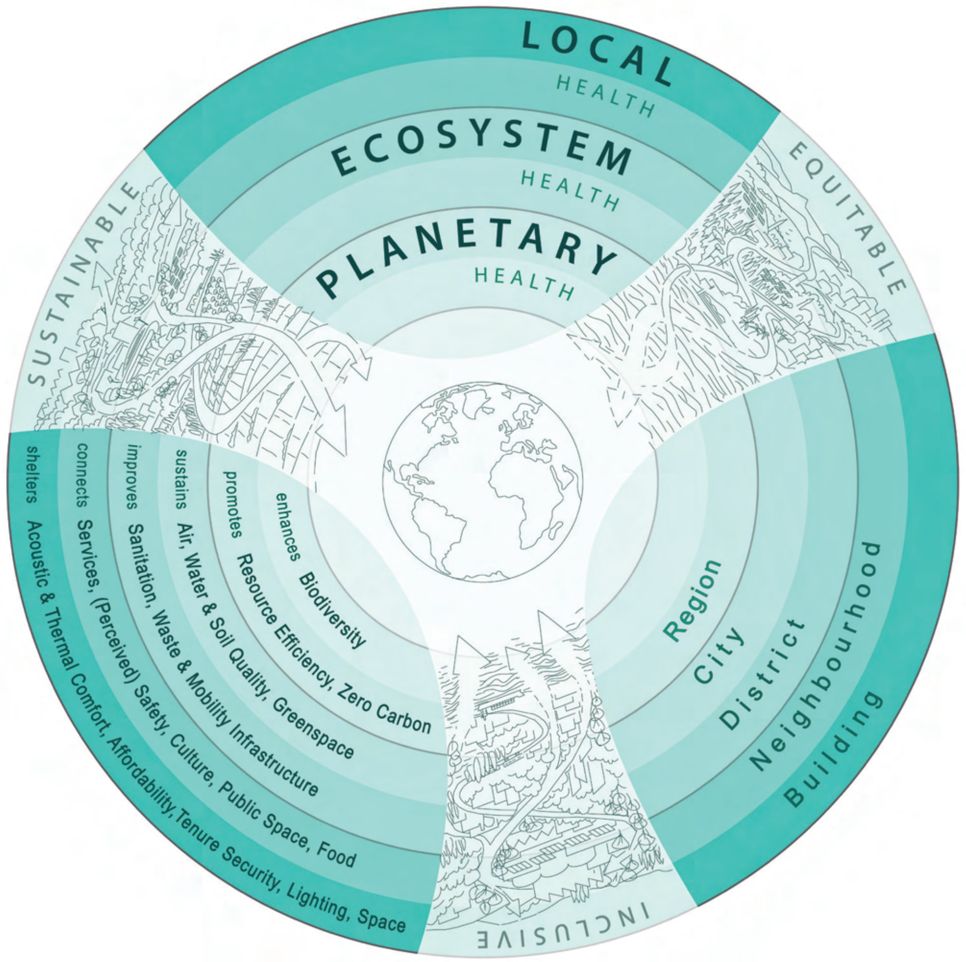


Figure 1.4 shows the THRIVES framework that links ecosystem health to urbanism and sustainable development (Pineo, 2022a; Pineo, 2022b).

1.2 Merging theories

What is ecosystem health?

Evaluating an idea for an expanded understanding of the concept through additional literature and theories that can make it more applicable to landscape architecture towards sustainable land-use development.

1.2.1 Transformation towards a new understanding

System theory

A system is defined as a group of interrelating, interacting or interdependent parts, or sub-systems that together make a complex whole (myNASAdata, n.d.) By using system theory – one can argue that all is interconnected and works within one system, as in one ecosystem. System theory was developed in an attempt to formulate some common rules applicable to all scientific fields to easier unify social and ecological science by Bertalanffy (1968) (n.a., 2020). According to system theory every system contains multitudes of sub-systems, and together, the whole is greater than the sum of all isolated (n.a., 2020). This is in tune with the ecological understanding of the Earth as a continuation of ecosystems, as expressed by Rutledge et al. «The whole surface of Earth is a series of connected ecosystems" (2022a). Within system theory one cannot explain the fundamental characteristics of a complex system by the characteristics of the separate systems, as the characteristics of the whole will emerge as something unique of them interacting, just like a cake is the result of different ingredients mixed and baked together (Bertalanffy, 1968; n.a., 2020).

"One man cannot do right in one department of life whilst he is occupied in doing wrong in any other department. Life is one indivisible whole"
- Mahatma Gandhi

System thinking

Out of system theory system thinking evolved as a mindset, a set of tools, a framework and a language (Anderson & Johnson, 1997). According to Anderson & Johnson (p. 18, 1997) some of the main principles of systems thinking are:

- Having the "big picture" in mind
- Balancing short- and long-term perspectives
- "Recognizing the dynamic, complex and interdependent nature of systems"
- Recognising both measurable and non-measurable factors
- "Remembering that we are all part of the systems in which we function, and that we each influence those systems even as we are being influenced by them".

Earth System Science

Bormann described Earth as a dynamic, self-regulatory ecosystem powered by solar energy, characterized by millions of species, humans included that are intimately bound together to each other and to non-living components (1996). Rapport (1989) stressed the three-dimensional spheres that should be considered with ecosystem health. Earth System Science uses system theory and this way of thinking to understand Earth as a system comprising of sub-systems: the atmosphere, hydrosphere, cryosphere, geosphere and biosphere, see figure 1.5. Earth is also considered part of a bigger system in the Universe or Milkyway (myNASAdata, n.d.; Steffen et al., 2020). Comparisons to the human body are drawn and emphasizes is laid on the fact that these sub-systems have to allow for the Earth to be in balance (myNASAdata, n.d.; Steffen et al., 2020). A change in one sub-system will affect the other and the whole, i.e. Earth (myNASAdata, n.d.; Steffen et al., 2020).

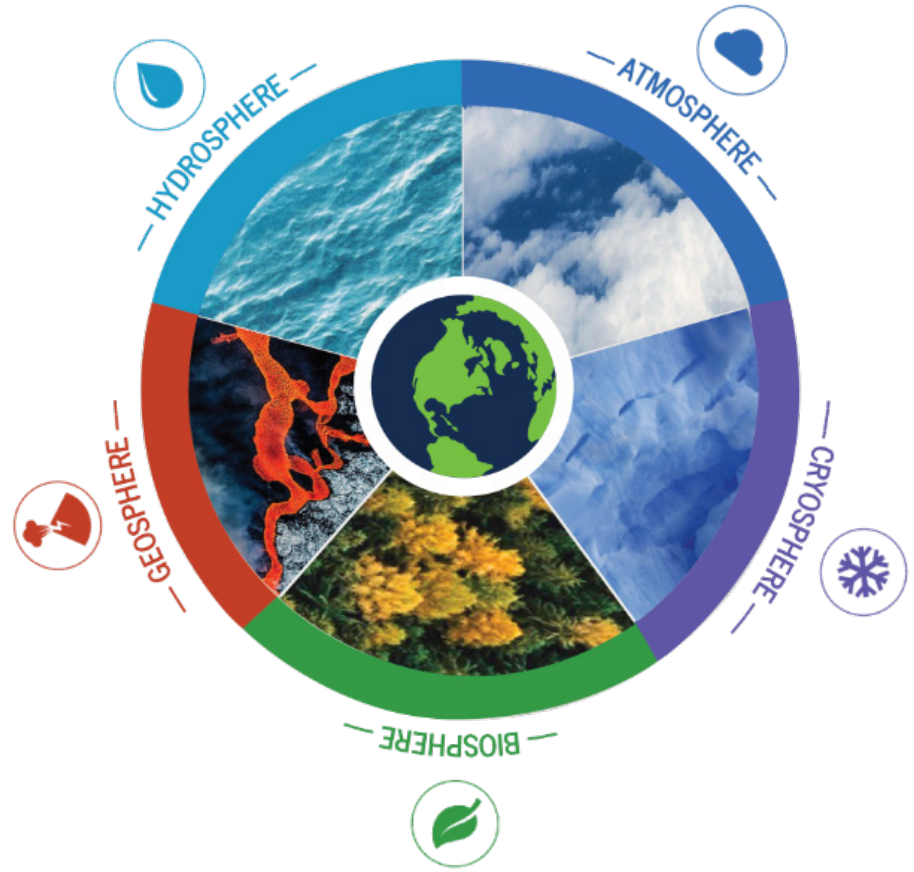


Figure 1.5 illustrating the Earth with its five components that together make out the complex whole of Earth according to Earth System Science. myNASAdata.

Transformation

Transformations are fundamental changes, either physical or qualitative in form, structure, meaning-making (O'Brien & Sygna, 2013) or as in alterations of fundamental attributes of a system (p.564, IPCC, 2012). When a larva becomes a butterfly, it undergoes a transformation to such extent that it cannot return to its previous state. Westley et al. (2011) define transformability as "the capacity to create untried beginnings from which to evolve a fundamentally new way of living when existing ecological, economic, and social conditions make the current system untenable." (p.763, 2011).

Three spheres of transformation

According to O'Brien & Sygna (2013) successfully achieving a transformation requires transformations on three levels, the personal, political and practical, illustrated in figure 1.6. "The personal sphere includes both individual and collective beliefs, values, worldviews and paradigms. The political sphere includes social and ecological systems and structures that enables transformations practically. The practical sphere represent behaviours and technical solutions, behavioural changes, innovations, institutional and managerial reforms" (p.4.5, O'Brien & Sygna, 2013). Their model evolved out of the personal and planetary levels of transformations presented by Sharma (2007) and builds on the system thinking of sub-systems that all have to be transformed for the system to be.

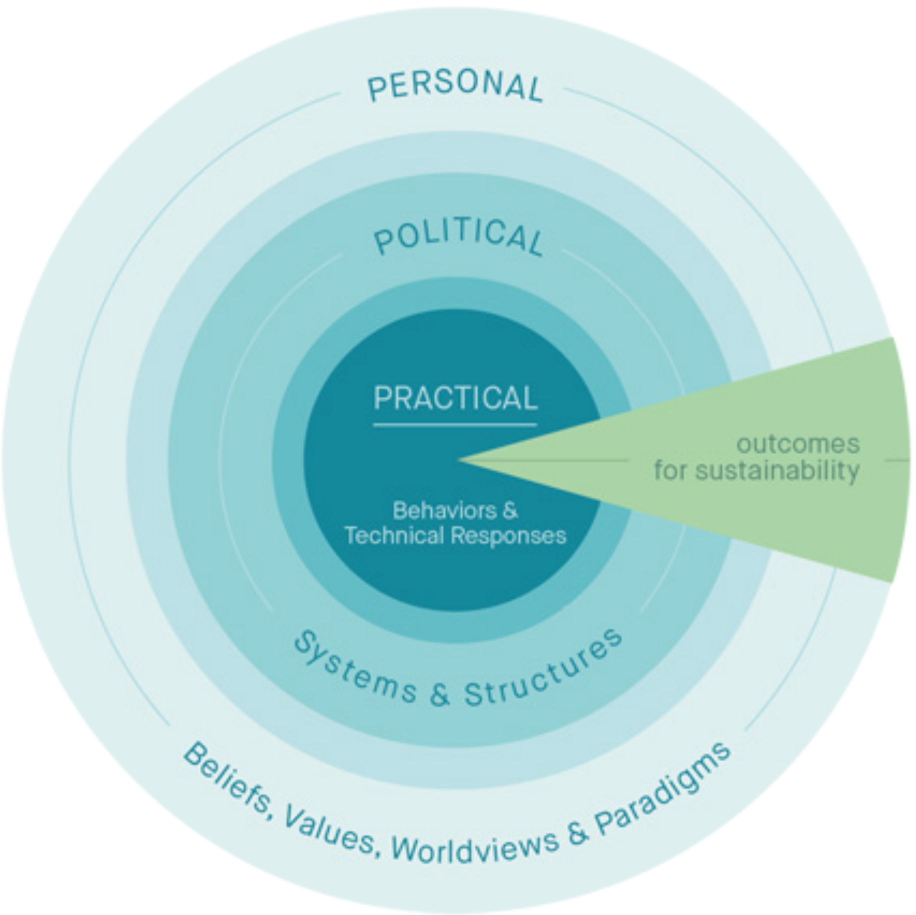


Figure 1.6 illustrating the three spheres of transformation that are neccessary for a successfull transformation of a system. O'Brien & Sygna, 2013 based on Sharma, 2007.

Other approaches with a similar understanding

Social-ecological systems is much referred to in the sustainability field and addresses the "Integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the humans-in-nature perspective» (Folke et al., 2010). The objective within socio-ecological systems is resilience (Folke et al., 2016). This approach much refers to biosphere stewardship linking back to McHarg's ideas of the human responsibility to govern and safeguard natural resources in a sustainable manner (Folke et al., 2016). Achieving ecosystem health can be understood as the system-level goal of stewardship in taking care of ecosystems, novel or natural to become resilient (Weller, 2014).

The socio-ecological model describing the ecology of human development was developed by psychologist Bronfenbrenner in the 1970s (Bronfenbrenner, 1979). The model illustrates the interrelations between individuals, social influences and environmental interactions across multiple levels, see figure xx (University of Minnesota: School of Public Health, n.d.). The view on Earth as a system supporting human and other activity is increasingly recognised, as with Inger Andersen who addressed the planetary life support system during the opening of the COP 15 (UNEP, n.d.-b). Figure text: The model in figure xx illustrates the levels of influencing factors to the human health and development, developed by Bronfenbrenner 1979. The influences can cross multiple levels.

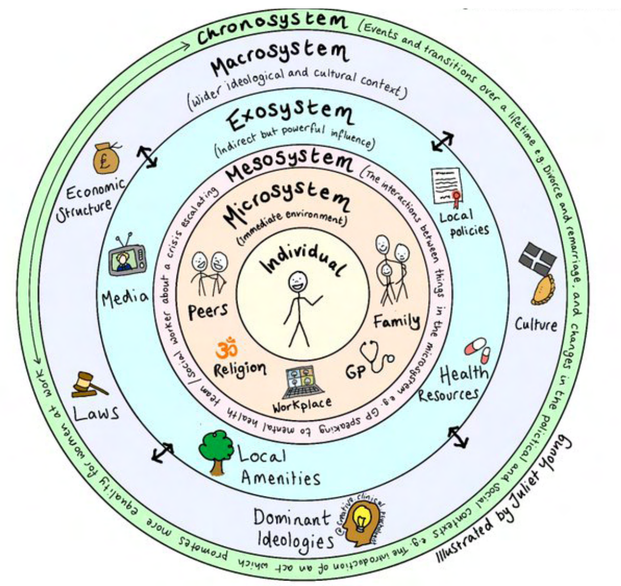


Figure 1.7 of the socio-ecological model developed by Bronfenbrenner in 1979. The model illustrates the levels of influencing factors to the human health and development. The influences can cross multiple levels.

1.2.2 A new understanding of ecosystem health

System theory can support the complexity of health influencing factors, as health is the result of multiple interfering "sub-systems" in the life of the subject (Bronfenbrenner, 1979). The understanding of good health as a surplus to tackle challenges and as a measure of "life-strength", capacity or resilience (Bronfenbrenner 1979) is equally relevant to ecosystem health as it is to human health.

Ecosystem health levels and sub-systems

Ecosystems can be understood to operate in multiple levels as in Earth System Science, the Earth is a big-scale ecosystem, a city might be a medium scale ecosystem, a pocket-forest a smaller ecosystem and the Boreal Forest a bigger one. Based on system theory, Earth System Science and the definition of an ecosystem one could define the Earth as a big scale ecosystem comprising of interactions between living organisms and their environment that occur within sub-systems. These sub-systems operate at and between multiple levels but as in Earth System Science, for the whole system to be at balance it requires balance and optimal functioning within all sub-systems (myNASAdata, n.d.). This is similar to the socio-ecological model by Bronfenbrenner (1979) that presented influencing factors to human health at multiple levels.

Ecosystem health presents a harmony between the environment and the organisms using it (Kuznetsova & Manvelova, 2022). Enabling a balance in the system, i.e. that the Earth ecosystem is healthy requires that the sub-systems are working optimally and are healthy as well (myNASAdata, n.d.). The health of the Earth ecosystem is uniquely given as the result of the health of the sub-ecosystems and the interactions that occur between them like Bertalanffy articulated in system theory (1968). There also constant up- and downstream effects between the sub-systems at different levels that impact the whole. Humans are considered a part of the ecosystem, as addressed by Rapport (1999) McHarg (1969), Bormann (1996) and the Millennium Ecosystem Assessment (2005).

A reflection

Rapport et al. (1999) described ecosystems as living, complex, interacting systems that are working together in a big system, and that goes hand in hand with the holistic way of thinking of a connected system determined by the sub-systems and their interactions. The system thinking element of balancing short and long-term perspectives links to sustainability (Andersen & Johnson, 1997). What Westley (2011) expressed on the need for transformations in systems that were untenable due to existing ecological, economic and social conditions speaks straight to the Earth ecosystem today with a need for sustainability within the natural and social systems.

Humans are not excluded from any of these levels, they are considered part of the ecosystem as supported by Rapport et al. (1999), McHarg (1969), Bormann (1996) and more. This new understanding of ecosystem health and ecosystems requires a philosophical and paradigm transformation to understand that the common goal for all developmental work is healthy ecosystems. The ecosystem approach lifted by the Millennial Ecosystem Assessment is one example of such an understanding, underpinning humans as an integral component of the ecosystems (Millennium Ecosystem Assessment, 2005). This philosophical transformation might also engage a personal exploration and stewardship feeling to what is right and wrong to our surroundings of both the natural and social system, and to ourselves. It is a belief that happier, healthier people can be able to nurture their environment to be happier and healthier too.

I believe the highest leverage point to succeed with a transformation is the one where one can foster a philosophical transformation in how we are seen as a part of the ecosystems as Bormann (1996), McHarg (1969) and Rapport (1999) already emphasized. As Bormann (1996) elaborated upon there is a need to increase the understanding of how the natural world works, with the natural and societal environment of political, economic and societal interactions. The aim should be to find the most effective ways in which humans can work with nature in harmony rather than against it (p.28, 1996). This reflects the goal of ecosystem health as the ultimate, system goal. When we describe and view nature as something separated from humanity, I believe valuable links are lost for understanding and achieving sustainable development. By transforming our understanding of ecosystem health with system theory, the paradigm shift can motivate us in achieving sustainability and health for the whole Earth ecosystem, including us.

Today the SDGs represent different aims for the sub-systems of society, however the core (sustainability) is a fundamental common trait of all. By extrapolating the understanding of sustainability to mean health to all might unite the work towards achieving these goals and make it easier. Rather than debating on, or developing additional frameworks, strategies, models a new, united system-level goal could maybe provide powerful.

Equally, there seems to be a lost understanding of the interconnections between sub-systems in society and solutions to solve current challenges. In february 2023 there were heavy debates and demonstrations in Norway on the development of windmill powerplants in precious nature areas (Senel et al., 2023). Enabling a green energy shift went at the cost of violating human rights of native people and their livelihoods of reindeer-herding, in addition to degrading unique ecosystems to such extent that they can no longer support the activity placed there (Senel et al., 2023). These types of trade-offs are not sustainable if they are done without thought for the consequences they can have for other sub-systems, in this case the social system of human rights, native people and the natural system of ecosystems, biodiversity and national treasures for future generations. A transformed understanding of ecosystems as the total of all sub-systems might elevate the chances for successful, united transformations toward sustainability.

The sustainability pillars

The sustainable development goals are based on the three pillars of sustainability that make a fundamental framework for all developmental matters, globally (Purvis et al., 2019). The three pillars of sustainability imply that to achieve sustainability we need sustainability in the whole system of society, economy and environment, see figure 1.8. These three aspects of society can be seen as cornerstones of human settlements, and if interpreted with system theory they constitute the ecosystem of the social system. The objective with the sustainability pillars is to achieve a harmonious state of sustainability, as reflected in the definition of healthy ecosystem by Kuznetsova & Manvelova (2022).

A systemic goal of ecosystem health could ensure sustainability at the cornerstones of society – the economic, social and environmental systems. By reaching such a point, the system would be flexible to accept that all sub-systems are forcers of the problems of today and all sub-systems might require unique solutions. Therefore, such a systemic goal makes ecosystem health an applicable objective to numerous sub-systems be it economy (Hyrynsalmi & Mäntymäki, 2018), politics, food production or public health. This is one of the strengths of the concept, its generic applicability. It is my belief that the flexibility within ecosystem health to be geared at different sub-systems with the system thinking in mind, gives the most potential for achieving the system-level goal.

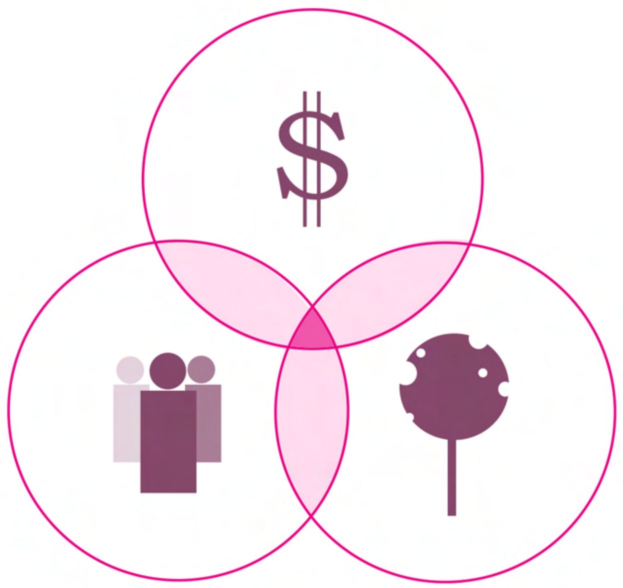


Figure 1.8 of the existing sustainability pillars representing the social, environmental and economic system that all have to be sustainable for a sustainbale development.

Landscape architecture and ecosystem health

According to Weller (2014) the highest ambition within landscape architecture "is to serve as the agent of large-scale landscape stewardship leading to an ideal state of sustainability" (p.1). As exclaimed by Robert Wheelright, the co-founder of Landscape Architecture Quarterly in 1924 "there is but one profession whose main objective has been to co-ordinate the works of man with pre-existent nature and that is landscape architecture." (p.86, Bormann, 1996). McHarg repeated the ideal human as a "good steward" to "green the earth, restore the earth [and] heal the earth" which speaks to the profession of landscape architecture (p.87). A key characteristic within ecosystem health is resilience which is relevant for the changes the world is facing with the climate, nature and exclaimed public health crises of our time.

What does ecosystem health mean for a landscape planner?

The particular strength of the system theory at the core of the concept is the whole picture perspective like with the three pillars of sustainability that speaks to multiple foundational sub-systems of society to achieve sustainability. For landscape architects I would say the following is possible to address with our work: social sustainability (i.e. creating meeting-places, facilitating social interactions, supporting contextual public health issues of mental and physical health) and environmental sustainability (i.e. solving or mitigating the climate- and nature crises). These objectives would, in the system level goal of ecosystem health give way for a developed meaning: a state in which the ecosystem no longer deprives but rather supports sustainability on all levels for all sub-systems of the ecosystem.

Sustainability and ecosystem health

In Earth System Science the biosphere is one of the five parts that make the Earth system which includes all living organisms like trees, insects and humans (myNASAdata, n.d.). However, for this thesis I suggest differentiating between the sub-systems more in the tunes of Wheelright (1924), as the natural and social system. The social system includes individuals, societies, human developments, artificial and innovative technologies, cities, buildings, vehicles and all in which humans have played a determining role. The natural system contains everything that is naturally present on Earth like vegetation, the climate, seasonal variations driven by cyclonic winds, soil, biodiversity and more. The natural system contains of numerous sub-systems that interact and make the complex whole, as in the social system.

For landscape architects to be able to utilize ecosystem health towards sustainable land-use development I will break it up even further. A landscape architect needs to deal with a layer of elements when designing, but typically it is the social aspect of public health, the natural aspect like local biodiversity and ecology, and the environmental aspect of reducing the climate footprint with the new design and use climate change mitigating solutions, like nature-based solutions or raingardens. The interconnected crises need to be solved as interconnected as I believe possible with a systemic goal of ecosystem health.

With that at the foundation, I will divide the natural system into the environmental and ecological sub-system to make it easier to understand and more applicable to achieve, see figure 1.9 on the next page. This is not to further drive a conception of two separated crises, but as a means of simplicity and accuracy for future implementations. The state of the natural and social sub-system together impacts the health of the Earth ecosystem, and each other. Sustainable development requires sustainability within all sub-systems of society. For ecosystem health, the three "pillars" can be modified to fit to the objective of sustainable land-use development and the sub-systems relevant. Therefore, one modification of the sustainability pillars that can work for ecosystem health is seen in figure 1.10 on the next page.

The Earth ecosystem with sub-systems relevant to landscape architecture

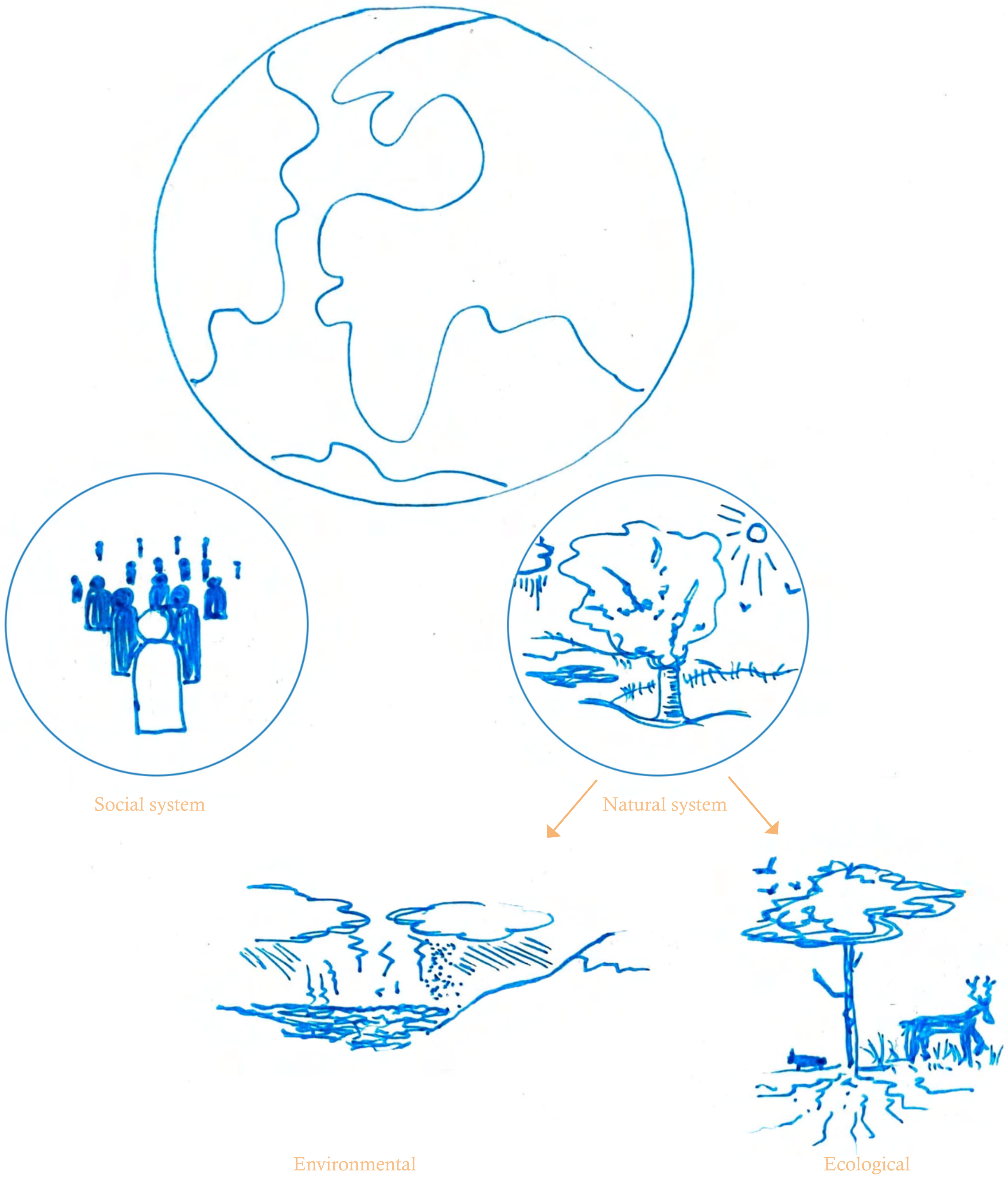


Figure 1.9 illustrates the Earth system with the relevant sub-systems of the ecosystem for landscape architecture, the social and natural system that again is sub-divided in the environmental and ecological system.

Sustainability for the three sub-systems

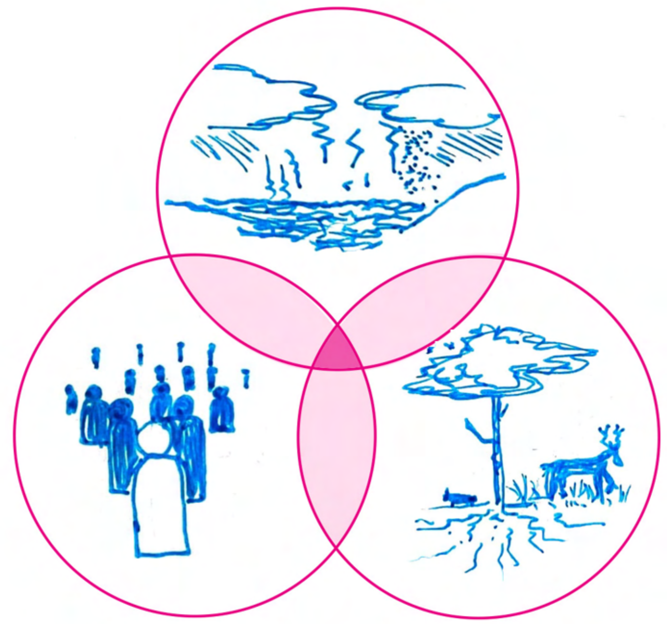


Figure 1.10 illustrates a modified version of the sustainability pillars that can fit the sub-systems of the Earth ecosystem that are addressed by landscape architects in the strive towards sustainable land-use development. Sustainability should be achieved for the social, the environmental and ecological sub-systems of the Earth ecosystem.

The socio-ecological model of Bertalanffy (1979) presented multiple systems at different levels where the outer level was the chronosystem, followed by the macro-, exo, meso- level and so forth (see figure 1.7). Based on this I will in part III in the thesis focus on three levels of ecosystems for analyses: the macro, meso and micro level that present ecosystems operating at different scales as sub-systems. The solutions landscape architects design speak to multiple levels of ecosystem health. The up- and downstream effects of healthy ecosystems in the layers determine the "total" health of the Earth ecosystem on the planetary scale. If landscape architects plan for ecosystem health in the lower levels and for all sub-systems involved, that will ultimately create positive feedback loops to the planetary level of the ecosystem health on Earth. Similarly, will design solutions that don't plan for ecosystem health, either socially (i.e. non-equitable or human-hostile design) or environmentally (i.e. not biodiversity friendly or design at the cost of nature) create negative feedback loops in the whole system that negatively affects the planetary scale.

"Our task must be to free ourselves... by widening our circle of compassion to embrace all living creatures and the whole of nature and it's beauty"
– Albert Einstein

II **Why** is ecosystem health relevant for sustainable land-use development?

Examples of unhealthy ecosystems in the world are presented through three current crises followed by identifying the outcomes of healthy ecosystems with the benefits they can provide. Landscape architecture and the lack of theory for solving problems is addressed, followed by ecological theoretical approaches. Finally, landscape ecology is introduced as a theory for landscape architects with ecosystem health as objective.

Keys of ecosystem health

Figure 2.1 with an illustration of ecosystems with some of the keys to the concept that were identified in part I of the thesis.

2.1 Unhealthy ecosystems

Considering the definition of ecosystem health as a harmonious unity between organisms and their surroundings (Kuznetsova & Manvelova, 2022) the current status of Earth with climate change, the nature crisis and a multitude of public health challenges might not qualify to be called healthy. The presented cases depict an unhealthy ecosystem on multiple levels and for multiple sub-systems of the Earth ecosystem.

Covid - a ~~gentle~~ reminder
The Covid-Pandemic that broke out in 2019 created massive attention from media, politics and science as it accentuated a dualistic relationship between human- and ecosystem health. The pandemic served a great example of typical negative feedback loops that come from unsustainable land-use and management of ecosystems, as addressed by Lawler et al. (2021) who emphasized the link between biodiversity, the nature crisis and the pandemic, and Robinson et al. (2022) who stressed stable and resilient ecosystems as core determinants for socioeconomic stability and health. Links have also been drawn back to the benefits of a One-Health approach for securing human, animal and planetary health as means for achieving health for all (Lawler et al., 2021).

Climate and nature crisis

20th of March 2023 the sixth synthesis-report by the climate change panel of the UN, the IPCC was published (IPCC, 2023). The objective of the report is to "survey" the state of the earth, previously done in 2014 (Åsnes et al., 2023; IPCC, n.d.). The message was alarming. Within the next seven years the world has got to rapidly act to limit global warming to 1.5 degrees as the consequences of climate change already are present with fires, floods, diseases and climate refugees (Ulvin et al., 2023). The report was coined "a survival guide for humanity" by the UN Secretary-General António Guterres and the IPCC presented a long list of measures needed to turn the trend (Ulvin et al., 2023). Guterres emphasized the need for climate action on all fronts and sectors, all at once (Ulvin et al., 2023).

Ecosystems cannot keep up with the demands of the human population globally and 1 of the estimated 8 million of the world's plant and animal species are threatened with extinction (UNEP, n.d.-a). The nature crisis threatens food production due to pollinator loss, between 100 and 300 million people are increasingly vulnerable to hurricanes and floods due to habitat loss along the cost and the trajectories of the nature crisis with declines in biodiversity and nature can undermine progress towards 35 of 44 SDG goals related to climate, oceans, land, health, water, cities, poverty and hunger (UNEP, n.d.-a). As the Living Planet Report (2022) emphasized, the climate and nature crises are two interlinked and connected emergencies that are human-induced and threaten the worlds living system of biodiversity, wildlife and humans (WWF, 2022). As Mr. Guterres expressed during the opening of the COP 15 in Montreal, corporations are "filling their bank accounts while emptying our world of its natural gifts" and by so making ecosystems objects for profit (UN News, 2022b). "Without nature, we have nothing" (UN New, 2022).

Public health challenges

Physical health
According to Lucero-Prisno III et al. (2023) the top 10 public health challenges of our time are "health systems, the mental health crisis, substance abuse, infectious diseases, malnutrition and food insecurity, sexual and reproductive health challenges, environmental pollution, the climate crisis, cancer, and diabetes" (p.2). In 2019 a pooled analysis from 146 countries on 1.6 million youth aged 11-17 was done on their physical activity levels (Guthold et al., 2020). On average only 1 out of 5 reach the activity targets for 2030 in the global action plan on physical activity by WHO (Guthold et al., 2020; WHO, 2018). Some call the present the era of "exponential growth of the metabolic syndrome and obesity" (p.1) and emphasis is put on the health benefits of physical activity for both physical and mental health (Sharma et al., 2006). Physical activity provides stress relief, improves mood, endurance, energy and stamina, reduce cholesterol and more, and provide evidence-based improvements to people's overall health (Sharma et al., 2006).

Climate change was coined the most critical health threat by the WHO with increasing temperatures, more frequent extreme weather events and disasters like heat waves, floods leading to heat strokes and suitable climates for the growth of disease vectors (Lucero-Prisno III et al., 2023; WHO, 2022). Environmental pollution decreases the quality of the living environment for people in polluted areas like cities, particulate matter is one of the pollutants with stronger negative health-effects with linkages to chronic respiratory and cardio-vascular diseases, asthma and other (Kim et al., 2015; Lucero-Prisno III et al., 2023). Microplastics are increasingly abundant in natural environments and eventually find their way back to humans (Lucero-Prisno III et al., 2023). Also for the global mental health, climate change represents a risk as there is increasing evidence for the psychological distress it causes (Gibson et al., 2020). Climate change causes emotional reactions that can lead to increased anxiety and therefore impede psychological well-being (Clayton, 2020). A study from 2022 examined the negative emotional responses to climate change for 23-year olds in 32 countries (Kaste, 2022; Ogunbode et al., 2022). The study found that more than ¼ of every young Norwegian had climate anxiety (Kaste, 2022; Ogunbode et al., 2022).

Mental health & evolution
People are mentally and physically affected by their surroundings and as more than 90 % of their lives is spent indoors, the lives of human beings has changed from our evolutionary origin (Evans, 2003). In his last book, Swedish psychiatrist Anders Hansen took on the questions on why people in society are feeling so bad when we are doing so well (Hansen, 2021). He explained a lot by evolution and that human beings are a result of evolution with adaptations that still are present today for how they react, why and what can impact the state people's mental and physical health (Hansen, 2021). Links were among others drawn to lifestyle and the physical environment of human beings. The Biophilia hypothesis developed by biologist Edward O. Wilson (1984) explains the positive associations between human well-being and nature as a believed innate affinity for the natural world. The hypothesis suggests it to be a biologically based need based on human evolution to prefer water, green vegetation of flowers over built structures of glass and concrete (Wilson, 1984). To quote Wilson (1984) biophilia is "the inherent human affinity for nature, whereby people evolved with, fundamentally depend on, and are inspired by nature" (p.76 in Forman (2008)).

A green view from a hospital window has been found to reduce recovery time for patients after surgery compared to those who had a grey view (Ulrich, 1984). Green structures have proven to be effective in lowering depression rates, improving mental well-being and life quality, providing reduced blood pressure levels (i.e. stress levels) and enhancing social cohesion improves, even enhancing worker satisfaction and productivity (Frumkin et al., 2014; Orr, 2002; Shanahan et al., 2016). These effects can be linked back to the Biophilia hypothesis (Wilson, 1984). There is increasing emphasis put on the need for interdisciplinary approaches to deal with the mental health crisis (Barton & Rogerson, 2017). As Barton & Rogerson (2017) stressed, utilizing existing knowledge on the mental health benefits of green structures can be very effective to tackle the public health challenges. “Green spaces provide vital health services as well as environmental services; they are equigenic, reducing socioeconomic health inequalities, facilitating activity and promoting better mental health and well-being. The integration of biophilic design may provide a cost-effective public health intervention, which promotes the evident positive links between green spaces and mental health.” (p.81, Barton & Rogerson, 2017). Nature connectedness has also been positively associated with well-being and negatively with mental distress, and was emphasized already in the 80s as a fundamental need for society (White et al., 2021; Wilson, 1984).

Digital world

The effects of increasing time spent on screens for people worldwide was discussed in a report by WHO from 2015, due to the negative impacts it can cause for public health (WHO, 2015). Smart phones and computers are stealing peoples’ focus, concentration and time with a limitless abundance of offers on social media channels and more. WHO suggested health consequences of these sedentary lifestyles to be associated with insufficient physical fitness, poor diets and other potential health risks, musculoskeletal problems, sleep deprivation, hinderance of social skill development and psychological problems like poor self-confidence, well-being and reduced work and academic performances (WHO, 2015). Discussions were even suggesting “internet use disorder” as a diagnose for excessive use, with similar characteristics to other substance use disorders (World Health Organization, 2015).

Novel ecosystems

As more people reside in built areas of cities and sub-urban sites with reduced physical activity and increased time spent on screens this has profound effects on the overall global public health. The built environment can impact mental health conditions negatively like increasing psychological stress, regulating social interactions, limiting physical activity, exposing people to noise pollution or limiting the provision of daylight (Evans, 2003; Perdue et al., 2003). The outdoors directly and indirectly influence public health through factors like air quality, facilitation of physical activity or proximity to green that can have positive effects (Perdue et al., 2003). Physical spaces can expose people to harmful pollutants or stressors (e.g. noise and light pollution) but they can also influence lifestyle choices by facilitating physical activity, play, social connection and directly improve physical health with linkages to diabetes, asthma and vascular diseases by for instance green structures (Perdue et al., 2003).

Unhealthy urban ecosystems

The intersections between social, economic and environmental activity are in cities. As Jansson (2013) elaborated on, cities are globally interconnected through political, technical and economic systems and through the biophysical life-support systems Earth provides. With a growing population some claim that when humanity is considered part of nature – cities can be regarded as networks of ecosystems (Bolund & Hunhammar, 1999). Compared to natural ecosystems, cities are often considered immature with rapid growth and inefficient use of resources (Bolund & Hunhammar, 1999). Human activity impacts the local and global climate like in cities through for instance vehicle traffic that pollutes the air, creates traffic noise and light and spreads particulate matter – and these factors again inflict with the local and global environment. With climate change the regional and local climates are altered and thus the livelihoods of living organisms: animals and humans.

Cities, climate and nature

There is a need to reduce the ecological footprint and debt of cities, connecting them to the biosphere and enabling them to provide ecosystem services that improve life-quality, health and resilience to their biodiverse inhabitants of humans and animals (Gómez-Baggethun et al., 2013). Despite cities covering only a small part of the surface on Earth, they are home to more than half of the world's population and have a disproportionately large impact on the biosphere and environment at local, regional and global scales, also beyond the city-borders (Grimm et al., 2008; Seto et al., 2012) in (Gómez-Baggethun et al., 2013). By viewing the city as an ecosystem, the surrounding landscapes of urban and rural land, with the interactions and impacts they give each other is also considered. A city is equally impacted by a number of environmental and social factors in the surrounding landscapes (e.g. air quality, wildlife, commuters) as those landscapes are from the city (e.g. land sprawl, air pollution). This interdependence across scales will be elaborated upon in the last part of the thesis.

Reflections on unhealthy ecosystems

In their paper, Dean et al. (2011) discussed if biodiversity can provide mental health benefits in an urban setting. They presented a model of an "ecological linkage mechanism" between environmental change and mental health outcomes given the ecosystem health condition as seen in table 2.1. This model speaks to the system thinking in ecosystem health as a number of sub-systems with constant up-and downstream effects and interlinkages. With current urbanisation and land-use trends comes green infrastructures and urban biodiversity (Dean et al., 2011). The quality of these is determined after the ecosystem health present, that again can lead to ecosystem services and mental health benefits (Dean et al., 2011).

Global mental and physical health, climate change and the nature crisis are linked together and the activity "between" these three crises can either drive or mitigate each other (Lucero-Prisno III et al., 2023). Pollution to the physical environment is harmful to nature in an ecosystem, to surrounding ecosystems and to humans (Lucero-Prisno III et al., 2023). Urban green is beneficial to people but also to biodiversity and the surrounding ecosystem that again can provide benefits to the city. However, as Lucero-Prisno et al. (2023) emphasized there is typically little inclusion between health and climate change programs despite the benefits it can provide. During the last COP27 in 2022, health was included as a global goal on climate adaptation (IPCC, 2022a). By doing so, the IPCC recognised the intertwined challenges and the solutions they together can provide. By aiming for healthy ecosystems, the sub-systems and their interlinkages are automatically acknowledged and from there it might be easier to prioritize solutions that benefit people, public health, nature and climate together (Dean et al., 2011).

Table 2.1 presenting a model that shows the ecological linkage mechanism that connects mental health with the environmental change given the ecosystem health (Dean et al., 2011).

Environmental Change	Ecological Linkage Mechanism	Health Outcomes
Urbanisation ↓ Landuse ↓ Green Infrastructure ↓ Urban Biodiversity	Functioning of healthy ecosystems: - resilience - organization - vigor ↓ Ecosystem health	Ecosystem services provisioning - regulating - culturally enriching ↓ City's ecological footprint ↓ Mental Health

2.2 Healthy ecosystems

What are the opposite of unhealthy ecosystems? Some of the qualities of healthy ecosystems based on their definitions are them to be active, resilient and productive (vigor) and free from distress syndrome that lead to undesired functioning (Costanza et al., 1992; Mageau et al., 1995; Rapport et al., 1999). Costanza (2012) elaborated that the goal of ‘ecological engineering’ should be to facilitate healthy ecosystems that may “perform desired functions and produce a range of valuable ecosystem services” (p.24) beneficial for nature and society. In addition, Costanza et al. (1992) were early on linking ecosystem health to economic, social and environmental aspects of sustainability and Rapport (1995) exclaimed it to constitute the bottom-line for sustainable development. Sustainable development and sustainability requires healthy ecosystems that can sustain the natural and social systems. One way healthy ecosystems can do so, is by the provisioning of ecosystem services.

Ecosystem services

Ecosystem services are the multiple benefits that society and humans obtain from ecosystems (FAO, 2023; Millennium Ecosystem Assessment, 2005). Categorizations of ecosystem services has developed over the years and led to four main categories, see figure 2.2 (Gómez-Baggethun et al., 2013). They are provisioning services like food and water, supporting services like nutrient cycling and habitat provision for species that maintain life sustaining conditions on Earth, regulating services like disease- and flood control, climate regulation and pollination, and cultural services like spiritual, cultural and recreational benefits (Millennium Ecosystem Assessment, 2005; Wittmer & Haripriya, 2012).

By providing mixes of natural and built structures in a novel ecosystem like a city, negative factors might be eliminated or mitigated through ecosystem services. Some of the ecosystem services provided by urban ecosystems are noise reduction, air purification, urban cooling and runoff mitigation (Gómez-Baggethun et al., 2013).

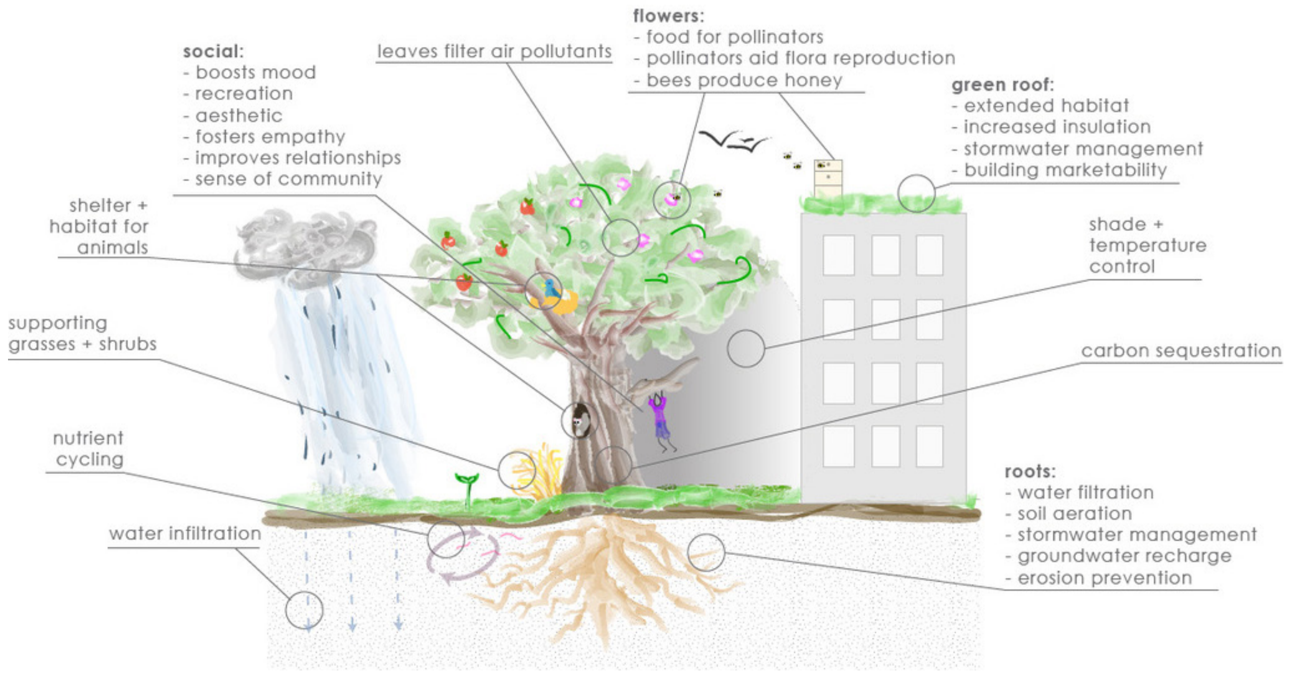


Figure 2.3 illustrates the ecosystem services provided by a tree. Linnean Solution, 2016.

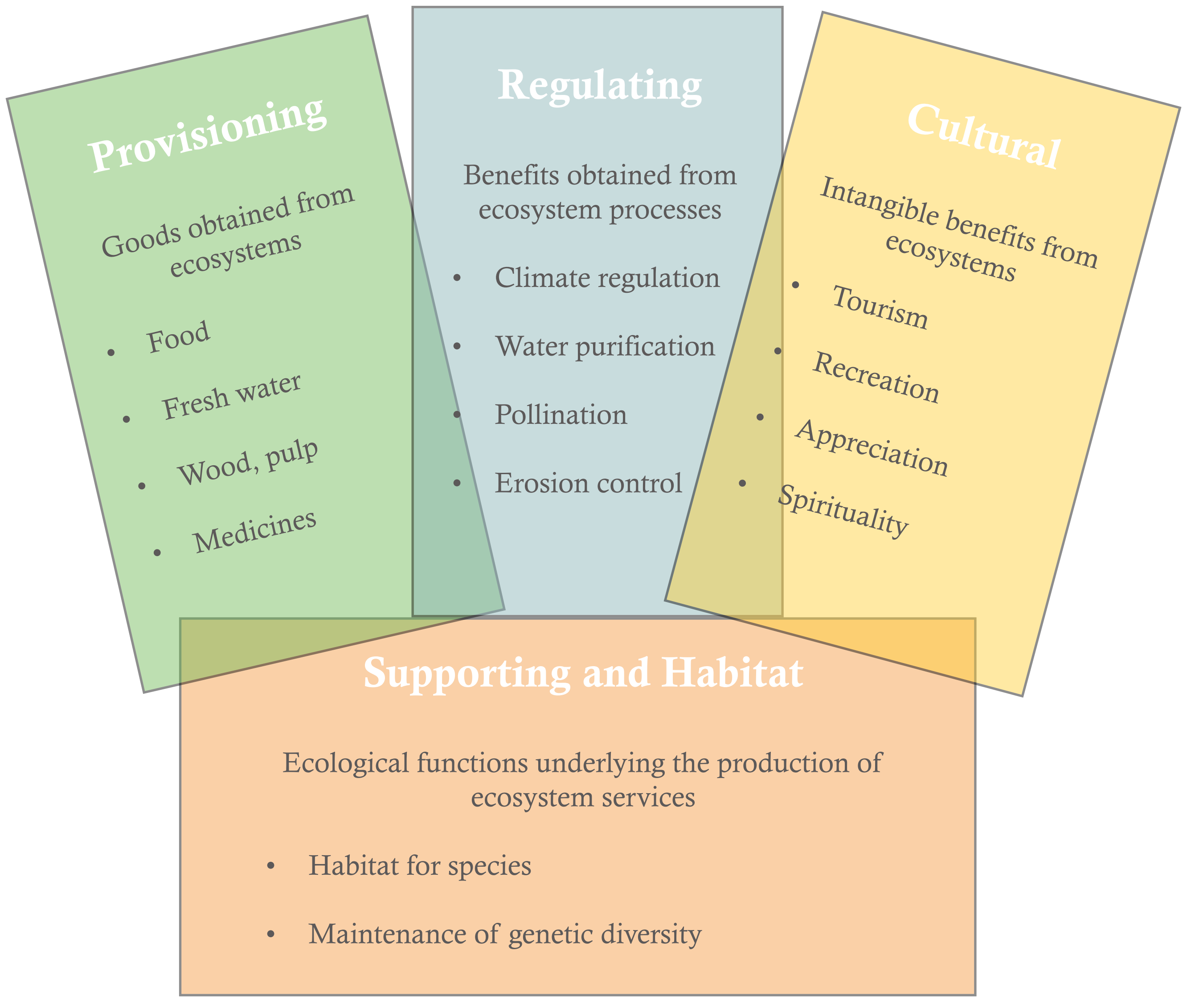


Figure 2.2 presenting the four types of ecosystem services with some examples. Inspired by Wittmer & Haripriya, 2012.

In many ways, ecosystem services enable human life and activity by providing nutritious food and clean water, recreational services beneficial for public health and supporting pollination of crops (FAO, 2023). In fact, every third bite of food one eats depend on pollinating services (FAO, 2023). Ecosystem services were in 2014 estimated to have a value of 125 trillion USD and increasing efforts are put in the development of methods to value ecosystem services or account for them so that they can function as indicators for the value of nature itself (FAO, 2023; IPBES, 2022b). However, this has been criticized, Turnhout et al. (2013) addressed the risk of extensively focusing on the money worth of ecosystem services as that can diminish biodiversity to “a series of quantifiable fragmented parts” (p.154) and reduce the worth of social-natural relations as it is hard to translate that value to market transactions (Turnhout et al., 2013).

Biodiversity is essential for ecosystem function and provision of services so to ensure a sustained provision of ecosystem services beneficial to human society both biodiversity and ecosystems need to be conserved, sustained, supported and protected (FAO, 2023). “Half of global GDP is dependent on ecosystem services” (European Commission, 2022) and ecosystem services is in the core of sustainable development as numerous systems of society depend on them (e.g. trade, public health, food production) (FAO, 2023).The argument of saving nature for the sake of human health and wellbeing is increasingly used, also to conservation efforts (Kaimowitz & Sheil, 2007; Kareiva & Marvier, 2007; Sachs & Reid, 2006).

Ecosystem services and ecosystem health

Ecosystem services and ecosystem health
Ecosystem services have become a clear argument for the benefits nature provides humans and society. However, little emphasis has been put on the link between ecosystem health and ecosystem services. It is imperial to see the value and need for nature itself to function and by so providing ecosystem services for the sake of its own organization. According to Rapport (1995), for an ecosystem to be healthy it could not provide ecosystem services at the expense of the system itself. "Obviously, if exploitation of an ecosystem for a particular 'service' were at the expense of other elements vital to the healthy functioning of the system, this would not confer overall health (…) Clearly the criteria for ecosystem health cannot contravene the criteria for sustaining the functioning of the system, which include mechanisms for self-maintenance and repair" (p. 298). Already in 1995 Rapport addressed the conflicting values that occur when using 'ecosystem services' as indicators for health. An ecosystem can still provide services to some extent (like a pocket forest cleaning the air) in an unhealthy state. This has been much addressed later on as by Palmer & Febria (2012) and by the Wildlife and Countryside Link (2015). From an economical, ecological and ethical perspective an ecosystem services approach with the objective of maximizing ecosystem services is often times poorly equipped to ensure biodiversity and ecosystem health (Wildlife & Countryside Link, 2015).

Following Rapport (1995), utilizing an ecosystem for the services it provides in an unsustainable matter, as exemplified by the Tragedy of the commons – that will not contribute to the health of the ecosystem (Banyan, 2022). As with the Tragedy of the commons, a concept popularized by ecologist Garrett Hardin, if a public good is exploited by all individuals in society – that resource will soon be derived to no longer sustain any individuals (Banyan, 2022). This illustrates a lack of system thinking (Banyan, 2022) and can be linked to what the Secretary General of the UN stressed during the opening of the COP 15 (UN News, 2022). As emphasized with the Kunming-Montreal agreement, if society desires sustained ecosystem services for humans to survive (e.g. food production and oxygen respiration) there is a need to recognise the state, or health of the ecosystems as a pre-condition to achieve this (CBD, 2022; IPCC, 2023). Without an intact natural system, the chances of intact social systems decreases.

Nature-based solutions

Nature-based solutions (NbS) are by the International Union for Conservation of Nature (IUCN) defined as "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefit" (p.6, , 2023). NbS provide benefits to society as well as to ecosystems and biodiversity, aim at addressing specific challenges, are determined by site-specific natural and cultural contexts, embrace nature conservation norms and more (IUCN, 2023). In one way, NbS can be considered an extension of ecosystem services put in a system of infrastructural solutions like storm water management through rain swales/rain gardens or urban cooling by green walls and roofs that also provide habitat for pollinators in urban/sub-urban areas. In this thesis, I have chosen to focus on the concept of ecosystem services but with that said, many of the suggestions in part III can also be understood as nature-based solutions. Further research could argue that there is nothing that limits them from being merged with NbS.

Ecosystem heatlh for a sustainable future

Can healthy ecosystems be one answer to solve the challenges of the Earth? The last IPCC report (2023) stated: "This report recognizes the interdependence of climate, ecosystems and biodiversity, and human societies; the value of diverse forms of knowledge; and the close linkages between climate change adaptation, mitigation, ecosystem health, human well-being and sustainable development, and reflects the increasing diversity of actors involved in climate action» (p.3). With this, the IPCC addressed ecosystem health as a part of the interlinked crises and system of environment, nature and human well-being. Also the European environment agency addresses the need for healthy environments in their report from 2020 "Healthy environment, healthy lives: how the environment influences health and well-being in Europe" (European Environment Agency, 2020). In the SDGs (nr. 3, 11, 13, 14, 15) 'ecosystem health' or 'healthy ecosystems' is not explicitly mentioned however, sustainability and the benefits of healthy ecosystems as with ecosystem services is highly valued (UNDP, 2023).

The IPCC urged ecosystem services and nature-based solutions as core solutions for climate change adaptation, mitigation and transformation (2023). The Kunming-Montreal agreement urged urban greening, tackling climate change by nature-based solutions, conserving, restoring and supporting ecosystems and biodiversity by nature-friendly practices(CBD, 2022). The Living Planet Report called for nature positivity within 2030 of having more intact nature with the countless benefits it would provide to society, climate and nature (WWF, 2022). Healthy ecosystems can sequester and store carbon, filter air and water, support and sustain biodiversity that provide services like pollination, help mitigate extreme weather risks of flooding, droughts and erosion, provide energy efficiency, regulate microclimates by providing urban cooling, sustain other ecosystems that can catalyse chains of benefits, improve public health of increasing well-being, physiological and psychological health, provide recreational and social arenas and simply take care of the social and natural system to last and thrive. Aiming at creating and sustaining healthy ecosystems could also lead to an increasing investing in urban/rural greening. By so, ecosystem health can be one answer to the Kunming-Montreal agreement (CBD, 2022), to the

2.3 Landscape architecture and ecosystem health

Landscape architects and planners have since long been addressed as key players in the role as stewards of Earth (McHarg, 1969). The council of the Europe Landscape Convention (ets No. 176) promotes protection, management and planning of landscapes, and urges international co-operation between all sectors involved with landscapes (Council of Europe Landscape Convention, n.d.).The term 'stewardship' has been around since 1969 when landscape architect Ian McHarg published his book "Design With Nature" where he embraced the concept of stewardship. "If one can view the biosphere as a single superorganism, then the Naturalist considers that man is an enzyme capable of its regulation, and conscious of it. He is of the system and entirely dependent upon it but has the responsibility for management, derived from apperception. This is his role—steward of the biosphere and its consciousness" (p. 124). As Lovelock reflected back upon, "It takes a lot of hubris to even to think of ourselves as stewards of the earth. Do we want the remote and infinitely difficult task of managing the earth? Do we want to be made accountable for its health...?" (Lovelock, 1988).

Historical pespective

Fredrick Law Olmsted, a landscape architectural "legend" was progressive in connecting landscape architecture with public health already in the 19th century (Karr, 2021). Olmsted called for public landscaping for public health, and promoted clean air through vegetation, called parks for breathing rooms and wanted recreational spaces and nature to be a public good with significant benefits to the public in times of industrial revolutions (Karr, 2021).

In 1966 a group of landscape architects were assembled by the landscape architecture foundation in America with a shared concern for the quality of the environment and its future (Miller et al.). It led to the "Declaration of concern" where they uttered their worries for how landscape architecture had lost its core of social and environmental communion and where "misuse of the environment and development (…) has lost all contact with the basic processes of nature" (p.1). As they proclaimed, landscape architects are the experts of landscape capabilities, that is of the geological, ecological, environmental and climatic preconditions and why plants, animals and humans flourish in some places and not in other (Miller et al., 1966). Landscape architects are also essential in maintaining the vital connection between man and nature (Miller et al., 1966). They emphasized landscape architecture to be a key in solving the present environmental crisis of their time.

A reflection of landscape architecture

Typical landscape architectural projects and designs can have high costs for nature and climate. Paving stone can be imported from China or India due to reduced costs compared to local stone, or local stone can be shipped to China or India for manipulation (e.g. cutting, surface treatment). Plants can be imported from the Netherlands and Germany with a risk of spreading plant pests and diseases to local biodiversity. Planting designs can require extensive maintenance of constant weeding or seasonal plants can be used for a higher aesthetical value throughout the year than from perennials. Rather than incorporating or moving existing vegetation in new designs vegetation is often completely removed and replaced in new designs. There is a number of decisions that are taken in a landscape design process that can give them a negative nature- or climate cost.

Often the planned longevity of designed landscapes is short with frequent re-designing. Increasing attention is raised from the public to the designed environment of buildings and landscapes that impact the social system. In Norway "Arkitekturopprøret" has a growing number of followers who desire different development of buildings, with more aesthetical value like colour and classical ornaments, figure 2.4. Biophilic design is a rising trend that builds on the biophilia hypothesis that promotes human-friendly design in touch with nature, figure 2.5 (Forman, 2008).

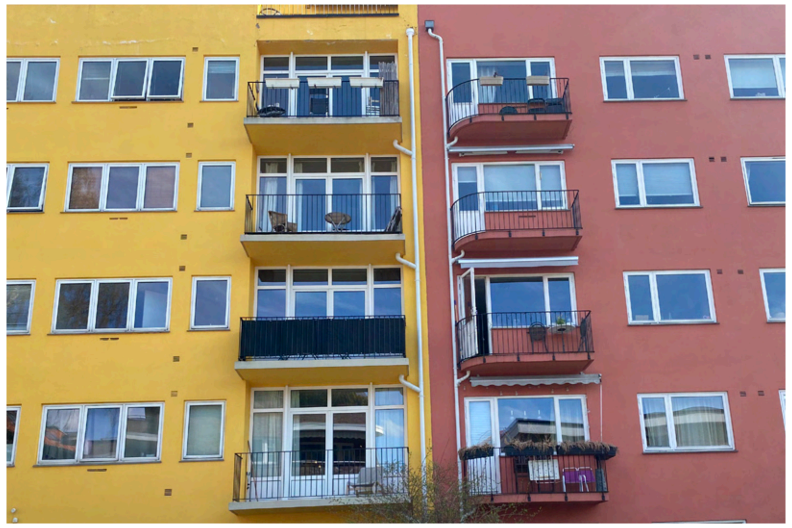


Figure 2.4. Photo of colourful facades in Oslo.

Figure 2.5. Photo of a walking path in Stockholm, in line with biophilic design thinking.

Landscape architecture today

50 years after the "Declaration of concern" a new vision for landscape architecture for the 21st century was crafted by the landscape architecture foundation with over 700 landscape architects on board (Landscape Architecture Foundation, 2016b). This declaration called for action and a new identity for society to be a constructive part of nature rather than the opposite. They emphasized the cultural and environmental systems that landscape architects are positioned to bring together, as landscape is the common ground of humanity (Landscape Architecture Foundation, 2016b). Landscapes sustain us with food, water and air – and human activity is constantly returned to the landscapes in various forms like pollution or land degradation (Landscape Architecture Foundation, 2016b). Landscape architects serve the higher purpose of social and ecological justice for all species and humans, vow to create places that nourish the vital communion with the natural world and one another and to serve health and well-being to all communities (Landscape Architecture Foundation, 2016b). In their action plan the expertise in context and scale is addressed, the fundamentals of interdisciplinarity and a system thinking of society and environment is highlighted (Landscape Architecture Foundation, 2016a). The new vision has a system thinking of addressing the social and natural system and the interlinkages in the hands of the profession.

Design as fragmentating force

Zooming out the increasing trend of landscape design reveals another issue, the constant fragmentation of landscapes through different designs and ideas (Dramstad et al., 1996). Forman (2008) uses the metaphor of beasts rampaging around in a restaurant and people responding to it by fixing a tablecloth, polishing some silver and picking some crumbs. With their land, humans seem to get lost in concentrating on isolated housing developments, new roads, new cabins or new designs to existing land-uses while together this leads to land degradation and transformation of valuable land into fragmented pieces (Forman, 2008). The life-supporting natural system that we depend on is being ravaged while we are fixed on designing new, building new solutions (Forman, 2008). Rather than following a holistic plan for regions there are constant interferences of plans that often don't share common objectives, values or strategies despite the SDGs. Thus there is a lack of continuity in the landscape and regional scale of planning that according to Forman (2008) is threatening and wasting our land.

Reflection

The constant fragmentation of land by landscape architectural interventions in land-use development is a negative and unsustainable trend. It says something about the hardship of designing sustainably as most landscape architects desire sustainable land-use development as stressed in the new vision (Landscape Architecture Foundation, 2016b). Maybe this can indicate that the implications of the SDGs are too vague for landscape architects. For landscape architects to facilitate healthy ecosystems in regions a systemic objective of ecosystem health might lead to prioritizing small-scale healthy ecosystems that promote the natural and social systems. In addition, the surrounding landscapes and the whole systems might be considered in such targets as they both impact and are impacted by the small-scale ecosystems. The benefits of an ecosystem health approach can be that it enables a systemic understanding of a site, its sub-systems, its context and the most pressing factors to prioritise.

Landscape architecture as a practice works with numerous elements on sites as they make the fundamental pre-conditions of the as-is and the future (Forman, 2008). In the pre-face of a design process a landscape architect analyse and map the present elements to get an understanding of the site, what is and what is lacking (Murphy, 2016). However, from there a lot is up to the specific projects, the objectives, frameworks and involved actors. Could one explanation of the fragmentating trend be a lack in methods and theories that landscape architects are trained to follow in the steps of both pre-face (research) and design, to reach sustainable land-use development?

2.4 Lack of theory and methods

Already in 1950, landscape architect Sasaki addressed the lack of theory and methodology taught to landscape architect students that, according to him led the practice on a lethargical trajectory without contact with the present problems of society (p.158). He lifted the case-study or project method in university courses where "isolated" landscapes are designed in courses of different topics: parks, cities, squares, infrastructure and so on. He addressed critical thinking with research, analysis and synthesis as core in a design process (p.160). Sasaki further urged the need for a basic approach to design. Still, there is a pronounced lack of this (Deming & Swaffield, 2011; Murphy, 2016).

Some typical methods of landscape architects are using visualisation as a design tool, graphic communication and using creative and critical thinking (Murphy, 2016). According to Landscape architect Murphy (2016) the quality of the outcome depends on the extent that human interactions is facilitated, together with fitting and honouring the ecological setting of the place in the design (p.297). In his book, "Landscape architectural theory – an ecological approach" Murphy (2016) addressed the current status of theory within the practice. As he expressed, there was an ongoing process of forming a clear theory for landscape architects, however, "If there were to be a single agreed-upon purpose in landscape architecture, it might be to change, with each new design, our concepts about how to learn from and reform the ordinary landscapes that shape and inspire our daily lives" (p.280). As he uttered, the quest of landscape architects should be to improve the conditions, and quality of life, for all within the two fundamental considerations of ourselves (humans) and our environment (p. 283, Murphy, 2016).

Designing landscapes

In the procedural phase of designing, design thinking is the main method for landscape architects (Murphy, 2016). Brown (2009) called it a way of reconceptualizing reality in putting together insight with innovative applications based on knowledge of the designer. Richmond & Peterson (2001) stated that the two activities within design thinking was: "constructing mental models and simulating them to draw conclusions and decisions" (p.117). Murphy (2016) further claimed this to be the definition of design (p. 264).

Understanding the existing situation that is to be changed by design requires an understanding of the shared environment and determining what that is and consists of, according to Murphy (2016). To do this both critical and creative thinking is required (De Bono, 1971). As designers, the ideas for reforming landscapes constitute the core of the advice that they sell to whomever is concerned (Murphy, 2016). Depending on how those advices are acted upon, they (the ideas) become manifested in physical and relational realities that can stay for years (Murphy, 2016).

Through the prism of ecosystem science

As Murphy (2016) exclaimed, the objective of a landscape architect should be to create "healthy human ecosystems" (p.283). He proposed an ecological approach for a landscape architectural theory that regarded human systems within ecosystem sciences together with highlighting the human perspective of landscapes (p.285). As he exclaimed, excellence in design would come as a result when all considerations relevant to a landscape architect (utility, economy, aesthetic experience, social vitality, ecological sustainability) were put together to achieve "a synergy of form and process that is greater than the sum of their parts" (p.283). With this, one would create a system that was dynamic and interactive, consisting of "vibrant, regenerative, and sustainable human-environment integration" (p.283). By designing human settlements according to the principles of ecology, things would fundamentally change according to Murphy (2016). The concept of waste would cease to exist and social diversity and complexity would not be seen as a source of conflict but rather as a stabilizing influence as in ecology (Murphy, 2016). "The landscape would be designed and managed for what it is and what it is doing without us, as well as for the benefits people derive directly from it" (p.285). This speaks straight to the essence of ecosystem health and the system thinking of ecosystems with sub-systems that together make the whole.

Biophilic design

The Biophilia hypothesis has led to Biophilic design thinking of buildings to limit their negative constraint on the environment and human health, and rather urge buildings and landscapes to boost human health, productivity and performance by strengthening the connection with the natural environment (p.76, Forman 2008). Biophilic design supports the social and natural system of lowering the environmental cost and impact of buildings and design, "providing habitat for targeted rare species, enhance surrounding natural systems, serve as steppingstones for species movement across a built area; attract a richness of fine-scale nature or small species on the texture of building surfaces: and even educate people for nature protection elsewhere" (p.76). According to Forman (2008) the cumulative effects of biophilic design in buildings and designed landscapes can be remarkable.

"It is evident that in our daily lives nature must be thought of not as a luxury to be made available if possible but as part of our inherent indispensable biological need "

- Federick Law Olmsted, 1982
(p.11, Dramstad et al., 1996).

Figure 2.6. illustrating an example of biophilic design. Picture from Tantolunden in Stockholm, a popular recreational area that enables public green for physical activity, swimming and relaxing in the middle of the city.

Spatial overlap and ecological planning

Ian McHarg was an influential landscape architect who in 1969 published his book “Design with Nature” (Yang & Li, 2016). McHarg had a strong political voice in his time and with his book an environmental decade started (Flemming, 2019). He emphasized ecological knowledge in landscape planning and had an ecological approach as a landscape architect.
Some of the key design features of his designs were according to Yang & Li (2016, p.21).
“: (1) multidiscipline integration to provide holistic design strategies,
(2) ability to tackle wicked design problems residing in a wide range of scales, and
(3) targeting landscape performance in a quantitative manner”

In his book, McHarg presented his “layer-cake” method of site analysis where he used spatial overlaps of maps with different elements to find the most optimal placements or needs for interventions (Flemming, 2019).

Reflection

It is often the natural wonders that give us goose bumps or sudden bursts of excitement. The sunset reflecting in the clouds above the roof-tops, the first blooms in spring, the warming autumn leaves or the sensation of snow under our feet. Our physiological reactions to natural beauty and diversity, to the shapes and colours of nature, to the motions and sounds of other animals are subjective matters that might be hard to explain but nevertheless they are impossible to ignore. These remarkable things, sometimes and to some can give moments of joy, calm, astonishment, appreciation and act as a reminder of the natural world that we belong in. Even though modern-day societies are far from what they once were, these elements are vital to human lives and life-quality.

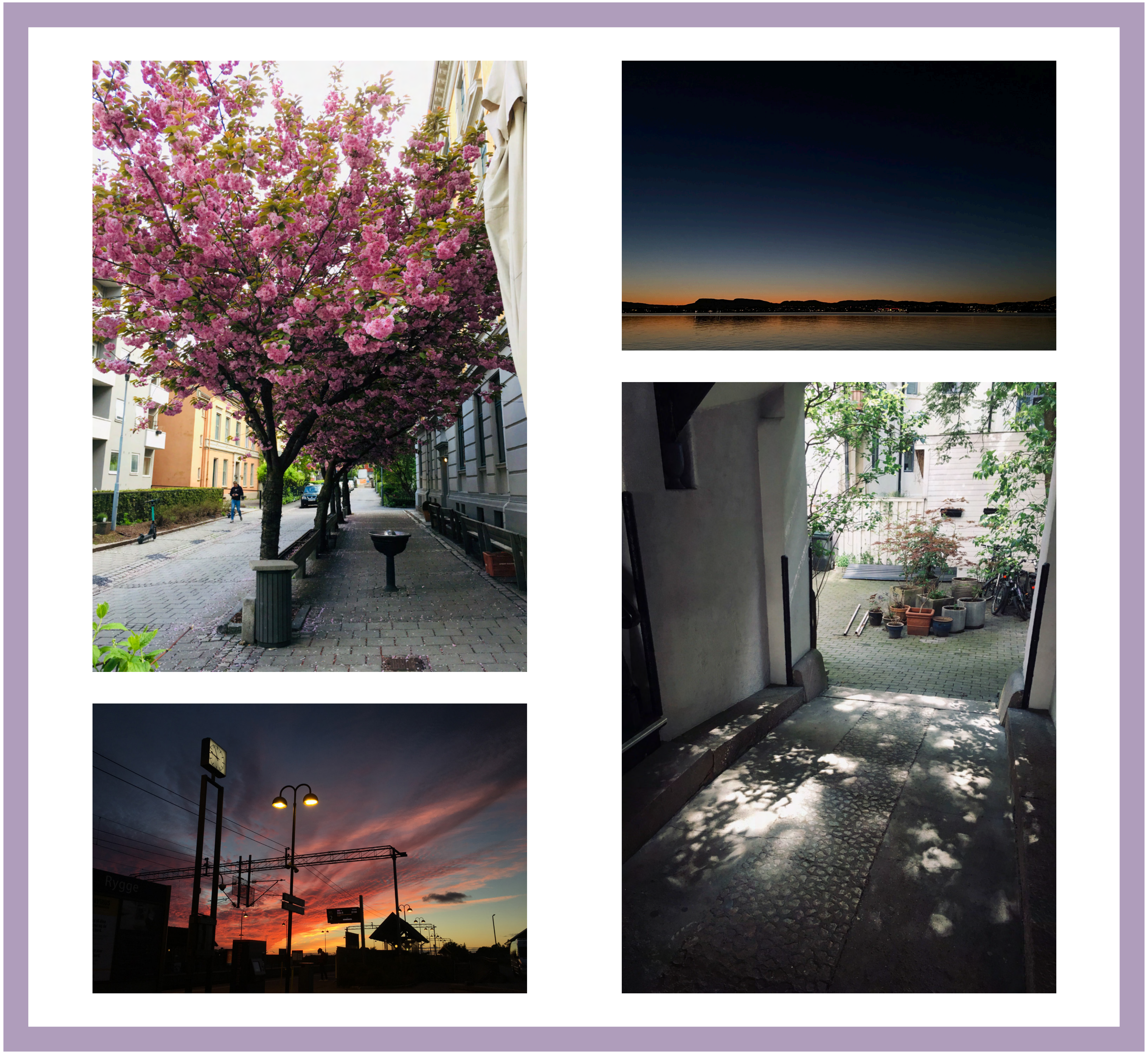


Figure 2.7.1 Photo series of natural wonders that can enhance life-quality and create small moments of bliss. Photos from Oslo, Vienna and Stockholm.

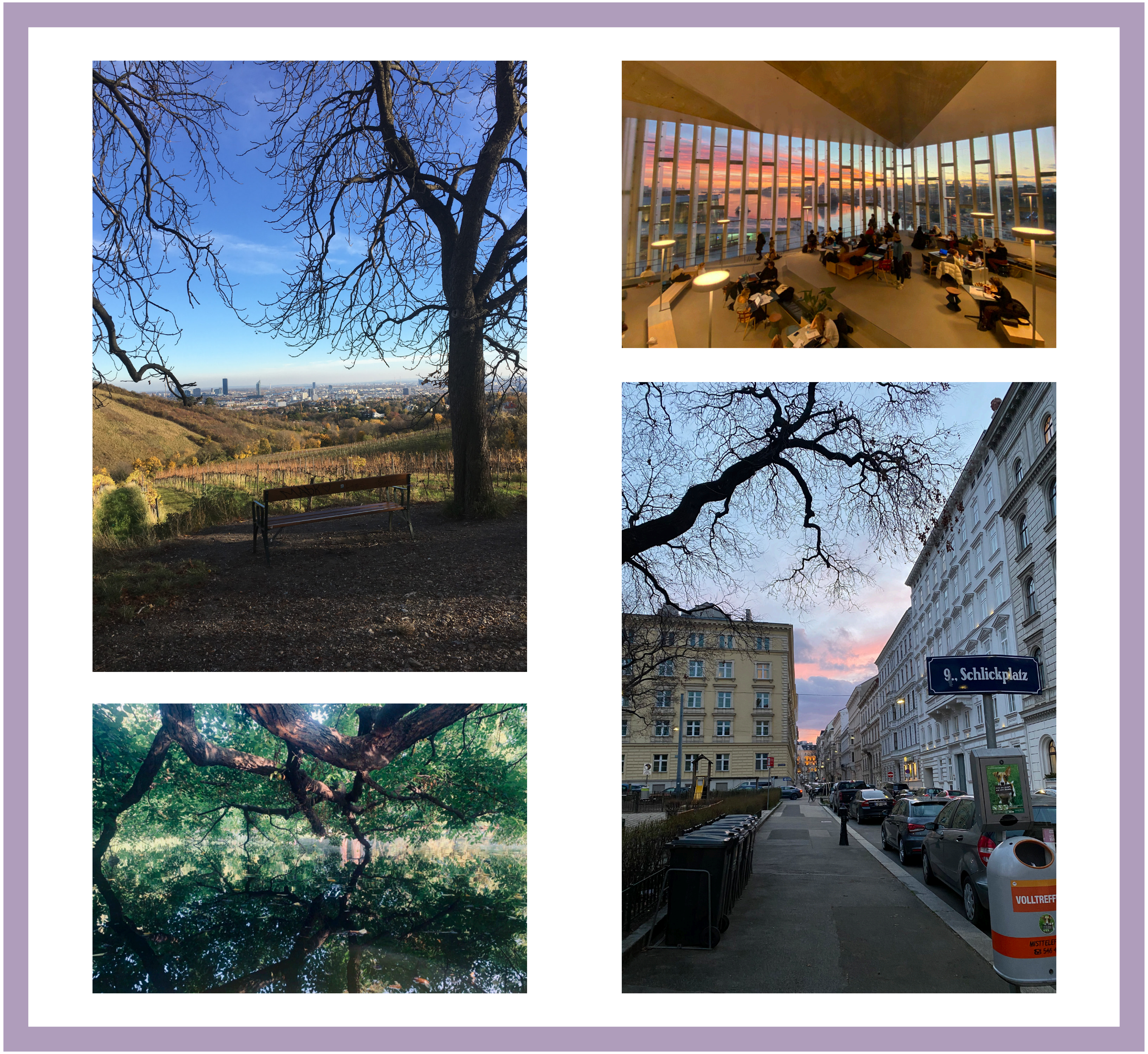


Figure 2.7.2 Photo series of natural wonders that can enhance life-quality and create small moments of bliss. Photos from Oslo, Vienna and Stockholm.

Figure 2.7.3 Photo series of natural wonders that can enhance life-quality and create small moments of bliss. Photos from Oslo, Vienna and Stockholm.

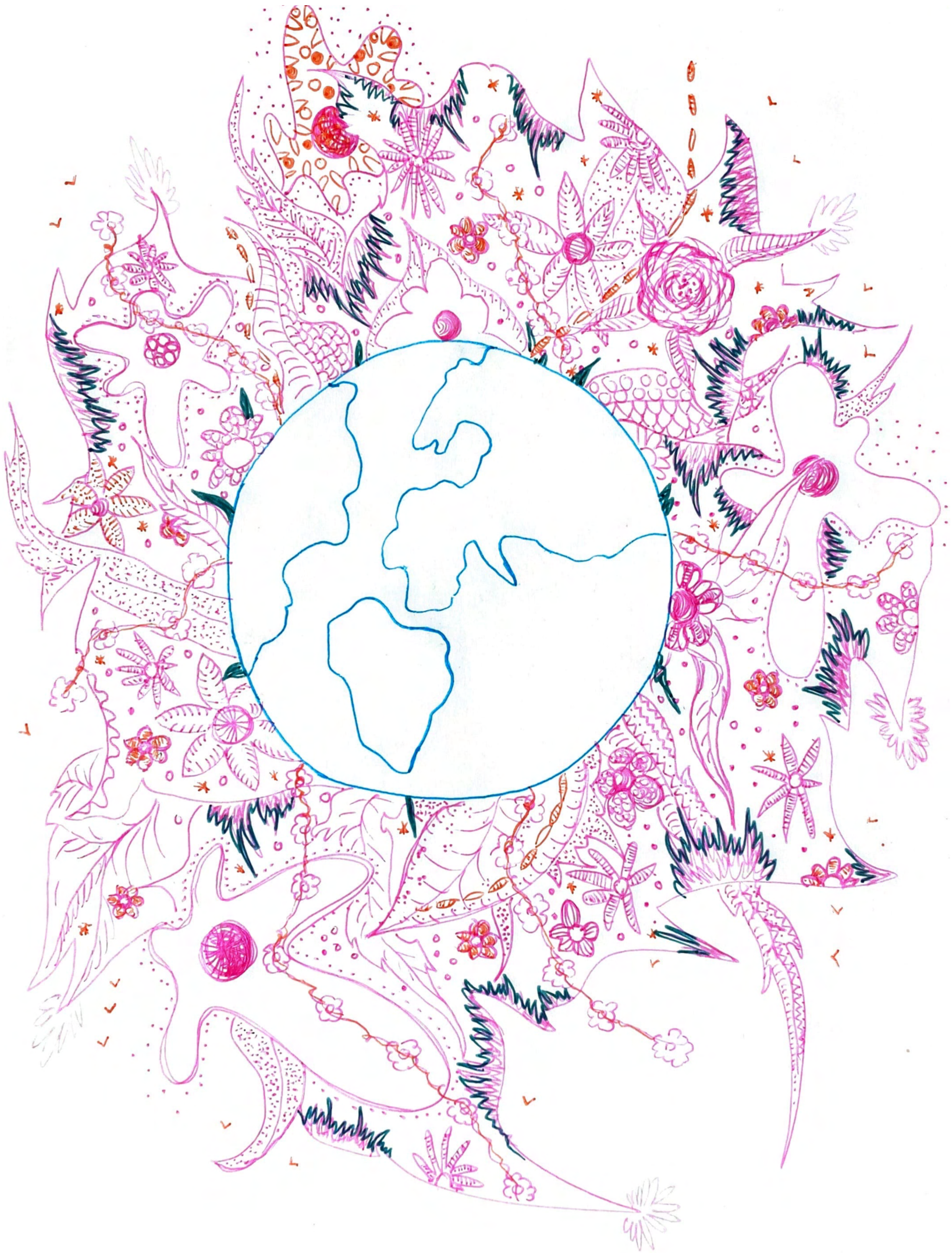


Figure 2.8 illustrating a blooming Earth ecosystem that is healthy and sustainable.

Landscape ecology as design tool

This thesis will pursue the ecological approach featured by Murphy and will test landscape ecological theory as an approach for landscape architects attempting to improve ecosystem health. The lack in theory addressed by Sasaki (1950), Deming & Swaffield (2011) and Murphy (2016), and lacking direction derived from design thinking has urged me to search for additional theory that can aid in solving the problems currently faced with. As a landscape architect I want to aim for achieving a harmonious entity between the living organisms and their environment of the landscape as of Kuznetsova & Manvelova (2022). The exclaimed goal for ecosystem health will be to facilitate positive feedback-loops between the environment and the users, both animals, humans and other organisms. The objective is derived from the definitions of the concept, that the ecosystem should be able to tackle and rather support the climate- and nature crisis and public health challenges of today, i.e. promote resilience and sustainability.

Why landscape ecology? A reflection by a landscape architects

As a landscape architect I believe that landscape ecology has the potential to be applicable to more than the natural systems, and more than what it has been used for in the past.I believe that the principles within landscape ecology for species survival, dispersal and population growth are applicable to the natural system of all ecosystems, and that the principles and theory could achieve a more prominent role within the field of landscape architecture and planning. I in the applicability landscape ecology can have for other fields, or as in this thesis, to other sub-systems within the ecosystem. I will in the following part (part III) explore the applicability of landscape ecological principles to the social and natural system – as in ecological and environmental system. In the last part of the thesis I will test the potential of landscape ecology as a tool for landscape architects in achieving sustainable land-use development (i.e. creating healthy ecosystems) and illustrate how that potentially can be done.

III **How** can landscape architects create healthy ecosystems?

Focusing on how healthy ecosystems can be achieved through landscape ecological theory that is introduced, with a reflection of its applicability to ecosystem health. Sources and sinks are chosen as core principles, and context dependency is addressed. A system is developed for testing the function of typical elements in outdoor rooms by scoring them according to their function as source or sink to the ecosystem health. A gradient for the scoring sheet with criteria is developed. To test the developed system, it is applied to four Norwegian case study sites where a joint assessment of the whole landscape, landscape metrics and elements' functions are analysed. Finally, suggestions of simple interventions that can change the source-sink dynamics are demonstrated.

3.1 Landscape ecology

Testing landscape ecological theory as a method for landscape architects in the attempt achieving healthy ecosystems.

The emergence of landscape ecology

Landscape ecology emerged in the 19th hundreds and many threads of science were weaved together in the shaping of the science field (Dramstad et al., 1996; Forman & Godron, 1986). The use of the term began when aerial photos became more available, with a focus on spatial patterns in sections of landscapes where there were interactions between biological communities and the physical environment (i.e. living systems), see figure 3.1 (Dramstad et al., 1996; Troll, 1968). German geologist Carl Troll was the one who coined the linkage between geographical and biological thinking 'landscape ecology' in 1939, and heavily modified landscapes of the Netherlands and West Germany were among the first to be assessed (Dramstad et al., 1996; Holtmeier, 2015; Wiens & Milne, 1989). During this weaving phase of landscape ecology practices like landscape architecture and land-use planning were incorporated (Dramstad et al., 1996). Since the 1980s the concept of «land mosaic» further evolved with a present system thinking of puzzle pieces fitting together, bringing a holistic focus of landscapes, regional planning and design (Dramstad et al., 1996; Forman & Godron, 1986; Forman, 1995; Wu & Hobbs, 2007).

Landscape ecological theory

'Landscape ecology' as a concept comprises of 'ecology', «the study of the interactions among organisms and their environment» (p.12) and 'landscape', «a kilometers-wide mosaic over which particular local ecosystems and land-uses recur» (p.13, Dramstad et al., 1996). Forman & Godron (1986) defined landscape as "a heterogenous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout " (p.11). According to Forman (2008) land is home and heritage, a source of inspiration and sustenance, land is capital and investment, and it is development.

Landscape ecology is "the science of studying and improving the relationship between spatial pattern and ecological processes on a multitude of scales and organizational levels" (p. 179, Wu, 2013).

Landscape ecology integrates human and natural systems and is applicable to different types of landscapes – agricultural, cultural, natural or novel (Dramstad et al., 1996; Forman, 2008). It is centred on spatial patterns and has a simple, easy and applicable language (Dramstad et al., 1996; Forman, 2008). The characteristics that are studied in the living systems are what the landscape consists of: **structure**, **functioning** and **change** (Dramstad et al., 1996; Forman, 2008). The landscape **structure** is the arrangement of landscape elements and spatial patterns (natural and human land uses in a land mosaic), the **functioning** is the flow and movement of animals, water, wind, materials, plants and energy through the structure and **change** is the dynamics between functioning and structure over time (Dramstad et al., 1996; Forman, 2008).

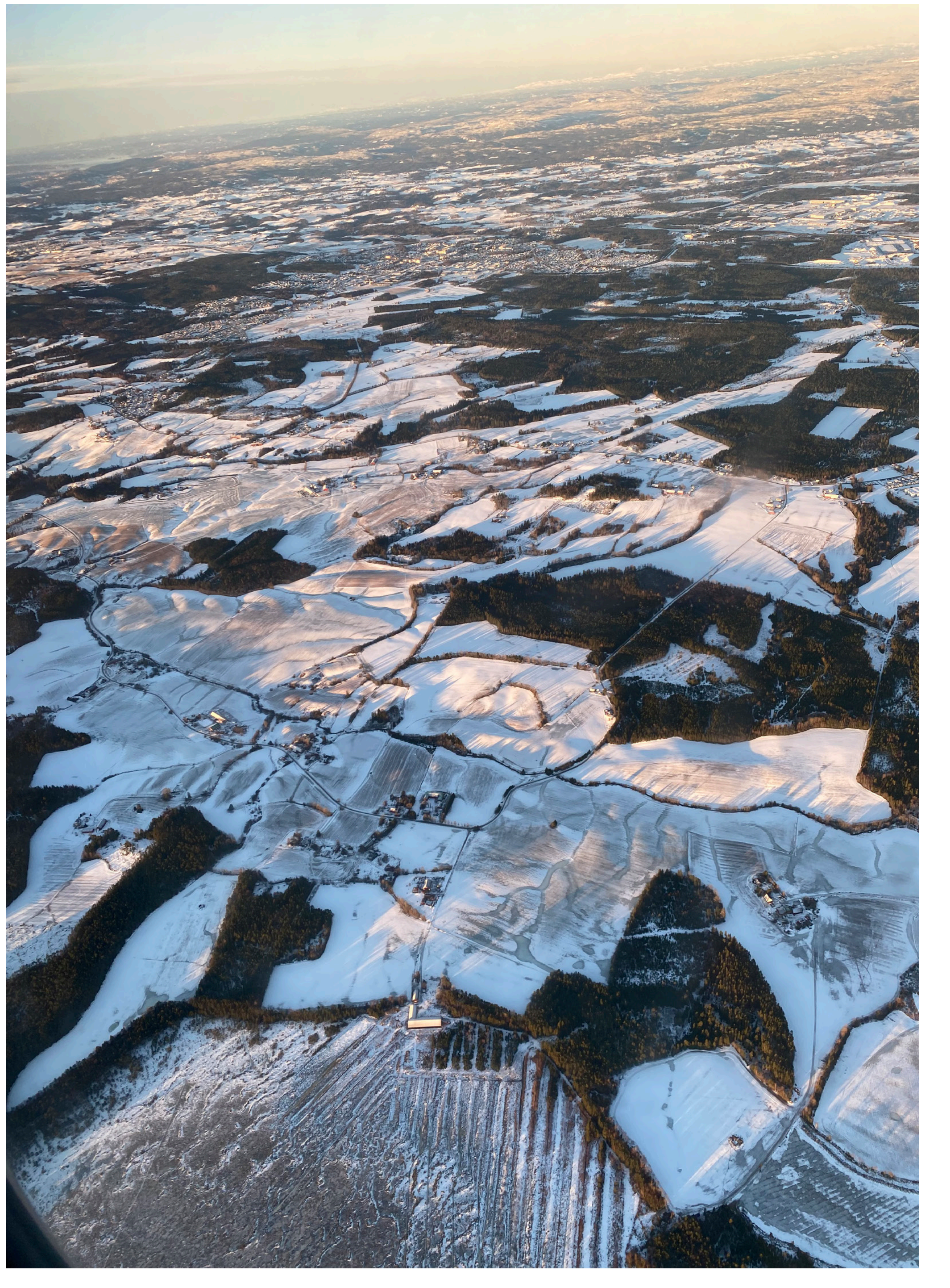


Figure 3.1. The view from an airplane window showing a landscape as in an areal photograph.

Figure 3.2 illustrating habitats in the natural and social system.

Someones habitat

The science-field is based on the structural patterns and functioning of the landscape that almost always includes the function as habitat to some species. For the ecological system "Habitat is the place where an organism makes its home" (Rutledge et al., 2022b). Habitat qualities like abundance of food and resources, nesting sites, disturbances and predator-prey balances can determine the function of the habitat together with the spatial structure and patterns. The world is the shared habitat of all organisms on Earth. Ecosystems, natural and novel are all habitat to some species, be it humans or animals and the habitats can be set in urban, sub-urban, rural or natural landscapes. Organisms function given the spatial patterns and quality of their surroundings (Forman, 2008).

Reflection

Reflecting on the definition of a habitat makes it equally applicable to the social system of people even though the habitat characteristics might be different (e.g. people live in houses and apartments with four walls and a roof rather than in nature). Are the desired and undesired qualities for a habitat in the ecological system similar to those of a social system? If so, can landscape ecological principles that promote ecological function and positive correlations between organisms in their habitat (landscapes) be applicable to the social system of humans in their novel habitats? As a landscape architect who needs to consider both the natural and social system in designing complex landscapes (Forman & Godron, 1981; Forman, 2008) this might give landscape ecological theory potential as a tool for ecosystem health. A pre-condition for healthy ecosystems is that all organisms in it, be it humans, pets, wild animals or insects thrive in their natural or novel ecosystems, be it cities or forests like a harmonious entity (Kuznetsova & Manvelova, 2022).

3.2 Landscape ecological principles and concepts

Patch-corridor-matrix model

The land mosaic or structural pattern can be understood by three types of elements in the landscape: patches, corridors and a background matrix (Dramstad et al., 1996; Forman, 2008). The patch-corridor-matrix model (see figure 3.3) can be applied to various landscapes (Dramstad et al., 1996) as a tool for comparing landscapes and develop principles of form and function (Forman, 2008). The model is relevant for land-use planners due to the role of spatial pattern to control function and change in both natural and social systems (Forman, 2008). The characteristics of the landscape structures control their function (e.g. a wide corridor can facilitate movement for bigger ground-moving animals or function as habitat for smaller animals) (Forman, 2008).

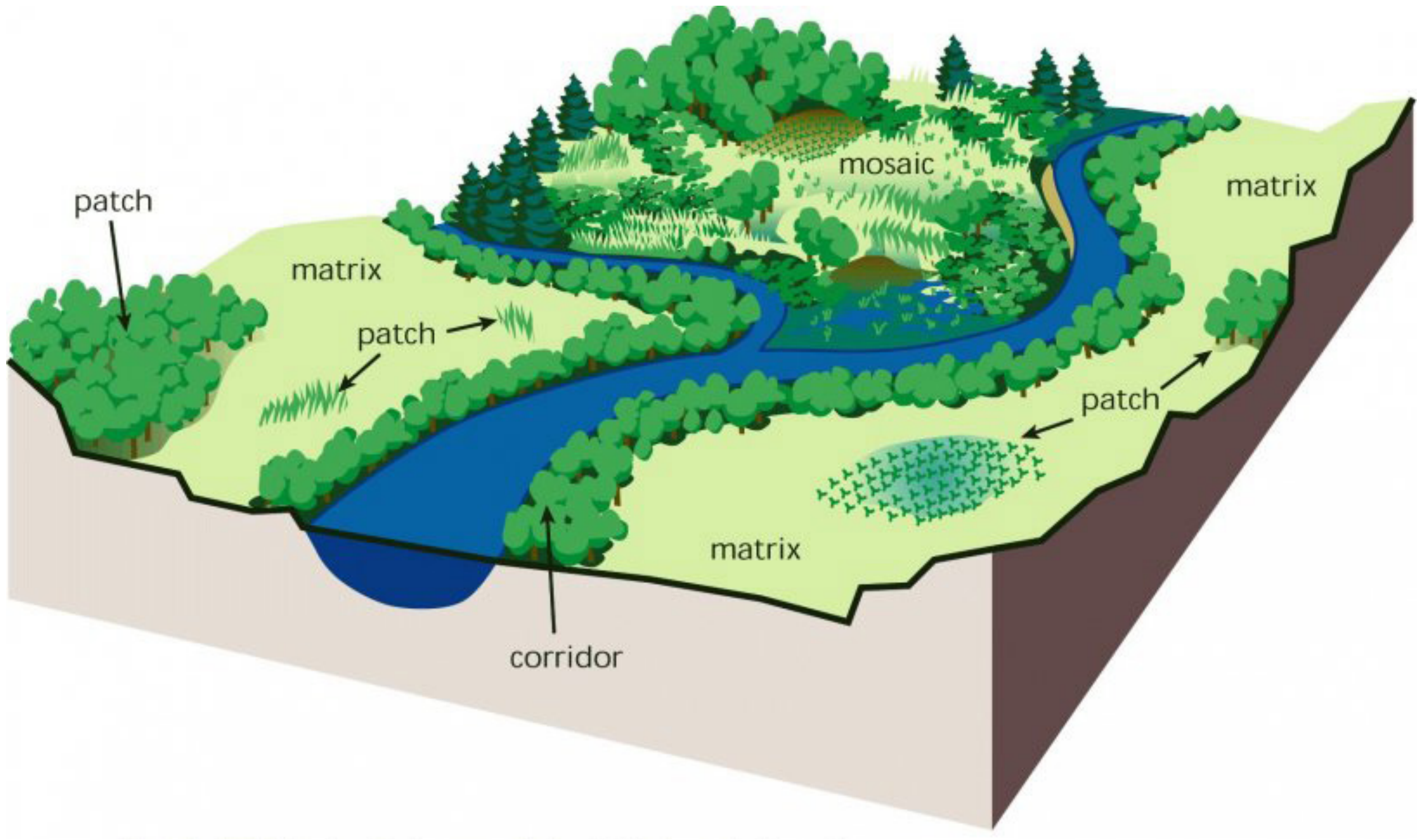


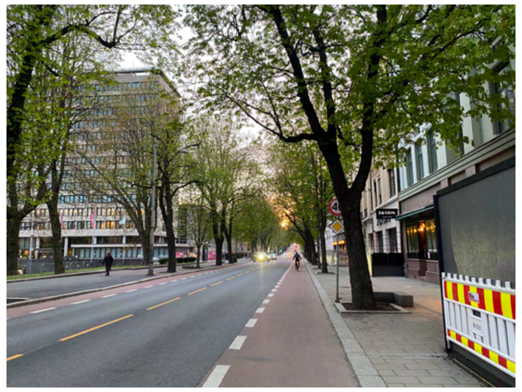
Figure 3.3. The patch-corridor-matrix model illustrates typical structures in a landscape that can be describes as patches, corridors, matrix or mosaics. Patches can be in the size of a corn-field, a single shrub or an entire forest with a strong size variable. The vegetation along the river can function as a corridor, as can the river itself. U.S. Department of Agriculture, 2015.

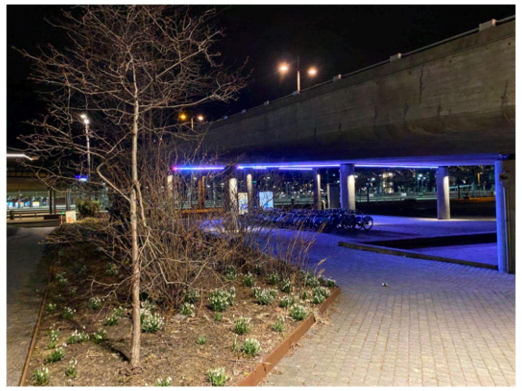
Patches

"Patches are communities or species assemblages surrounded by a matrix with a dissimilar community structure or composition" (p.734, Forman & Godron, 1986). In a patch the internal, heterogenous structure is repeated throughout the patch area (Forman & Godron, 1986; Forman, 1995; Wiens, 1976). Patches can originate from disturbances (i.e. a clear-cut area in a bigger forest matrix), be introduced (i.e. if the clear-cut was turned into a pasture), be remnants (i.e. clusters of trees in an agricultural field) or environmental resources (i.e. wetlands in a city) (p.19, Dramstad et al., 1996). Patches can be small (e.g. a beetles nest in a tree) or big (e.g. national park), round, square or elongated, clustered or dispersed, many or few and these characteristics determine their function (Dramstad et al., 1996; Wiens & Milne, 1989). However, important to understand with patches is the discontinuity they produce in the landscape that in "the real world" consists of "environmental patchworks" (p.81, Wiens, 1976).

Corridors and stepping-stones

Depending on the corridor characteristics (i.e. width and length) and overall connectivity corridors can function as habitat, conduit, filter, barrier, source or sink (p.36, Dramstad et al., 1996). Corridors can be of natural origin such as river systems or novel like roads and powerlines. Novel corridors can also have natural characteristics like hedgerows or alleys. Corridors can together with stepping stones (i.e. small, connected patches, see figure 3.4) contribute to landscape connectivity by providing higher quality linkages between habitats that in turn can buffer the negative effects of fragmentation and isolation, see photos in figure 3.5 (Dramstad et al., 1996). As with barriers the function of corridors depend on the species and surrounding landscape as seen in figure 3.6.





Figures 3.5 A-C illustrating tree-rows, front gardens, alleys and vegetation that can function as stepping stones and corridors. Photos from Oslo.

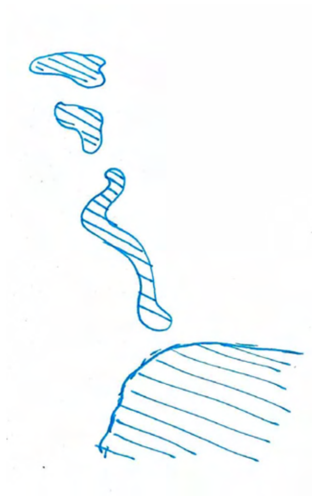


Figure 3.4 illustrating stepping-stones.

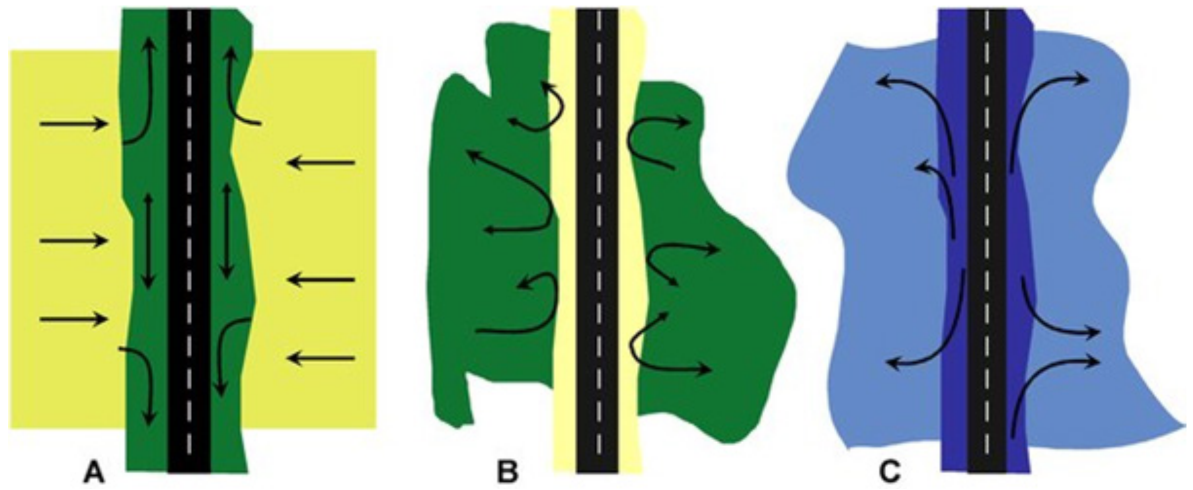


Figure 3.6. The function of corridors illustrated. A) With a surrounding agricultural landscape a vegetated road verge can both function as habitat and enable movement. B) With a surrounding forested landscape and open, grassy road verges new edges can be introduced and the barrier effect for interior species can be increased. C) Road verges can also function as source of dispersal and spreading into new habitats. Seiler, 2003, modified from Mader, 1987.

Matrix and mosaic

The landscape matrix is the dominant or background land cover in a landscape such as a forest, agricultural, urban or rural matrix, see figure 3.7 (Ercan, 2013). The matrix can be heterogeneous or homogenous (Dramstad et al., 1996; Forman, 2008).

The land mosaic is the collection of patches, corridors and matrix' that are dispersed randomly throughout the landscape, see figure 3.8 (Forman, 2008). Development plans for new housings, roads or nature reserves will make changes to the mosaic patterns and form-and-function principles can help understand how this impacts the landscape functioning (Forman, 2008).

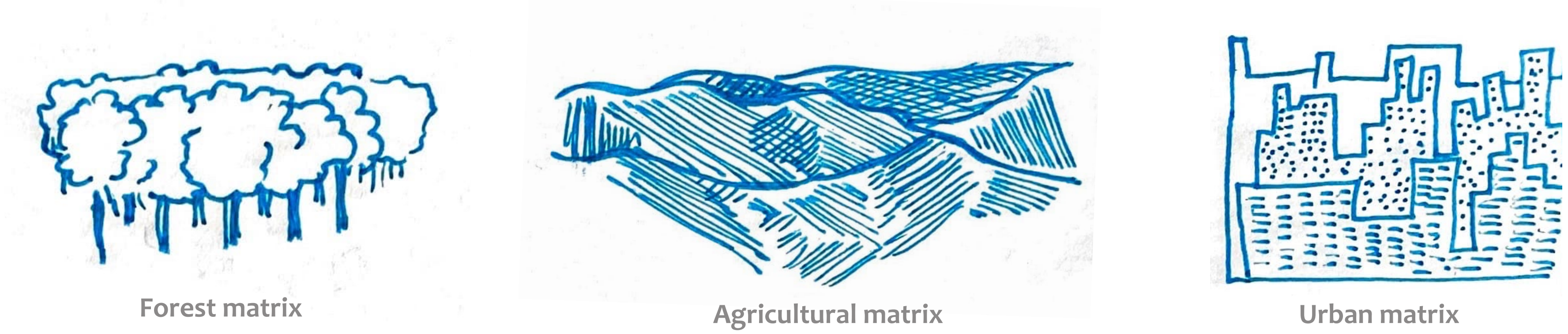


Figure 3.7 Different types of matrix.

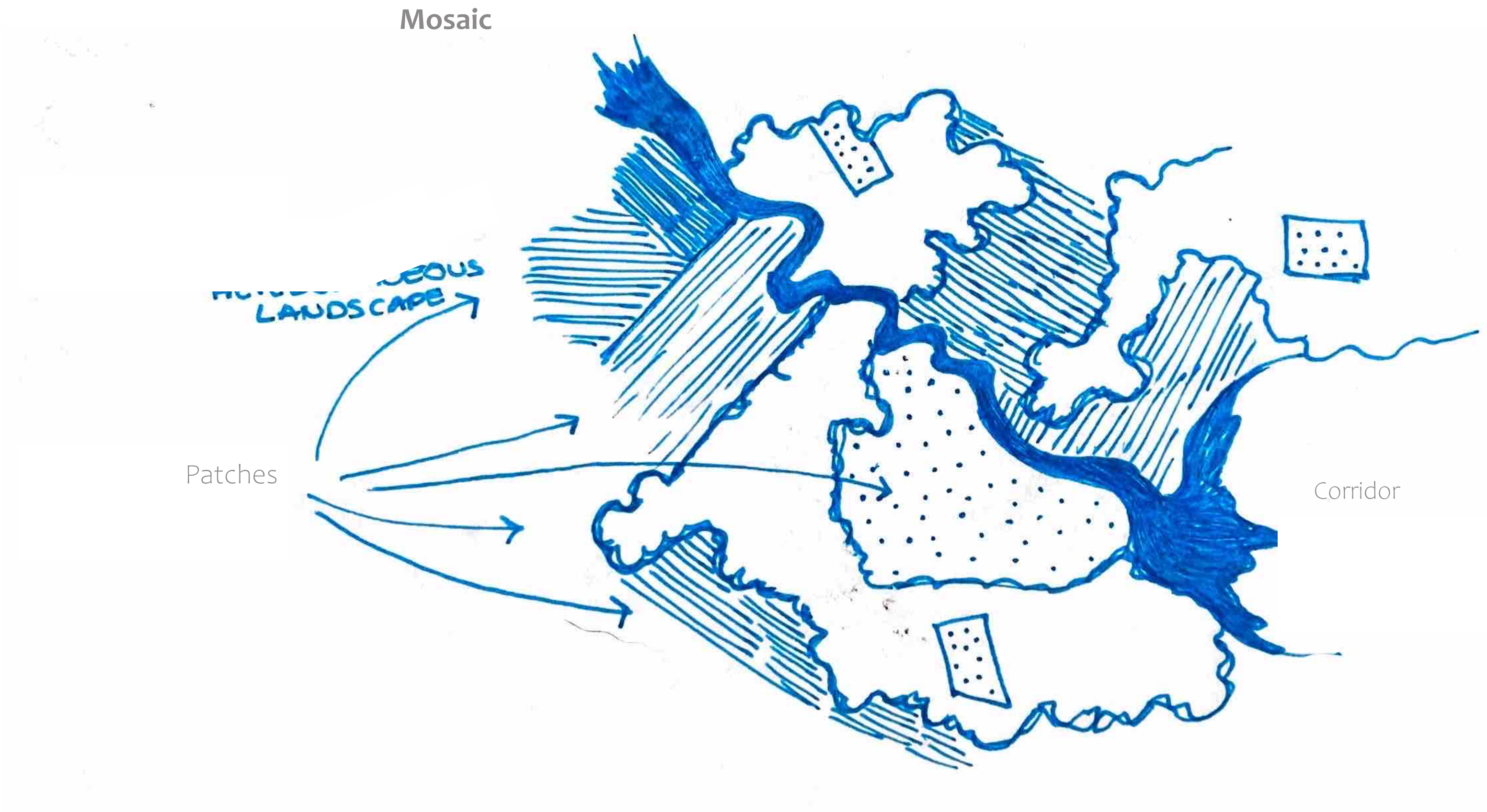


Figure 3.8 illustrating a land mosaic with different types of patches and a river corridor.

Figure 3.9. Aeral photo of a land mosaic with agricultural patches, residential areas surrounded by a forest matrix. Multiple river corridors are running through the mosaic. Flisa, Norway. Map from Applemaps.

Scale dependence

The overall structure and function of the landscape mosaic depends on both pattern and scale (Dramstad et al., 1996; Forman, 2008). According to Dramstad et al. (1996) scale needs to be recognised as a precondition for landscape function and dynamics as feedbacks and interactions occur across all scales in ecological landscapes (Newman et al., 2019).

Wiens & Milne (1989) emphasized the dependence of the environment, its structure, heterogeneity and effects to the landscape dynamics studied in landscape ecology. This is equally relevant to human-modified landscapes, and the effects of mosaic patterns should be scaled to what is relevant and necessary, be it a landscape- or organism-level (Wiens & Milne, 1989). As Wiens & Milne (1989) emphasized, what is a heterogenous patch from the perspective of an ant may be contained within a homogenous patch from the perspective of a bird, see figure 3.10. It depends what species you are studying, the present structures and how they function in the dynamics between organism and environment (Wiens & Milne, 1989). Wien and Milne (1989) thus proposed an adoption of a multi-scale perspective on landscape patterns and dynamics and introduced "microlandscapes" as small scaled landscapes of for example beetles.

Wiens & Milne (1989) argued that microlandscape-studies also can work as models for larger scaled landscape systems (e.g. trophic dynamics) and that these microlandscapes enable studies that are more detailed, accurate and easy to perform (e.g. experiment replication over multiple plots). The patterns they found when studying beetle-movements in a habitat structure in grasslands confirmed a scale-dependence for the form and function dynamics (Wiens & Milne, 1989). According to them, the biases and errors of studying kilometers-wide landscapes are reduced when using microlandscapes, also for bigger animals. The behavioural responses of animals from their environment will always be different, like when comparing an antelope and a beetle. However, by scaling the systems adjusted to the size and home-range variances of the organisms, the landscape mosaics might be contextually and geometrically similar. For instance, they proposed that the responses from various animals of a fractal landscape geometry could be used to develop theories of how landscape fragmentation influence organisms in a scale- and species-independent way. This based on studying the landscape structure relevant to the organism of study (Wiens & Milne, 1989).

According to Wiens & Milne (1989) landscape ecology focuses on entire landscapes, the arenas where people interact with other organisms and "their environments on a kilometers-wide scale" (p.87). They argued for a multi-scale perspective on landscape patterns and dynamics (i.e. landscape ecology) since landscape patterns, or the responses of them vary as functions of scale. Dramstad et al. (1996) accordingly suggested at least 3 scales when assessing landscape ecological dynamics that were 1) macro – the regional scale, 2) meso – the landscape scale and 3) micro – the site scale. According to Forman (2008) these three scales are core in an analytic approach of spatial arrangements that can lead to different synergies and solutions (2008).

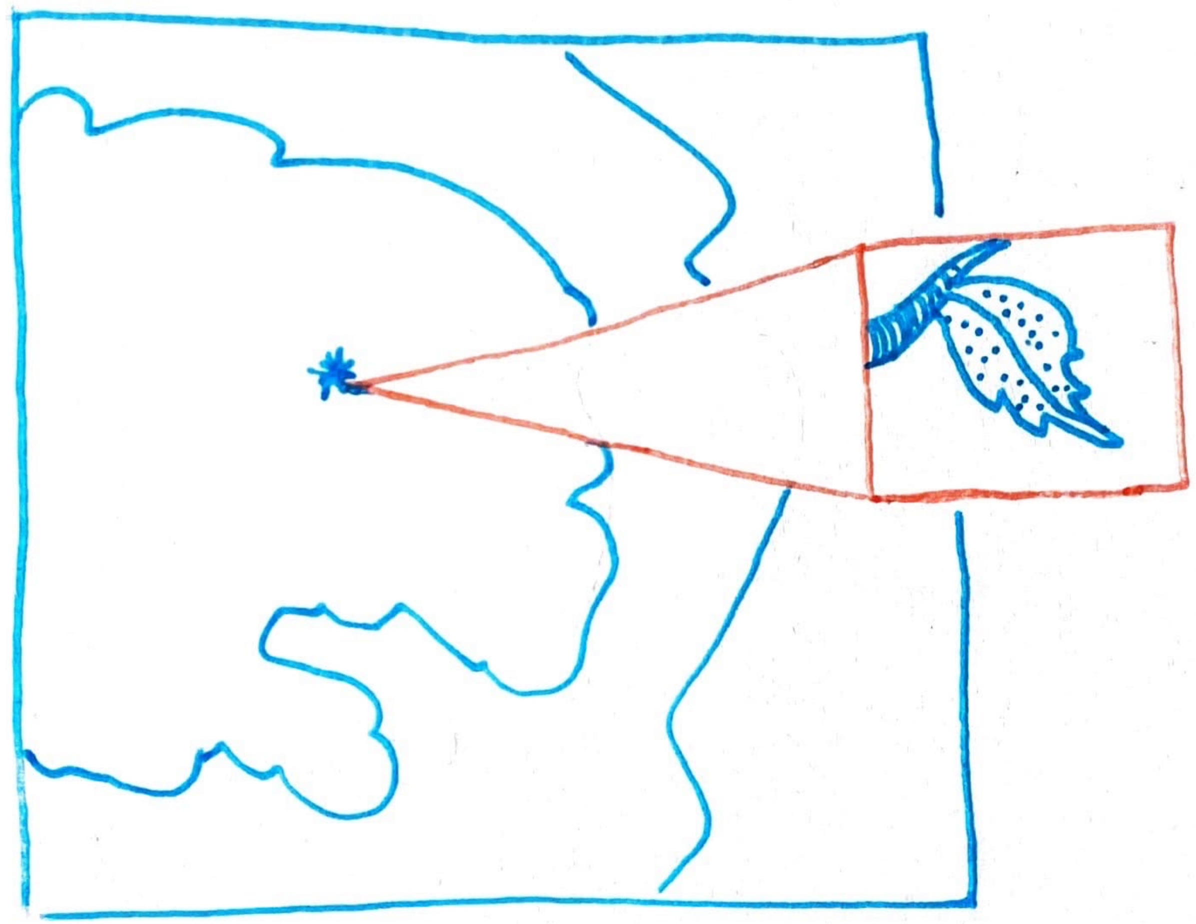


Figure 3.10 illustrating the scale dependence of how landscapes are perceived, as by a beetle and a bird.

Fragmentation

Landscape fragmentation occurs when a larger/ intact habitat is broken up into smaller, dispersed patches (p.25, Dramstad et al., 1996). Fragmentation can lead to isolation (i.e. loss of connectivity) and/or loss of habitat (Dramstad et al., 1996). Fragmentation can occur naturally (e.g. wildfires or floods) but is mostly a result of human activity and land-use change (e.g. urban sprawl and landscape degradation of natural areas (Forman, 2008)). Increasing fragmentation has made Wiens (1976) call landscapes for "environmental patchworks" (p. 81).

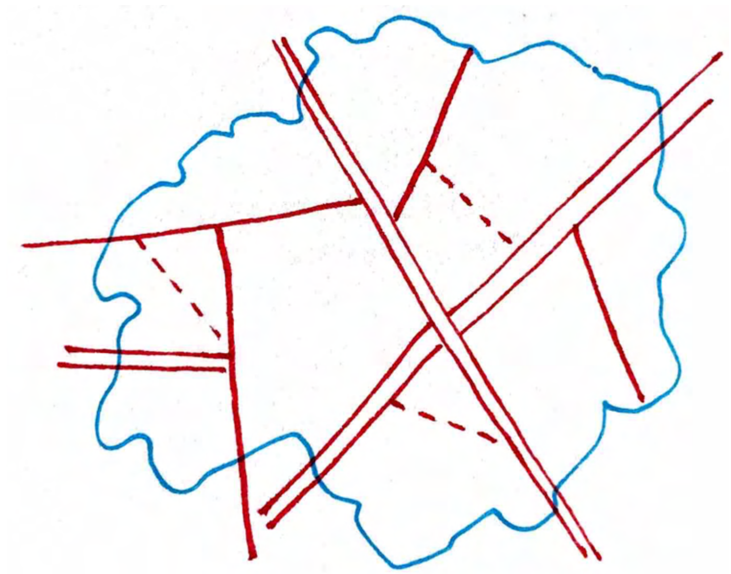


Figure 3.11 illustrating landscape fragmentation of breaking apart a whole to multiple pieces.

Barriers

A barrier is a landscape feature that hinders movement between ecologically important areas or simply hinders flow of movement and thus connectivity (p.1, McRae et al., 2012). The barrier function of an element depends on the characteristics of the element and the species assessed. A river can function as a barrier to mammals who don't swim, and road fences can function as a barrier to ground-moving animals however for animals who can swim or for birds neither the river nor the road fences have a barrier function, see figure 3.12.

Figure 3.12 illustrating different types of barriers, both novel and natural like roads, rivers, fences or built structures that can hinder flow of energy.

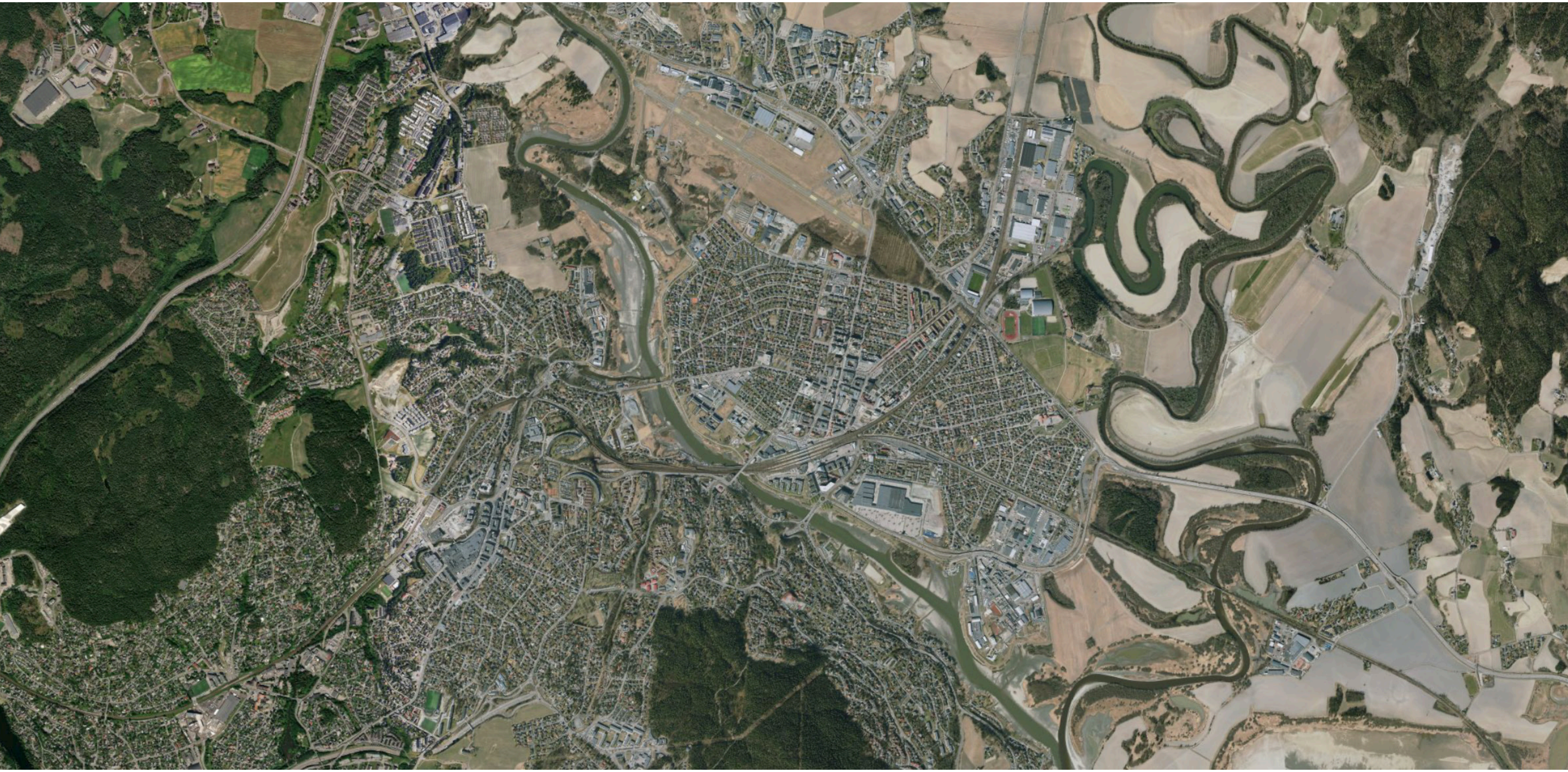


Figure 3.13 Aeral map of Lillestrøm, Norway illustrating a fragmented landscape of different matrixes and land-use types. Map from Applemaps.

Figure 3.14 illustrating island theory as in island biogeography where ocean islands were studied.

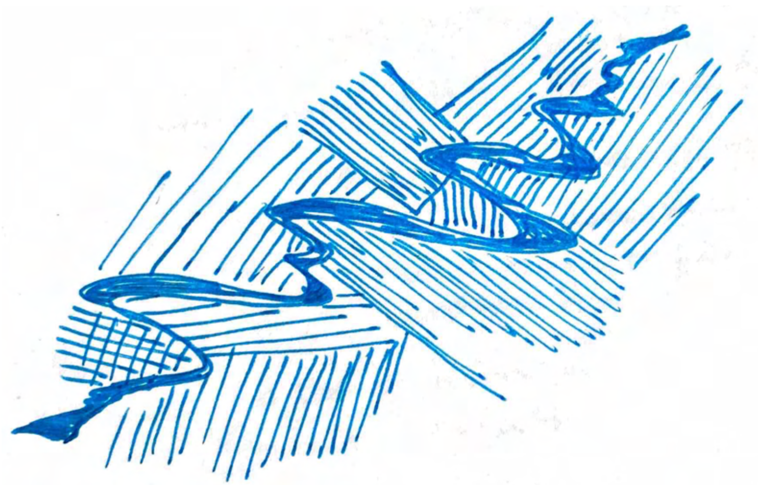


Figure 3.15. Illustration of an agricultural landscape that can be perceived as a homogenous landscape to a bird, however to a mouse the different agricultural patches might be perceived as heterogenous.

Connectivity and isolation

Landscape connectivity is "the degree to which the landscape facilitates or impedes movement among resource patches" (p.571, Taylor et al., 1993) and is a key function that is given the structure of the landscape. What is desired with connectivity is species movement as a key component for species survival (Taylor et al., 1993). According to Dramstad et al. (1996) connectivity in the natural system is "one assay of ecological health" (p.41). Network connectivity (i.e the degree to which all nodes are linked by corridors) and network circuitry (i.e. the degree to whips loops and alternative routes are present) can indicate the effectiveness of the connectivity (Dramstad et al., 1996).

Isolation dynamics, was by McArthur and Wilson (1967) studied on islands and resulted in their island biogeography theory that explained the distribution and abundance of species on ocean islands, see figure 3.14. Soon analogies were drawn to fragmented landscapes as island patches in oceans of landscapes and the theory became much used in landscape ecology to explain the dynamics of isolation (Babu, 2016). Negative effects of isolation can be mitigated by surrounding "islands" as in patches in a given distance (i.e. stepping stones), as well as corridors and an overall satisfactory network of connectivity and circuitry. As with island biogeography larger, less isolated islands will have more species diversity while smaller, more isolated islands will have less (McArthur & Wilson, 1967). The more isolated patches, the higher the pressure will be on the resources available, and the stronger predator-prey imbalances will occur.

Landscape hetero- and homogeneity

The way the habitat is organised can impact its quality and landscape hetero- or homogeneity can determine the ecology and dynamics (Wu, 2013). A heterogeneous landscape is defined by the different types of land cover (i.e. compositional heterogeneity) and the spatial arrangement (i.e. configurational heterogeneity) (Lovett et al., 2005).

Landscape **heterogeneity** is related to the complexity of diversity and pattern in the habitats studied (Lovett et al., 2005). Li et al. (2020) addressed the increasing body of evidence for the positive associations between compositional heterogeneity with a higher abundance of natural resources and increased species diversity and/or abundance (Collins & Fahrig, 2017; Fahrig et al., 2011; Molina et al., 2014). With a heterogeneous habitat the amount of resources, structures, vegetation types, etc. is typically big enough to support more species than a homogenous habitat.

Homogeneity in landscapes comes from homogeneity in biology and a homogenous landscape is often comprised of repeating, similar structures, functions and dynamics (e.g. agricultural field little compositional heterogeneity of few crop species and little configurational heterogeneity with vegetation in one layer). Typically, land-use intensification and homogenization can be found in production land with negative effects for biodiversity (Stjernman et al., 2019). According to Sumasgutner et al. (2019) landscape homogenization can disrupt ecosystem dynamics for avian predators where the landscape mainly consisted of large, agricultural fields with a strong homogenous character.

Both landscape hetero- and homogeneity are scale dependent concepts, as illustrated in the example with the beetle and the bird in the section above ("Scale dependence") for how differently a landscape can be perceived and function, see figure 3.15 (Wiens & Milne, 1989).

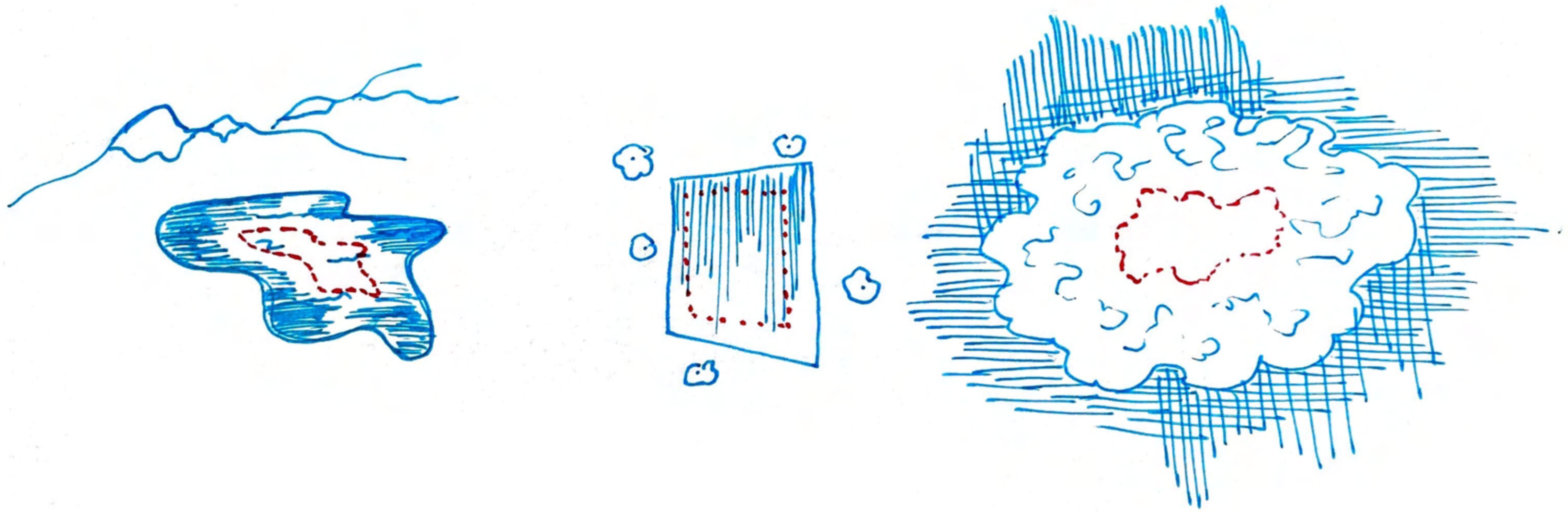


Figure 3.16 illustrating different types of cores and their respective edges. The shape of the patch determines the size of the core and edge.

Figure 3.17 illustration of "it depends" to highlight the significance of relativity in landscape ecology.

Edge and core effect

Around all interiors there are edges. Depending on their characteristics edges can have multiple functions as barriers, corridors, filters or habitats (Dramstad et al., 1996). Natural, so called "soft" edges are often perforated, non-linear, curved and covered with multi-layered vegetation and typically represent a more gradual transition (Bannerman, 1998; Dramstad et al., 1996). So called "hard" edges often represent more abrupt changes between two habitats and can be linear, straight and share the characteristics of an edge of a clear-cut forest (Bannerman, 1998; Dramstad et al., 1996). These characteristics "influence the flow of nutrients, water, energy or species along or across it" (p.27). These key transitional zones between ecological and social systems or human and natural habitats hold great opportunity/potential as they today are recognized as drivers of many ecosystem processes (Dramstad et al., 1996; Porensky & Young, 2013).

The quality of edge and core habitats can be quite different, prevalent in the different species that habituate them. Edge habitats can have different microclimatic conditions than interior habitat like soil characteristics (i.e. moist or dry) humidity and evapotranspiration, wind and sun-exposure, wind speed and turbulence, more frequent disturbances from species and human activity, temperature stability and so forth (Bannerman, 1998). Some species can thrive in edges (e.g. elk, deer and moose) while other species can require interior habitat conditions (e.g. forest-dwelling birds like the "northern spotted owl who require big areas of contiguous forest to sustain breeding populations" (p.5, Bannerman, 1998).

Sources and sinks

Within landscape ecology one can address the function of different elements as sources and sinks to population survival, growth or similarly. A sink is something that typically "drains" a population, i.e. something that hinders population growth and rather shrinks populations (Gilroy & Edwards, 2017). Sources have the opposite effect; they promote sustained populations and growth (Gilroy & Edwards, 2017). According to Chen & Fu (2008) "source landscapes" contribute positively to the ecological process while a "sink landscape" is unhelpful to the process. A habitat can be a source, a habitat resource can be a source, a corridor can be a source and equally for sinks. However, when it comes to the concepts of sources and sinks it depends on what is measured or desired (e.g. populations, species dispersal, connectivity or ecological integrity). So far, no one seems to have connected sources and sinks to the objective of ecosystem health.

Reflection on the complexity of ”it depends”

What is a barrier to one species, can be a corridor for another, or a source or a sink. It all depends. Outdoor lights can be a barrier for species movement as they are confused by the artificial lights that disturb them from their original routes, see figure 3.19. However outdoor lighting works as a corridor for human dispersal and movement along it as it can provide a feeling of safety, figure 3.18. To the environmental system extensive outdoor lighting can lead to light pollution, see fiure 3.20.

Connectivity is a source to the natural and social system and Dramstad et al. (1996) even called it "one assay of ecological health" (p. 41). It can mitigate isolation limited habitat quality by providing dispersal routes and movement. To the social system connectivity is necessary to enable access to services in a society and to create a society where people can interact. Connectivity that enables physical mobility will have even stronger benefits to people in all ages and enable kids to independently bike to school or to the soccer pitch without needing a parent. However, connectivity can mean disturbances to the ecological system, and Doherty et al. (2021) found that disturbance from human activity like recreation and hunting had a much stronger impact on animal movement than habitat modification like logging and agriculture. This stresses an understanding of the complexity within ecosystems and the interactions that occur between the natural and social system (Doherty et al., 2021).

Landscape heterogeneity is a source to wildlife in the natural system with a higher abundance of resources, nesting sites and similarly and to the social system landscape heterogeneity can provide more value or less. Agricultural fields are typical homogenous landscapes because that is what is most effective for producing food despite its negative impacts to the natural system. Heterogeneity in other forms like activities or facilitations of a place for the social system can attract more users and higher satisfaction. All of these factors can together determine the landscape quality in total and its function as source and sink to the objective, that can be ecosystem health.

Figure 3.18. Photo of a dark forest that can be perceived as scary without any lights. Here, outdoor lighting can benefit the social system.

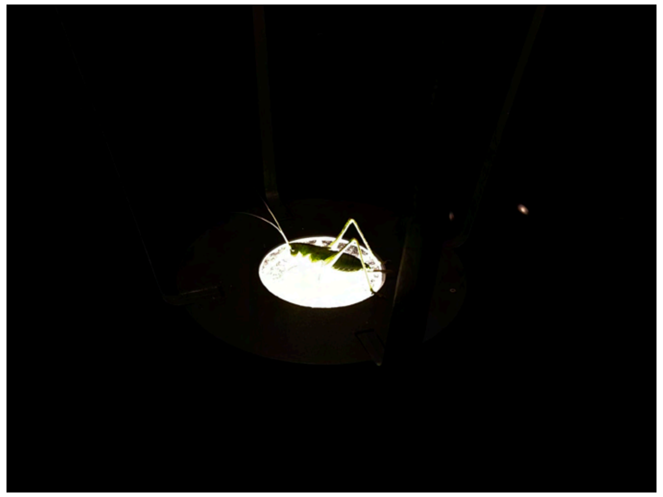


Figure 3.19. Photo of a medium tall lightpole in a natural area. The light attracts insects and can have negative effects for the ecological system.

Figure 3.20. Photo from Stockholm at night where extensive outdoor lights can lead to light pollution with negative effects for the environmental system.

Benefits of a landscape ecological approach

By focusing on patterns and processes a dynamic mosaic is revealed between people and nature (Forman, 2004). As Forman (2008) argued, landscape metrics like the ones in landscape ecology provides an ecological understanding that is key for planning landscapes. In addition, the benefits of a land-use approach rather than an approach fixed on legal or regulatory matters that are fluctuating is that it provides a long-term future for design (Forman, 2008). Urban planning typically focuses on life-quality for people (Fainstein & Campbell, 1996; Hall, 2002) while conservation planning typically focuses on the natural systems and nature on which people depend and live on (Dale & Haeubner, 2001; Marsh, 2005; Noss & Cooperider, 1994). The land-mosaic perspective that has emerged from landscape ecology and other related practices meshes the two to sustain and maintain natural systems and people (Forman, 1995; Forman, 2004) in (p.16, Forman, 2008). That is the core of ecosystem health.

Sources and sinks

Within landscape ecology one can address the function of different elements as sources and sinks to population survival, growth or similarly. A sink is something that typically "drains" a population, i.e. something that hinders population growth and rather shrinks populations (Gilroy & Edwards, 2017). Sources have the opposite effect; they promote sustained populations and growth (Gilroy & Edwards, 2017). According to Chen & Fu (2008) "source landscapes" contribute positively to the ecological process while a "sink landscape" is unhelpful to the process. A habitat can be a source, a habitat resource can be a source, a corridor can be a source and equally for sinks. However, when it comes to the concepts of sources and sinks it depends on what is measured or desired (e.g. populations, species dispersal, connectivity or ecological integrity). So far, no one seems to have connected sources and sinks to the objective of ecosystem health.

Social system - reflections

By identifying desired and undesired functions of different landscape structures similarities to the social system emerge. Starting with habitat, organisms in both the natural and social system desire good quality habitat, with more sources than sinks, abundance of resources and nesting sites and an overall good connectivity to the surrounding environment. Corridors and steppingstones in different scales can counter the isolation effects of non-connected areas. If in a park or parking lot, too much of an island effect is undesired as it makes people feel exposed and insecure without hiding spots or walls to lean into. In a park with too many walls the feeling of being trapped without escape routes can occur. Or, the walls can create possible hiding-spots and feel threatening for that reason. Barriers are negative by hindering free movement, however some places barriers can be good to ensure safety (e.g. road-fences along bigger roads).

A heterogenous park divided in different sections to utilize different activities can enable a heterogeneous user group. However, a fragmented landscape that lacks connectivity and hinders flow of movement will negatively impact use by limited facilitation (e.g. a web of roads between housing developments, schools and sports arenas might hinder kids from walking or biking to school or afterschool activities and can therefore have a social barrier effect). A heterogenous landscape that provides diverse connectivity and enables mobility is different from a fragmented landscape that is broken up into random pieces lacking connectivity.

Figure 3.21 showing an illustration of fragmentation in the social system. If land-uses and activities are dispersed randomly and without adequate connectivity a fragmented area might become less attractive and used.

Common habitat qualities for the social and natural system

- Good habitat quality with compositional and configurational heterogeneity
- Compositional and configurational heterogeneity in landscape metrics, matrix, patches, corridors and steppingstones with wide distribution and abundance
- Minimal landscape fragmentation
- Minimal undesired barriers, creating permeable barriers that can enable some flow of movement where possible
- Soft edges and maximized interiors
- Maximized connectivity with corridors and steppingstones with heterogenous quality to facilitated connectivity for multiple species (ground-moving and flying animals)
- Heterogeneity in services, offers and facilitations

Together, these elements can alter the functioning and dynamics of a landscape and can be summarized as sources and sinks to ecosystem health.

As a planning vision the spatial arrangement of the land mosaic should make both the natural and social systems thrive long term (Forman, 2008). “The size and shape of patches (…) should be dependent on ecological processes such as the perceptual abilities and behavioural tendencies of different organisms.” (p.1133, Girvetz & Greco, 2007). To avoid too strong barrier function alternative dispersal routes are necessary (e.g. underground conduits or wild-life passages over highways) and an assessment of the species that can be affected by plans should be done. In addition, permeable barriers that allow for some movement or dispersal can be better alternatives by not stopping all flow of movement. Or, simply adding some openings in fences to allow flow of energy can mitigate negative effects.

Landscape ecology for ecosystem health

With the emergence of landscape ecology came a deeper message of linking ecology and culture, land and people, nature and humans (Dramstad et al., 1996). The core of landscape ecology lays on focusing on the consequences of design proposals and land-use changes have for nature, ecosystems, biodiversity, users and the overall landscape dynamics (Dramstad et al., 1996; Forman, 2008). Rarely do landscape architects and planners consider the “larger, ecological context of the landscape or region” in which they are designing (p.47, Dramstad et al., 1996). Landscape ecological considerations and principles are applicable to all scales, site- or regional and can contribute to improvement or maintenance of ecological integrity and the overall ecological health of the environment (Dramstad et al., 1996). I therefore see great potential in using landscape ecology as a tool for landscape architects in the strive towards healthy ecosystems.

3.3 Implementing landscape ecology for ecosystem health

A key reference for the following section is **"Urban Regions – Ecology and Planning Beyond the City"** by Forman (2008). Landscape ecology can be useful for maintaining and constituting ecosystem health on the landscape level of thinking structures and functions between the landscape patterns and the organisms using it (Forman, 2008). "It explicitly integrates nature and people" (p.17). The vision for planning a land mosaic should be to make both the natural and social systems thrive long term (Forman, 2008). Landscape ecology can be effective with a core spatial analysis that determines structures, functions and dynamics between living organisms (i.e. humans and animals) and the environment (i.e. natural and built landscape). Spatial analyses of the regional and landscape level can provide an understanding of the ecological dynamics. However, a lof of the function is also determined in the site-level of ecosystems.

Landscape systems

Forman (2008) emphasized the value of an inward approach to the site-level with 3 arguments:

1. The cumulative effects of fine-scale areas
2. The hierarchy theory
3. Human perception

Firstly, the fine-scale areas of patches are typically widely repeated in similar patterns in built landscapes like urban or rural regions (Forman, 2008). Therefore, the cumulative effect of good models for these sites could be determining for the landscape- and upper levels (Forman, 2008). These can be gullies, streams, villages, towns, highways, parking lots and edge parks and by developing generic solutions that address the natural and social systems benefits can be achieved to the additional scales (p.292) (p.292, Forman, 2008).

Secondly, the 'hierarchy theory' "predicts that complex ecological systems, such as landscapes, will be composed of relatively isolated levels" (p.203) and the scaled structure can therefore be advantageous for analysing complex landscapes (O'Neill et al., 1989). One can see three scales within a landscape hierarchy, where the outer/broader scale of the scale of object will have effects inwards, the inner scale will have effects outwards to the level of object and the scale of object will exert competitive or collaborative effects by the many similar sites on that scale (Forman, 2008). The inner scale therefore has just as determining prospects as the other scales as they all interact with each other and determines the dynamics of the overall landscape through constant up- and downstream effects between the scales.

Thirdly, the human perception of sites is mainly based on the fine-scale sites in a human scale unless in an airplane or as a planner working with maps (Forman, 2008). «The public mainly sees and relates to small spaces» (p.19) so to accomplish translating public preferences into planning means focusing at the fine-scale sites can be effective (Forman, 2008; Johnson & Hill, 2002; Nassauer, 1997).

Furthermore Forman (2008) addresses the so-called "paradox of management" for solving challenges within land-use planning (Forman, 1995; Seddon, 1997). "Focus on a solution that is big enough to have some chance of continued success, and small enough that your efforts are visible" (p.2, Forman, 2008). To solve big problems he argued for breaking them into parts and addressing enough of them to alter the balance of solutions (Gladwell, 2000).

Fine scale interventions and economy

Forman (2008) also discussed the economic perspective of interventions to improve and mesh the natural and social systems. Big-scale interventions are often costly and resource demanding, especially if quickly needed to address changes in crises (Forman, 2008). Fine-scale solutions are not always that expensive, and, by addressing a legacy of cumulative impacts the cost is spread out over time (Forman, 2008). But maybe most importantly is the cost and negative impact for both natural and social systems of doing nothing (Forman, 2008).

Additionally there is economic gain to be expected from such fine-scale improvements according to Forman (2008) both due to the substance of ecosystem services (sources) but also practically as investing in natural systems can lead to maintained agricultural productivity on the best soils, less waste of land, concentrating development to reduce costs for infrastructure and servicing, investing in key areas for natural protection and nature-based tourism, rethinking floodplain design to limit potential flood-costs and so on (p.5). In the long term perspective these changes can be beneficial economically. By prioritizing the best uses for fundamentally distinctive and somewhat fixed land resources the future of a landscape or region will be more promising, with benefits to society, economy and nature (Forman, 2008).

The emerald network

Forman (2008) highly emphasized the value of the emerald network as a system of connected patches and corridors that can support the natural and social systems in the landscape, as prevalent in the Emerald Necklace in Boston (link). Providing habitat, ecological sources, wildlife movement and dispersal, nature conservation, recreational trails for people and other benefits to society like ecosystem services are some of the benefits provided with such a network of heterogenous green (p.272).

The emerald necklace

The Emerald Necklace is the name of a landscape design plan in Boston developed between 1878-1896 by Frederick Law Olmsted, who by many is called the father of landscape architecture (Emerald Necklace Conservancy, n.d.). The emerald necklace is a connected series of parks with different character (e.g. botanical gardens, waterways, meadows and tree museums) providing active or passive recreation and that made a green corridor through the city of Boston and connected people to the greenery (National Park Service, n.d.). The name emerald necklace refers to the different park patches as jewels – and each of the jewels contributed with connecting nature to people or each other (National Park Service, n.d.). "Today it provides important habitat, aesthetics, recreation and connectivity for species and numerous people" (p.298, Forman, 2008).

Analysed within landscape ecology the network of parks connected by green waterways or green corridors creates connectivity, both considering the natural system (e.g. vegetation and biodiversity) and social system (e.g. mobility, accessibility). The different patches, or islands of parks has different characteristics and their linkages between each other contributed to them not being isolated islands, either by corridors or steppingstones. This park system was maybe one of the first landscape projects with a presence of landscape ecological principles benefitting the natural and social system. Emerald networks of natural landscapes function as systems of patches and corridors with benefits for biodiversity and stability in the natural system and for the social system by providing recreation, public accessibility to green spaces and health-promoting surroundings (p.146, Forman, 2008).

Figure 3.22 with a map of the Emerald Necklace in Boston. Emerald Necklace Conservancy, n.d.

Urban sustainability

To achieve urban sustainability, Forman (2008) presented three approaches. The first once again builds on the cumulative effects a multitude of fine-scale solutions can give for a bigger landscape. These small solutions could be of a "single type, multiplied together many-fold", or as "an array of types with potential synergies" (p.317). Suggestions were facilitation of public transport, energy-efficient building materials, water conservation techniques, recycling waste and growing food on balconies, implementing biophilic design with green roofs, equipping cityscapes with storm-water swales, porous pavement, rich biodiversity and aesthetic design, cities with a dense park and greenspace corridor network are other suggested solutions (Forman, 2008). As Forman (2008) emphasized, a weakness with this approach is the limited potential for long term nature to thrive as it is anthropocentrically focused.

The second approach is taking a systems view of the city analogous to "urban metabolism" (Forman, 2008) where the city as part of a larger system is seen as a box with inputs and outputs, or exemplified with Hong Kong in 1971 as a sponge absorbing tons of freshwater, oxygen, petroleum, food and cargo goods and sending out pollutants, sewage and materials (Forman, 2008). Addressing the spatially separated or connected greenspaces and their potential function to enable flow and movement by improved connectivity can have broad implications for the system of the city (Forman, 2008). Together, all separate structures or patterns (i.e. patches and corridors) make an interactive, dynamic system (i.e. land mosaic and overall ecosystem).

The third approach emphasizes the prime-footprints model of a city of identifying primary landscapes that provide most of the inputs to a city, and similarly identifying the landscapes that receive the most output (Forman, 2008). This model refers to the main out- and input areas as the sources and sinks for a city. By achieving a balance between the natural and social system within these frames Forman (2008) believes this approach is the most successful to achieving urban sustainability.

Discussion of theory

In the theory presented by Forman (2008) he clearly emphasized the value of fine-scale interventions as most designed landscapes consist of these fine-scale solutions (Bolund & Hunhammar, 1999). In addition, Wiens & Milne (1989) argued for the value of micro-landscapes that could function as models for larger landscape systems as they could detect scale- and species-independent responses between landscape mosaics and organisms' responses. By focusing the lens on the site-scale or microlandscapes one can more easily detect the causes of different ecological responses and dynamics (Wiens & Milne, 1989).

These fine-scale solutions are multiplied countlessly in rural and urban contexts and even globally so the cumulative effect of some generic 'better' solutions that strengthen the natural and social systems would be effective. These ultimate "bad" solutions have potential in being improved by landscape architects to become ultimate good and serve the cause of ecosystem health. These fine-scale sites interrelate and are part of the dynamics between all scales in an ecosystem, and not only does their structure impact the overall network of green in the landscape, but also the function of the organisms using it. One can also add the local context of places with local challenges that can

Figure 3.23 illustrating a city with its surrounding landscape and the input and output between them.

3.3 Implementing landscape ecology for ecosystem health

Identifying sources and sinks for the ecosystem health

Building on the proposal of microlandscapes from Wiens & Milne (1989) one could develop a theory that was based on the relationship between the present landscape structures that function in the ecosystem-specific context to create the unique dynamics present. This dynamics is what constitutes the health of the ecosystem, the harmony or disharmony (Kuznetsova & Manvelova, 2022) between the environment and its organisms. The landscape structures that function as sources and sinks to the ecosystem health could be determined in the site-scale similarly to the prime footprint model presented by Forman (2008) as domains that hinder or promote the ecosystem health.
By analysing landscape structures and functions on three scales as suggested by Dramstad et al. (1996) the regional, landscape and site level will be identified. By using the principles of spatial overlaps inspired by McHarg to identify what the ultimate good and bad are one would get a better understanding of how elements function for the different systems. The results of this could lead to a prioritization of best and worst land uses in accordance to elements function as sources and sinks (Forman 2008).

As already mentioned, climate change, the nature crisis and the public health crises indicate unhealthy ecosystems on multiple layers, climate change representing unhealthy ecosystem on the outer layer of Forman (2008) and the unhealthy ecosystems at site level representing the micro-layer. For landscape architecture these three crises can and should be addressed in design and planning, and the scales at which the practice operates is typically either on the regional (macro), landscape (meso) or site-level (micro).

As an answer to the analyses that will be conducted fine-scale interventions will be demonstrated within four main land-use sites of the social system to provide a tool-box of applicable, generic solutions to improve ecosystem health from the bottom level of the micro-level. Like LEGO bites the suggested solutions are presented in a gradient of their source-effect and they can either be added individually or combined with other elements that impact the dynamics in the sites. Despite the differences within the four case-study sites they represent complex ecosystems with a set of dynamics sub-systems. The given context determines the dynamics, and this dependency urges solutions that are fit to address the elements that function as sinks to the present ecosystem health. The case study sites are chosen to illustrate typical landscape features that are abundant in our surroundings, to enable a broader audience and a bigger applicability. Even though the rural typologies are in a sub-urban setting their characteristics visualise the typical ecosystems and are useful as examples. The combination of analyses on three levels enables a joint assessment for a holistic approach towards ecosystem health.

The analytic approach based on landscape metrics will create an understanding of the state of the ecosystem health on the landscape-level. A mesh of the approaches presented by Forman (2008) will be used. I will focus on cumulative, fine-scale solutions with a systemic view on a shared ecosystem (in his words of city) with sources and sinks, not in the way he understood them as main areas of out- and inputs but rather as what functions as sources and sinks to the ecosystem health. This will be based on the spatial analysis t in the land-use type that determine the functioning and "health" of the present ecosystem (corridors, barriers, homogenous habitat etc). Using the prime footprint model to recognize what limits and promotes the ecosystem from being healthy (the source and sink functions) can lead to a prioritization of the best possible land uses. The solutions will therefore not only be focused on landscape ecological fixes on the structure, but rather on what in the ecosystem can make it a source for ecosystem health rather than a sink. This is a rather new and unexplored trajectory within landscape ecological theory as it often is focused on the landscape metrics rather than elements in the fine site-scale. Analysing element function as source and sink is as far as I am concerned not done before.

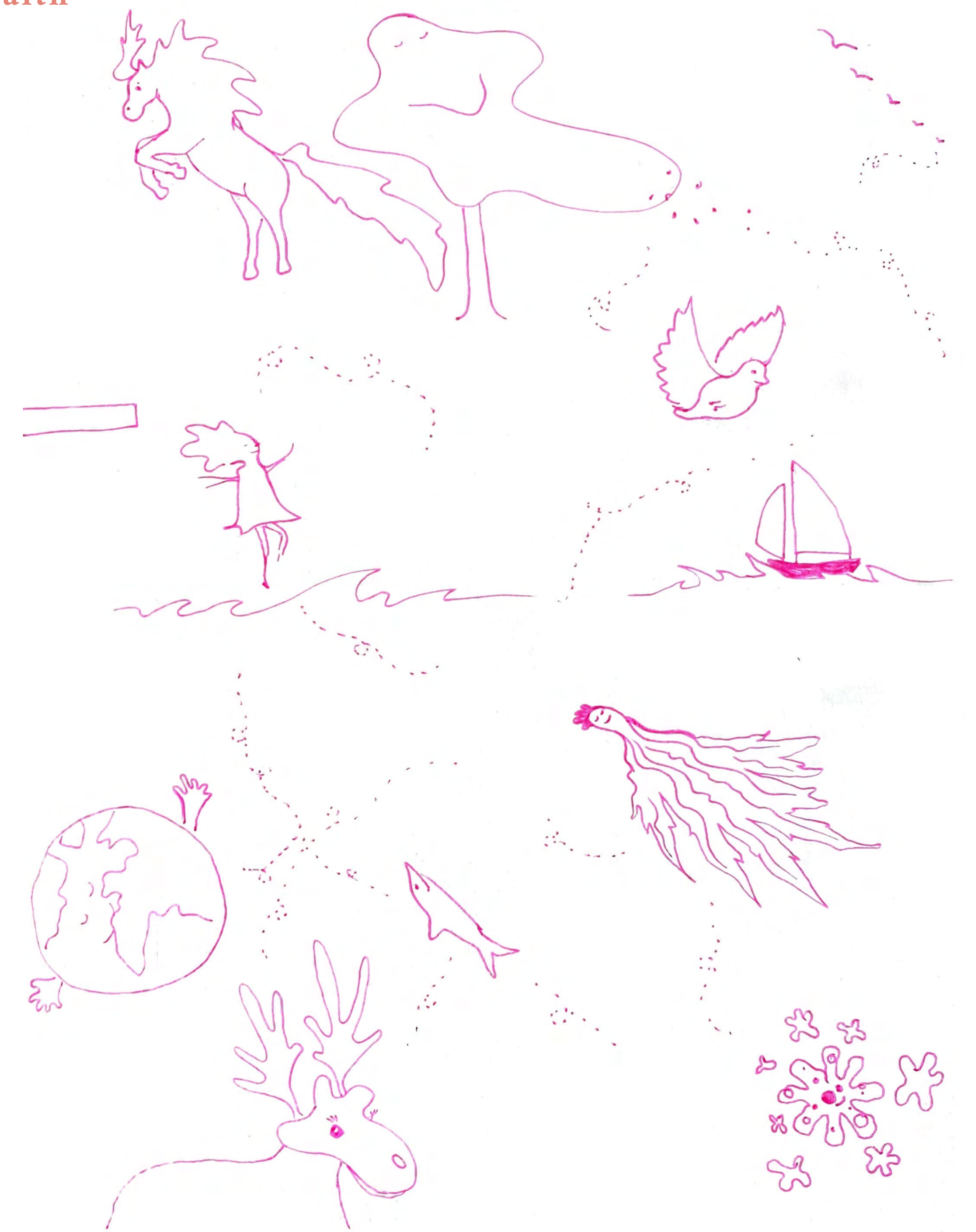


Figure 3.24. Visual mindmap of the vision to create healthy ecosystems for all.

3.3.1 Land-use types

Land-use in Norway

Urbanization is also occurring in Norway, with a strong centralization trend with growth of sub-urban and urban areas (Statistisk sentralbyrå, 2023b). The number of people that reside around and in big municipalities and cities like Oslo, Bergen, Trondheim and Stavanger is increasing (Statistisk sentralbyrå, 2023b). Remote municipalities and districts are shrinking with a growing amount of elderly residents (Statistisk sentralbyrå, 2023b).

For a place to get a city status it has since 1997 required a minimum of 5000 inhabitants (Statistisk sentralbyrå, 2023b). Today Norway has almost 110 cities (Statistisk sentralbyrå, 2023b). Statistics Norway differentiates between urban and rural areas as where people live closely together (i.e. cities) and where the distance between neighbors is greater (rural/sub-urban) (Statistisk sentralbyrå, 2023b). For an area to be considered residential a collection of houses with more than 200 residents living within a proximity of 50 metres is required (tettsted) (Statistisk sentralbyrå, 2016).

Land-use types

The share of built area in Norway is only 1.7 % (Statistisk sentralbyrå, 2022a). The distribution of this built land is presented in table 3.1 and the distribution in Oslo is presented in table 3.2.

What these tables present is that residential and industrial built areas are the most dominant land-uses, together with transport and technical infrastructure (Statistisk sentralbyrå, 2022a). Landscape architects are involved in the planning of all of these land-uses, e.g. roads, residential areas in urban or rural matrix, industrial sites like shopping malls, fulfillment centers, railway stations

and commercial areas. Industrial and residential areas are often mixed-use developments but still have typical characteristics. The industrial and residential case study sites that are chosen for this section represent typical qualities for these land-uses. Their characteristics are not site-specific but rather context-specific in relation to the land-use they provide. There are differences between their layout in an urban or rural matrix and that is why I have chosen to present them both for the two matrixes. The case study sites represented are:

1) A sub-urban industrial site of a big-scale warehouse in a neighborhood of shopping malls, fulfillment centers, a highway and similarly.

2) A sub-urban residential site of terraced- and single-housing developments with gardens, small roads and recreational areas.

3) An urban industrial site of high-rises, office buildings, roads and public transportation and multiple commercial offers at the ground level.

4) An urban residential site of apartment buildings, blocks and single housings with schools, streets, squares and multiple commercial, gastronomic offers at the ground level.

Table 3.1 showing the disitribution of built area in Norway categorized after the type of built land. Transport and technical infrastructure is the widest distributed followed by residential housing. Numbers from Statistisk sentralbyrå, 2022.

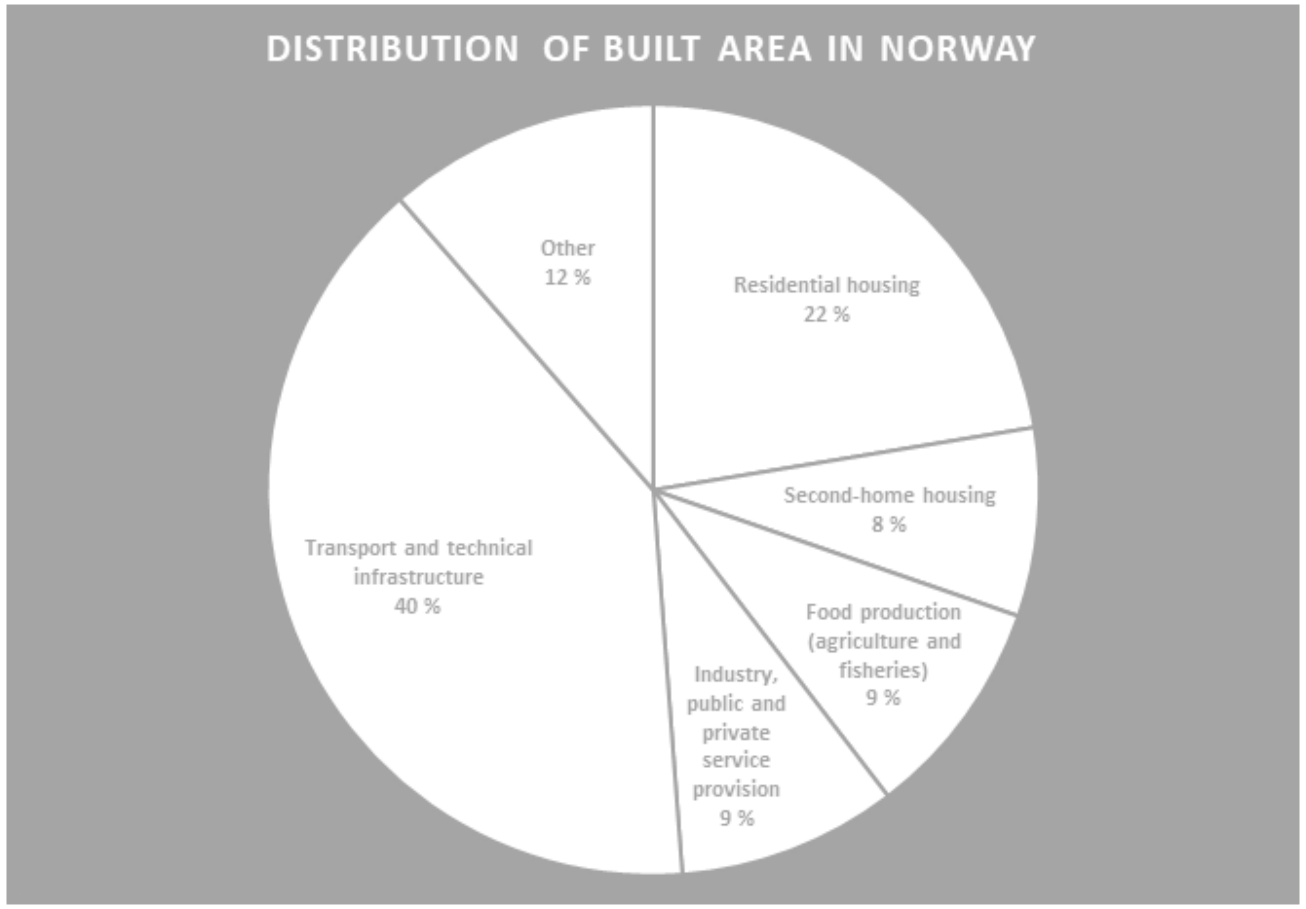
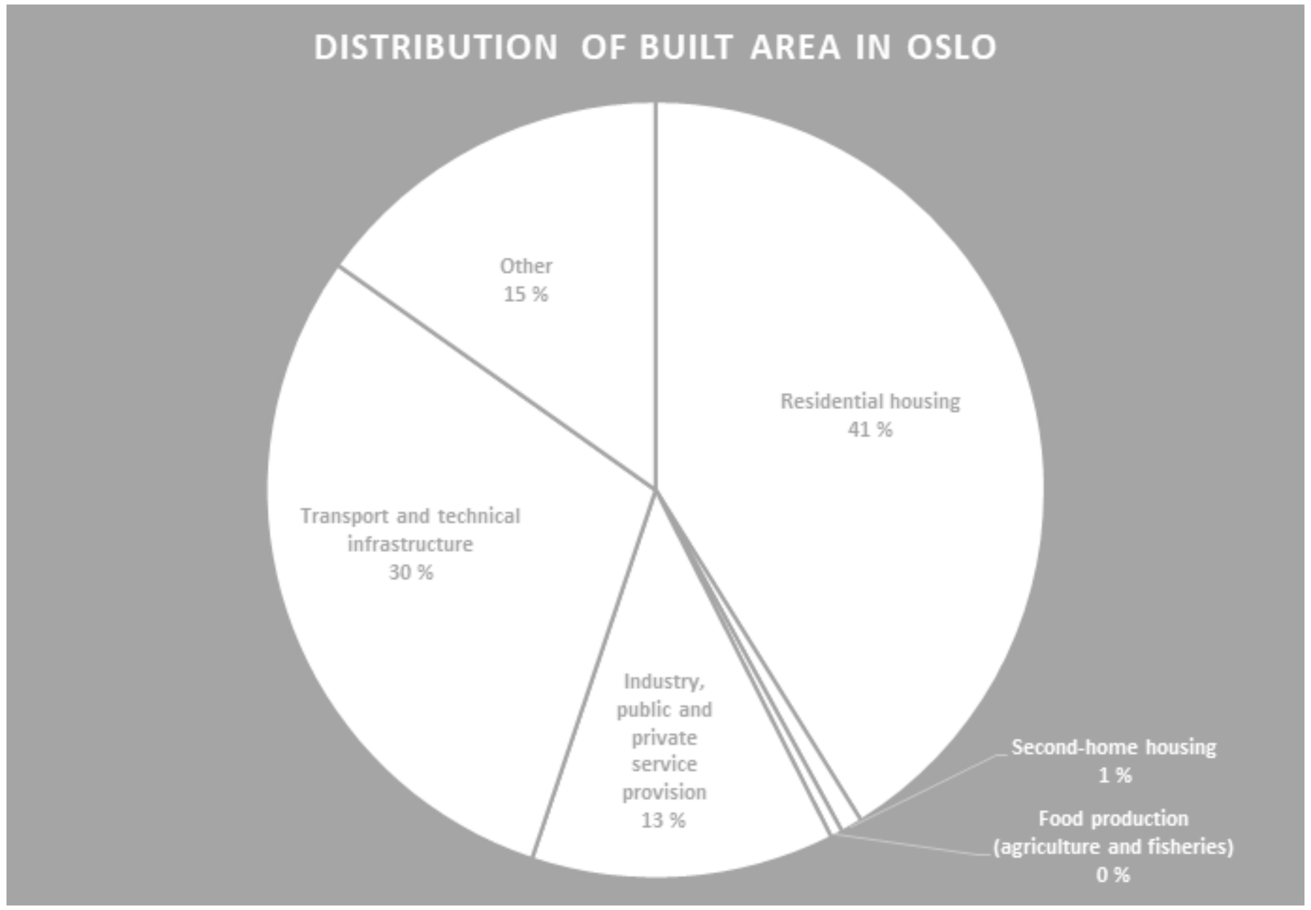


Table 3.2 showing the disitribution of built area in Oslo with the biggest distribution of residential housing before transport and technical infrastructure. Numbers from Statistisk sentralbyrå, 2022.



In this part four different places from the city of Oslo, Norway will be analysed. These places represent the most typical land-uses in an urban and sub-urban matrix, industrial and residential. The sub-urban sites represent characteristics that also are common for the rural matrix.

The selection of these four sites is done based on the most common land-uses and matrix' of development today, illustrated in figure 3.25, 3.26 and 3.27. They have contrasting characteristics and functioning in the landscape, and in my opinion, they represent typical features of the social system that often have conflicting interests with the ecological and/or environmental system.

Figure 3.25 shows a typial landscape section illustrating the transitions from a rural matrix to the right, to a sub-urban/rural matrix to an urban matrix to the left.

URBAN MATRIX

SUB-URBAN MATRIX

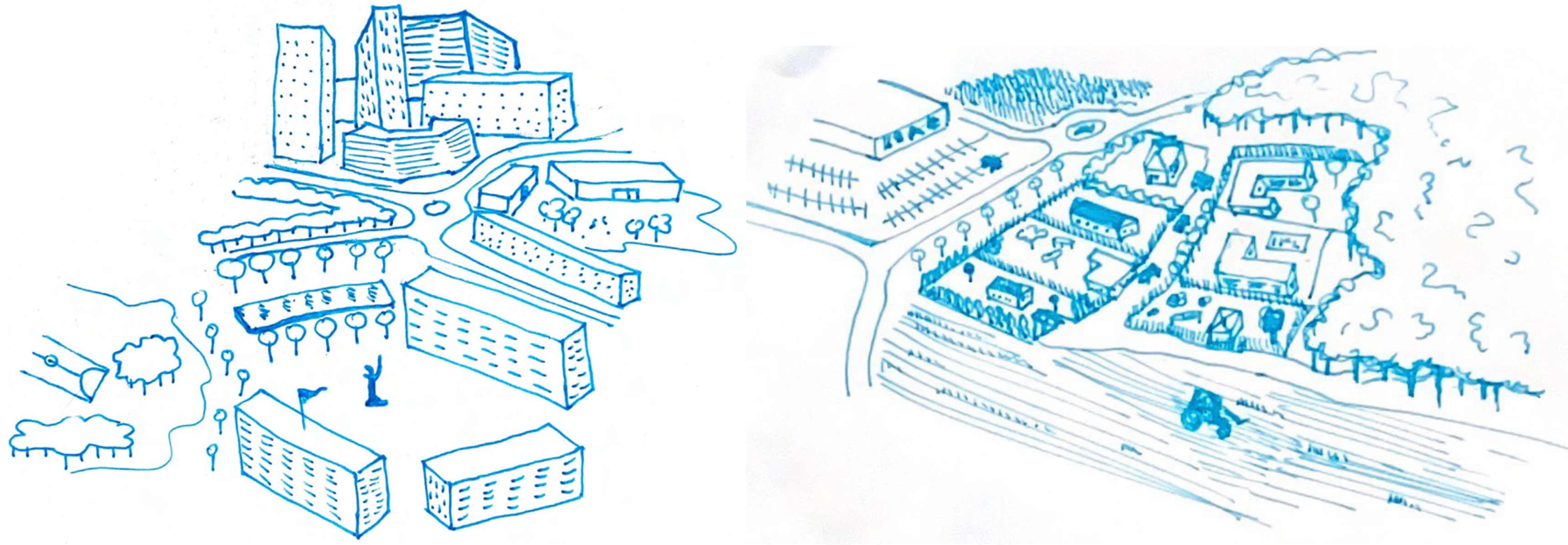


Figure 3.26 shows sketches of typical features present in an urban and sub-urban or rural matrix.

Industrial

The industrial areas represent a mixed land-use with commercial, industrial and business activity with offices, warehouses, malls, terminals, train stations, harbours and other infrastructures. With these follow a strong presence of typical structures like parking lots, over-sized buildings and high-rises and dense road connectivity. The activity present is dominated by the land-uses and contain less recreation and residency with a higher intensity of vehicles, less pedestrians, more traffic and pollution that follows of e.g. noise, light, air and particulate matter. These sites are typically grey with impermeable surfaces on the ground and roofs, hard building surfaces of glass and concrete and a limited aesthetic value.

Industrial areas have a concentration of energy and use during work-hours at daytime in the weekdays. During the night the majority of these areas are typically empty and dead with a lack of program. This is marked by a moon-symbol.

URBAN

SUB-URBAN

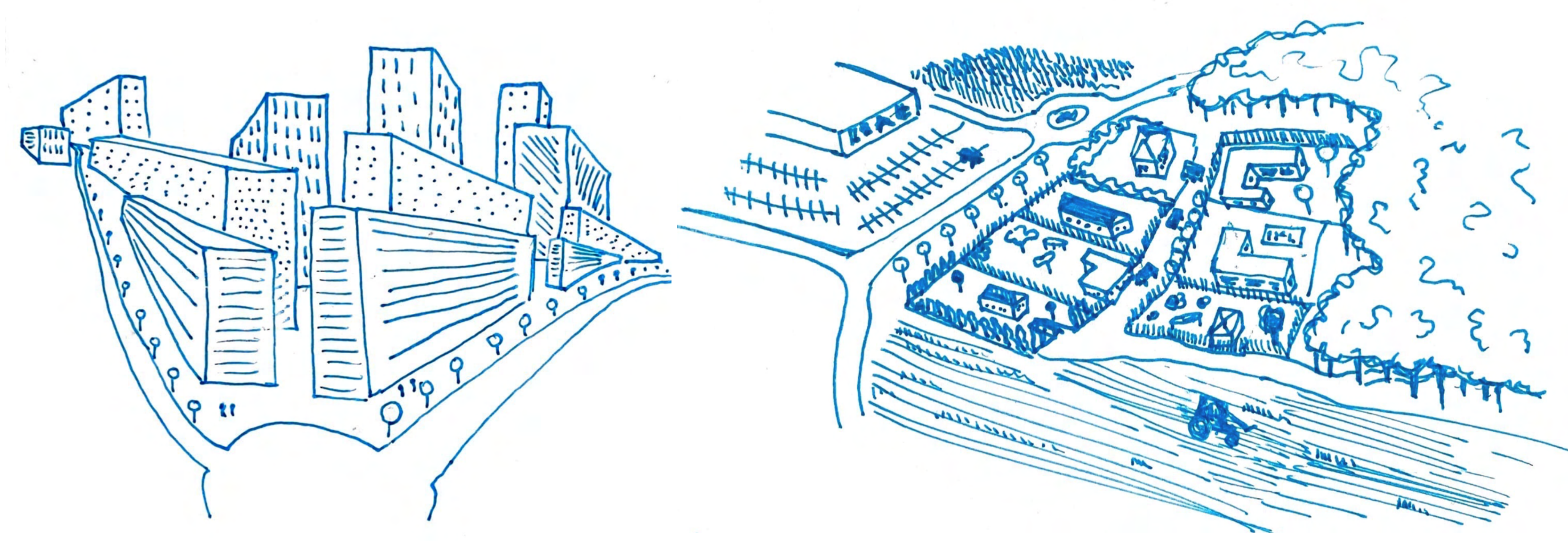


Figure 3.27 A illustrating a typical industrial site in an urban (to the left) and sub-urban (to the right) matrix.

Residential

The residential areas represent modern and traditional housing in apartment complexes, single-housing, terraced housing, remote detached houses and similarly with typical infrastructure of interconnecting roads, gardens, backyards, playing grounds, schools, kindergartens and other social services. Based on the Norwegian definition a collection of houses with more than 200 residents living within a proximity of 50 metres to each other can be considered residential (tettsted) (Statistisk sentralbyrå, 2016). The activity is typically more facilitated for movement of pedestrians, bikes, cars and a slower pace. The quality of the environment is context dependent but due to safety, life-quality and neighbourhood communities the desired qualities are often the same of minimized traffic and pollution of noise, light, air and particulate matter. The structures are often more heterogenous with a mixed structure of grey and green and a desire for aesthetic value.

Residential areas have a concentration of energy and use after work/school in the afternoons, nights and weekends.

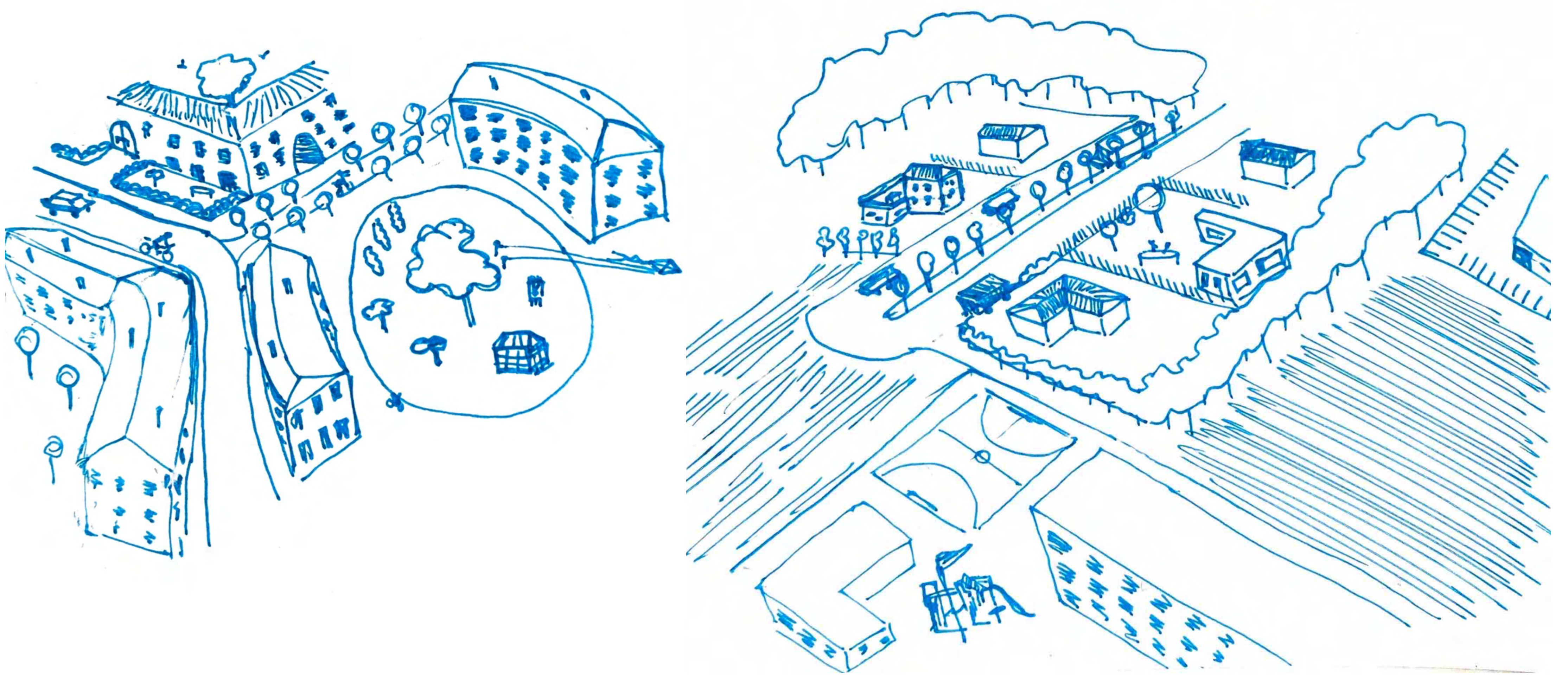


Figure 3.27 B illustrating a typical residential site in an urban (to the left) and sub-urban (to the right) matrix.

3.3.2 Case study sites

-industrial sub-urban-
IKEA Furuset

IKEA is typical industrial site found in a sub-urban and rural matrix, often in relation to an urban sprawl process. These land-use types are growing in distribution to meet a constant increased consumption and are often strategically placed near infrastructural hotspots like highways. These sites are typical sites for landscape projects aiming at reconnecting the surrounding and fragmented green.

The characteristics of this land-use type is huge, homogenous parking lots with asphalt, little aesthetic value in and around the warehouse, more grey than green surfaces and some green edges that provide much desired shade for families or dog-owners who try to find suitable parking spots during the summer. There is often a lacking human scale in these types of sites with vast parking lots and over-sized warehouses, and a weak presence of friendliness in the design.

There is often a strong presence of infrastructural elements like street lights, big roadside fences and a faster pace of traffic.

See photos (figures 3.28 A-D) for an overall feel of IKEA Furuset.

Figures 3.28 A-D illustrating four different settings in IKEA Furuset. A (top left) shows groups of trees in the edges of the parking lot, B (top right) shows the grey facade of the IKEA warehouse, C (bottom left) shows the green edges of trees around the grey, homogenous parking lot and D (bottom right) illustrates the impermeable ground cover surface of the parking. Photos from Google Streetview.

-residential sub-urban-
Korsvoll

Korsvoll is a typical residential site in a sub-urban or rural matrix. The residential site contains a multitude of houses, designs, gardens and fences of different character. It is often found next to a natural or agricultural matrix as it is typically a developed patch from that matrix, in this case the forest (Oslomarka). These sites typically represent a multitude of individual housing developments and are widely distributed in Norway. Typically there is less building of single-houses due to the inefficient use of area it provides compared to terraced housings or apartment buildings.

The characteristics of this land-use type is a multitude of fragmented, heterogenous green garden patches of varying quality, typically with finely cut lawns, evergreen hedges and dense fencing. There is a more human scale with heterogenous single-houses with elements like outdoor lighting of house and lawn, garages or private cars in the street. They are often in closeness to green and contain a fine web of walking trails, short cuts and a slower pace of traffic. These areas often present a stronger friendliness.

See photos (figures 3.29 A-D) for an overall feel of Korsvoll.

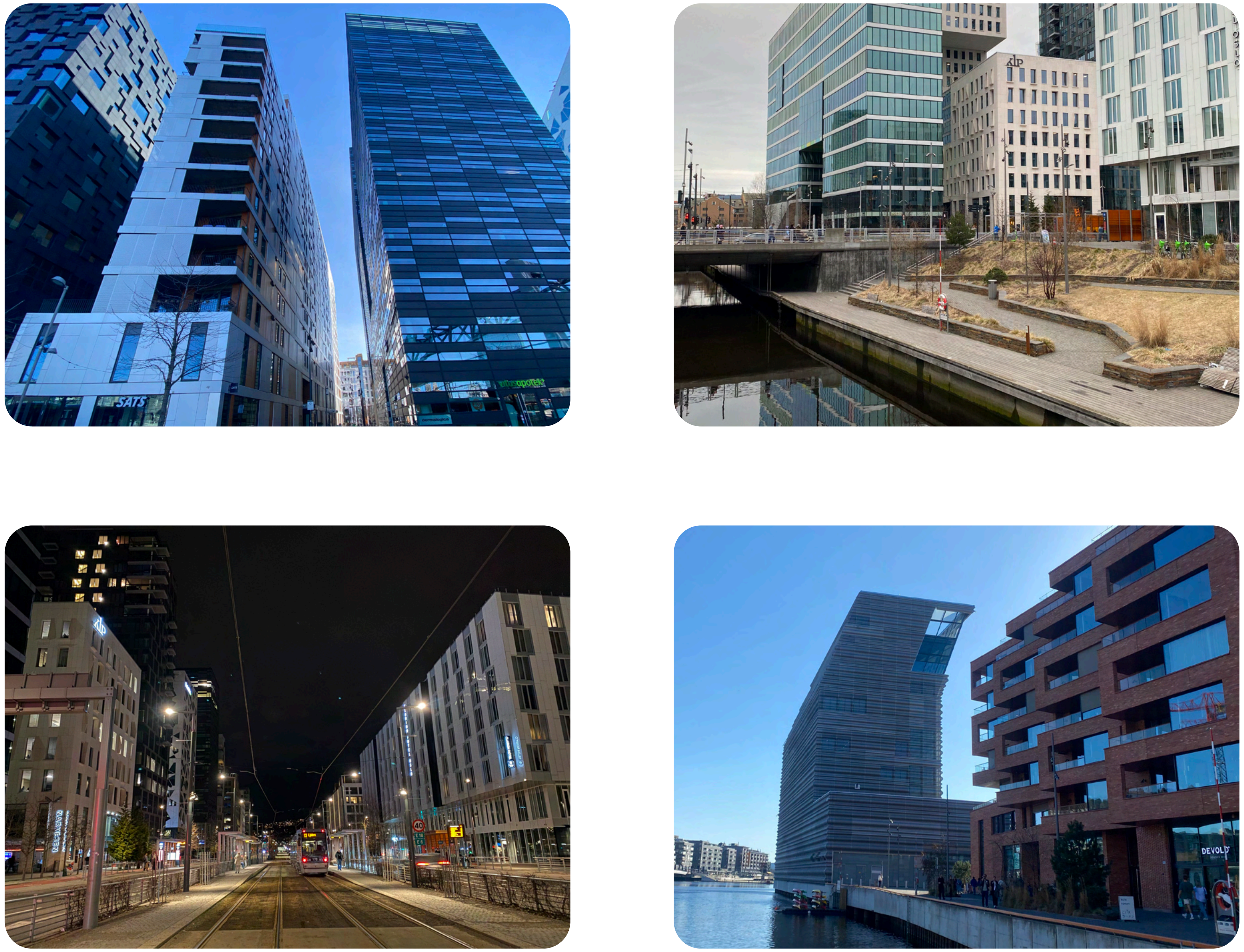
Figures 3.29 A-D illustrating four different settings in Korsvoll. A (top left) shows different types of vegetation in one garden with a fence, lawn, trees and shrubs, B (top right) shows a garden with a lawn without fences, C (bottom left) shows different types of permeable, green "fences" as in shrubs in a small neighbourhood street with single-housing, and D (bottom right) shows more impermeable, artificial fences between houses. Photos from Google Streetview.

-industrial urban-
Bjørvika

Bjørvika is a typical industrial site in an urban matrix. The site represents a typical mixed-use development of office buildings, conference centres, hotels, ware-houses, commercial and gastronomic services. These are often placed on the ground level, whilst the upper levels constitute offices or some times residential apartments. Mixed-type developments either use old, pre-industrial or abandoned buildings or are built in modern developments.

The characteristics of this land-use type are over-sized, high-rise office-buildings or skyscrapers with materials like glass, concrete and steel. The surrounding streetscape is typically characterized by grey, impermeable surfaces, shade and increased wind speed due to the buildings. These buildings can lack a friendliness to humans due to their scale and biodiversity, and the sites often have a strong presence of infrastructure like lights, light pollution, traffic, mobility options and a fast pace of humans and vehicles. The abundance of green is context dependent but in Bjørvika the main street (Dronning Eufemia) provides green character of street-trees, lawn and shrubs and there are pauses of green between the train rails from the train station (Oslo S) and the waterfront (the Oslofjord).

See photos (figure 3.30 A-D) for an overall feel of Bjørvika.



Figures 3.30 A-D illustrating four different settings in Bjørvika. A (top left) shows high-rises with facades of glass and metal, B (top right) shows Akerselva (a river that runs through Oslo) where it runs out in the fjord with vegetated patches and facilitated recreational use, C (bottom left) shows the main street Dronning Eufemias gate where public transportation and traffic is focused in between the high-rises and and D (bottom right) shows the Oslofjord and the residential houses focused around Stasjonsalmenningen behind the Munch museum with multiple caffees and restaurants at the ground floor.

-residential urban-
Frogner

Frogner is a typical residential site of older age in an urban matrix. The residential site typically contains apartment buildings, single-houses, terraced houses of different age and schools and kindergartens. In addition there is typically a handful of commercial offers like cafés, restaurants, grocery stores and some additional commercial activity. The ground level often contains service offers while the upper levels contain residential apartments and some times offices.

The characteristics of this land-use type is a more human-friendly design with a human scale on buildings (height), invested aesthetic value in the architecture and more colors. There is often a greener streetscape with good connectivity through front-gardens and backyards, street trees, parks, squares and recreational landscapes. In Frogner the green abundance and connectivity is very high. The traffic pace is slower and adapted to pedestrians and bikers, and there is a good connectivity of public transportation like city trams and buses.

See photos (figures 3.31 A-D) for an overall feel of Frogner.

Figures 3.31 A-D illustrating four different settings in Frogner. A (top left) shows a residential street of apartment buildings with front gardens and green edges along the street, B (top right) shows single-houses with private gardens of diverse vegetation, C (bottom left) shows a street with some traffic and street trees and D (bottom right) shows Gyldenløves gate, a street with green edges of street trees and an alley in the middle with a vegetated ground cover.

3.3.3 Identifying source and sink dynamics in the case study sites

To do so, ypical source and sink elements need to be detected, together with the criteria for achieving the different scores as sources and sinks.

Table of source and sink elements

The following table, table 3.3 presents typical elements for outdoor rooms.

Based on literature the function of the elements as sources (+) or sinks (-) is determined based on their effect as something that either promotes or hinders the ecosystem from being healthy. Some elements can have contrasting positive and negative contributions to the ecosystem and are therefore graded "scores" as sources or sinks (+/- or -/+) based on a personal evaluation.

The elements in the table are a selection of some of the most typical elements and are used to illustrate the dynamics between elements and function for ecosystem health. They are categorized in 4 main categories:
infrastructure, urban green, permeability of ground cover and disturbances.

Additional ecological functions of the elements are given in the far right column.

The literature can be found in Appendix 1.

LABELS
Source +
Weak source +/-
No function: 0
Weak sink -/+
Sink -

	SYSTEM			
ELEMENT	SOCIAL	ECOLOGICAL	ENVIRONMENTAL	ADDITIONAL ECOLOGICAL FUNCTION

Figure 3.32 illustrating the system of the table that will determine the source and sink function of different elements.

Elements' function depends

The idea behind the table was to develop a system for scoring elements that are typically found in outdoor rooms according to their function to the ecosystem health dynamics of a place. The foundation of the scoring lays in literature on elements' function for the different systems, interpreted as source or sink function.

In some cases, elements have the same function as sources or sinks in all of the systems, e.g. grey and green walls, roofs, permeable vegetated ground cover and urban green. It is beneficial for the social, ecological and environmental system with green walls that sequester carbon, filter the air, reduce the urban heat island effect with a cooling effect, provide habitat to insects and birds, improve the microclimate, provide aesthetical value and can improve both physical and mental public health.

In other cases, elements have varying function for the different systems, e.g. outdoor lighting, fences, sports facilities, mobility and public green. Outdoor lighting provides safety and functions as a source to the social system but a sink to the ecological function as a disturbance factor that impedes with the ecosystem and have lethal potential to some species. Fences most often provide desired functions to the social system but hinder flow of energy to the ecological system. Sports facilities with artificial turf enables usage all year round, however the ecological impact of plastic turf is negative. Public green functions as a social source however it can provide a high disturbance load to the ecological system that makes it a sink.

Some elements might even have contrasting effects within the same system and these must be evaluated based on the context and main functions of the site. Outdoor lighting has a positive impact on public health when by providing safety that enables usage for/by all users at all times of the day. However, their negative impact on the environment by contributing to light pollution hinders surprisingly many people from seing the night sky on a daily basis. Therefore the element gets a +/- score based on the evaluation that safety provision weights more in a public health consideration than night sky vision.

Some elements also dont have a function to all systems, like noise pollution, fences or public green not impacting the environmental system directly or in the same way as the other systems. Whether a green area is publicly available or surrounded by fences is not impacting the environmental system. The negative environmental impact of e.g. fence production is outside the scope of this thesis and is therefore not considered in the scoring system.

Table of source and sink elements part I

Table 3.3 of elements functioning as sources and sinks with references.

LABELS

Source +
Weak source +/-
No function: 0
Weak sink -/+
Sink -

ELEMENT	SYSTEM: SOCIAL	SYSTEM: ECOLOGICAL	SYSTEM: ENVIRONMENTAL	ADDITIONAL ECOLOGICAL FUNCTION
Infrastructure: mobility	+	- Baxter-Gilbert et al., 2015; Müller & Berthoud, 1997	-???	Barrier
: Fences	+	- Jakes et al., 2018; McInturff et al., 2020	0	Barrier
: Grey walls/facades	- Kellert & Wilson, 1993; Qi et al., 2019	- Klem et al., 2009; Parkins et al., 2015	- Azkorra et al., 2015; Wesołowska & Laska, 2019	Barrier
: Green walls/facades	+ Azkorra et al., 2015; Wesołowska & Laska, 2019; Wong et al., 2010	+ Azkorra et al., 2015	+ Azkorra et al., 2015; Wesołowska & Laska, 2019	Habitat
: Grey roofs	-	-	-	
: Green, vegetated roofs	+ Hansen & Espedal, 2021; Kotzen, 2018	+ Li & Yeung, 2014; Williams et al., 2014	+ Li & Yeung, 2014; Williams et al., 2014	Habitat and stepping stones to avian organisms
: Sports facilities w. artificial turf	+ Burton, 2021	- Burton, 2021	- Cheng et al., 2014; Frischknecht et al., 2021	
Green structures	+ Bolund & Hunhammar, 1999; Elderbrock et al., 2020; Hunter et al., 2019; Lederbogen et al., 2011; Mitchell, 2013; Peen et al., 2010; Remme et al., 2021; Shanahan et al., 2014; Ulrich, 1984	+ Aronson et al., 2017; Muñoz-Pedreros et al., 2018	+ Folke et al., 1997	Habitat, corridor and stepping stone
: Public green	+ European Environment Agency, 2020; European Environment Agency, 2022; Suárez et al., 2020	- Erfanian et al., 2021	0	
: Individual trees	+ Cimburova & Berghauser Pont, 2021	+	+ Bolund & Hunhammar, 1999	Habitat, stepping stone

Table of source and sink elements part II

Table 3.3 of elements functioning as sources and sinks with references.

LABELS
Source +
Weak source +/-
No function: 0
Weak sink -/+
Sink -

	SYSTEM			
ELEMENT	SOCIAL	ECOLOGICAL	ENVIRONMENTAL	ADDITIONAL ECOLOGICAL FUNCTION
: Tree rows or alleys	+	+ Beninde et al., 2015; Weber et al., 2014	+ Bolund & Hunhammar, 1999	Corridor
: Heterogenous vegetation patches (structure, layers, vegetation types, function)	+/- Bjerke et al., 2006; Gamfeldt et al., 2013; Jansson et al., 2013; Suárez et al., 2020; Talal et al., 2021	+ Allouche et al., 2012; Gamfeldt et al., 2013; Thomsen et al., 2022; Tylianakis et al., 2008; Vilà et al., 2007	+ (Derkzen et al., 2015; Elderbrock et al., 2020; Gamfeldt et al., 2013; Jonsson et al., 2019)	Habitat
: Homogenous vegetation patches	+	+/-	+/-	
Impermeable ground cover	+	- (Hu et al., 2018)	- Bolund & Hunhammar, 1999	
Permeable ground cover	+ Çelik, 2013	-/+ Minixhofer & Stangl, 2021	+ Minixhofer & Stangl, 2021	
Permeable, vegetated ground cover	+ Minixhofer & Stangl, 2021; Sun et al., 2023	+ Bastida et al., 2021; Fan et al., 2023; Hoorman, 2016; Hu et al., 2018; Minixhofer & Stangl, 2021	+ Bernatzky, 1983; Minixhofer & Stangl, 2021	Habitat, stepping stone
Disturbances: Outdoor lighting	+/- **Positive** Haans & de Kort, 2012; Kaplan & Chalfin, 2022; Portnov et al., 2020 **Negative** Chepesiuk, 2009; Falchi et al., 2016; Pauley, 2004	- Czaja & Kołton, 2022; ffrench-Constant et al., 2016; Gaston et al., 2013; Grubisic et al., 2018; Longcore & Rich, 2004; Meng et al., 2022; Meravi & Kumar Prajapati, 2020	-	Barrier
: Noise pollution	- Bolund & Hunhammar, 1999 World Health Organization, 2010; World Health Organization, 2022	- Francis et al., 2012; Kight & Swaddle, 2011; Senzaki et al., 2020	0	
Vegetation to mediate noise pollution	+ Bolund & Hunhammar, 1999; Dzhambov & Dimitrova, 2014; Ow & Ghosh, 2017; Wong et al., 2010	+	+	

Analyses of land-use types

For the following analyses different landscape metrics will be analysed in 3 different scales: macro, meso and micro.

1.

MACRO
The macro scale of the regional level will analyse the following:

What is the matrix?
What are the natural corridors?
How is the overall green connectivity through the matrix?

In addition, the level of fragmentation, heterogeneity, land-use and infrastructure will be identified.

2.

MESO
The meso scale of the landscape level will analyse the following:

What are the patches, barriers, corridors and stepping stones?

In addition, the ecological and social connectivity, patch quality, heterogeneity and edge-interior quality will be identified.

3.

MICRO
In the micro scale of the site level analysis results of the study site will be presented as personal suggestions to

What elements in the site function as sources and sinks to the ecosystem health?

This is determined in accordance to the table to the right presenting the source-sink gradient of what the criteria's are for the different "scores". The gradient follows a descending order from strong source to strong sink, and is defined for the social, ecological and environmental system. The final results will be illustrated in analyses for the different systems with coloured elements explained by their function as sources or sinks. These suggestions are based on literature (table on sources and sinks) and a personal evaluation of the site context and main challenging elements.

REMINDER:

A source to ecosystem health promotes and strenghtens the system to be healthy.

A sink to ecosystem health prevents or drains the system from being healthy.

Source-sink gradient with criterias

Table 3.4 presents the criterias for elements to function as sources or sinks within their given system. The gradient follows a descending order from strong source to strong sink. The criterias for the different scores are given within the different systems as the function of an element as source or sink depends on the system of objective. For instance, publicly available green spaces can be a source to the social system but a weak sink to the ecological system as it can contribute with a high disturbance load. This is what the gradient will try to differentiate between and clarify.

The suggestions are based on literature (table 3.3, Appendix 1) and a personal evaluation of the site context and main challenging elements present.

The gradient will be used in the final results of the analyses of what elements function as sources and sinks in the case sites.

The table is presented on the next page.

	SYSTEM		
	SOCIAL	ECOLOGICAL	ENVIRONMENTAL
Strong source			
Weak source			
Weak sink			
Strong sink			

Figure 3.33 illustrating the gradient system of the table that will present the crtieria for the source and sink function of different elements.

For the environmental system a selection was made for what elements to include and not. It was decided that only the present environmental functions (in- and outputs) would be considered, i.e. not the emission of producing an element or the energy consumption of outdoor lighting. Rather, the microclimatic regulatory functions of present elements that could contribute to factors like urban cooling or stormwater management were chosen. Also elements that could be utilized for green energy were included and an overall assessment of the benefits of maximizing the green distribution concerning ecosystem service provision. Forman (2008) addressed the matter of reducing "wasted land" and this idea fostered a desire to include resource utilization and green distribution to the system as those elements can increase the worth of land (functioning) and reduce its wasted potential.

Gradient part I - sources

Table 3.4 of criteria for the different scores as strong source, source, sink and strong sink.

SOCIAL	
Promotes public health i.e. physical and mental health and well-being (socially sustainable)	
Green structures	• **Abundance:** high • **Provision of ecosystem services:** unlimited (recreation, well-being, improved air quality) • **Quality:** high (aesthetically pleasing, facilitates use like recreation, sports and play) • **Accessibility:** unlimited (encourages use) • **Restrictions for use:** none (free "usage program", allowed to sit on lawns, touch flowers etc.) • **Availability:** public (majority of green publicly available)
Infrastructure	• **Coverage (e.g. lights, impermeable surfaces, trash cans, parking):** extensive
Disturbances	• **Disturbance load:** low (few conflicting interests or activities) • **Pollution (air, light, noise):** low (high mitigation on site due to unlimited provision of ecosystem services)
Facilitation	• **Additional facilitations:** e.g. improved health (ecosystem service), strengthening community feeling of togetherness
Connectivity	• High (facilitates active mobility by foot, bike or public transportation)
Priority in areal planning	• The social system (e.g. public transportation, people-friendly, feeling of safety)
Green structures	• **Abundance:** medium • **Provision of ecosystem services:** limited (green walls don't facilitate recreation, physical activity or sports) • **Quality:** high/medium • **Accessibility:** limited (roofs accessible to those with access) • **Restrictions for use:** some (not able to smell vegetation on green walls) • **Availability:** semi-private / private green (backyards, gardens)
Disturbances	• **Pollution:** medium (medium provision of ecosystem services or relatively small possibility to mitigate present pollution)
Facilitation	• **Additional facilitations:** social or cultural services (Opera in Oslo offers a unique experience to walk on the roof)
Connectivity	• Medium

ECOLOGICAL	
Supports biodiversity, native species and ecosystem functioning (ecologically sustainable)	
Green structures	• **Abundance of green:** high • **Quality of green:** high. Heterogeneous vegetation and layering • **Support to ecosystem functioning (enabling ecosystem service provision):** high • **Cost of ecosystem service provision:** low, not at the expense of the system itself • **Accessibility:** unlimited (to all species, on the ground)
Disturbances	• **Disturbance load:** low (noise, activity, traffic)
Additional effect	• Sustains the ecosystem to thrive long-term
Green connectivity	• High
Priority in areal planning	• **Priority:** green connectivity and quality
Green structures	• **Abundance of green:** medium • **Quality of green:** medium • **Support to ecosystem functioning:** medium (roofs can only function as habitat for specialists who can deal with the special conditions present like strong wind and sun exposure) • **Cost of ecosystem service provision:** low • **Accessibility:** limited (roofs)
Disturbances	• **Disturbance load:** medium (garden maintenance, human activity)
Green connectivity	• Medium

ENVIRONMENTAL	
Climate change mitigation and transformation (environmnetally sustainable)	
Green structures	• **Green coverage:** high • **Green heterogeneity (correlation with provision of ecosystem services):** high • **Provision of ecosystem services (e.g. carbon sequestration and flood risk mitigation):** unlimited. Benefits the microclimate and global climate. • **Cost of ecosystem service provision:** low, not at the expense of the system itself
Resource utilization for optimal efficacty	• High (solar panels on grey roofs)
Additional effect	• Sustains the ecosystem to thrive long-term
Priority in areal planning	• Maximize green coverage for maximized ecosystem service provision (nature-based solutions)
Green structures	• **Green coverage:** medium • **Green heterogeneity:** medium • **Provision of ecosystem services:** limited (a lawn sequesters less carbon than a forest). Benefits the microclimate • **Cost of ecosystem service provision:** medium

Gradient part II - sinks

Table 3.4 of criteria for the different scores as strong source, source, sink and strong sink.

SOCIAL		ECOLOGICAL		ENVIRONMENTAL	
				Limited climate change mitigation	
Green structures	• **Abundance:** low • **Provision of ecosystem services:** limited • **Quality:** low • **Accessibility:** very limited (fencing or opening hours) • **Availability:** private (majority of green is private) • **Restrictions for use:** many (not allowed to touch or smell flowers, forage berries and fruits or use a lawn)	Green structures	• **Abundance of green:** low • **Quality of green:** low. Homogenous vegetation and layering • **Support to ecosystem functioning:** low (little habitat or natural resources) • **Cost of ecosystem service provision:** medium • **Accessibility:** limited (too strong barrier effect)	Green structures	• **Green coverage:** low • **Green heterogeneity:** low (homogenous) • **Provision of ecosystem services:** limited • **Cost of ecosystem service provision:** high
Infrastructure	• **Coverage (e.g. lights, impermeable surfaces, trash cans, parking):** fluctuating	Disturbances	• **Disturbance load:** High (barriers, people, conflicting activity)	Resource utilization for optimal efficacty	• Low
Disturbances	• **Disturbance load:** medium (noise level becoming a barrier for use) • **Pollution:** medium	Green connectivity	• Low, fragmented		
Facilitation	• **Additional facilitations:** none (parking lot provides parking but not other services like ecosystem services that can increase the aesthetical value)				
Connectivity	• Medium to low (less facilitation for active mobility)				
Does not promote public health (*not* socially sustainable)		**Threatens or suppress' biodiversity, further driving the nature crisis (*not* ecologically sustainable)**		**Unsustainable, further driving the climate crisis (*not* environmentally sustainable)**	
Green structures	• **Abundance:** none/low	Green structures	• **Abundance of green:** none • **Support to ecosystem functioning:** none (degrades ecosystems, deprives species of habitat end perturbates ecosystem functioning) • **Cost of ecosystem service provision:** high, at the expense of the system itself. • **Accessibility:** none	Green structures	• **Green coverage:** none • **Cost of ecosystem service provision:** high, at the expense of the system itself
Infrastructure	• **Coverage (e.g. lights, impermeable surfaces, trash cans, parking):** marginal				
Disturbances	• **Disturbance load:** high (limits use or quality of the experience) • **Pollution:** high (llack provision of ecosystem services)	Disturbances	• **Disturbance load:** High (barriers, people, conflicting activity)	Resource utilization for optimal efficacty	• None
Facilitation	• Business, commerce and infrastructure with low social quality • Evokes negative responses or activities in society • Causes negative mental and physical health impacts/responses • Discriminates (socio-economic, demographic or ethnic groups)	Additional effect	• Pollutes or destroys natural resources (artificial turf) • Kills or hurts species (traffic) • Exhausts the ecosystem	Additional effect	• Pollutes and destroys natural resources to such extent that it hinders provision of ecosystem services • Exhausts the climate and environment, locally and globally
Connectivity	• **Connectivity:** low (facilitated for private vehicles)	Green connectivity	• Low, very fragmented		
Priority in areal planning	• **Priority in areal planning:** industry and private vehicles as main mobility option	Priority in areal planning	• Ecosystem conservation and support, and green connectivity	Priority in areal planning	• Traffic and infrastructure

3.3.4 **Analyses and results** of case study

I sub-urban industrial
II sub-urban residential
III urban industrial
IV urban residential

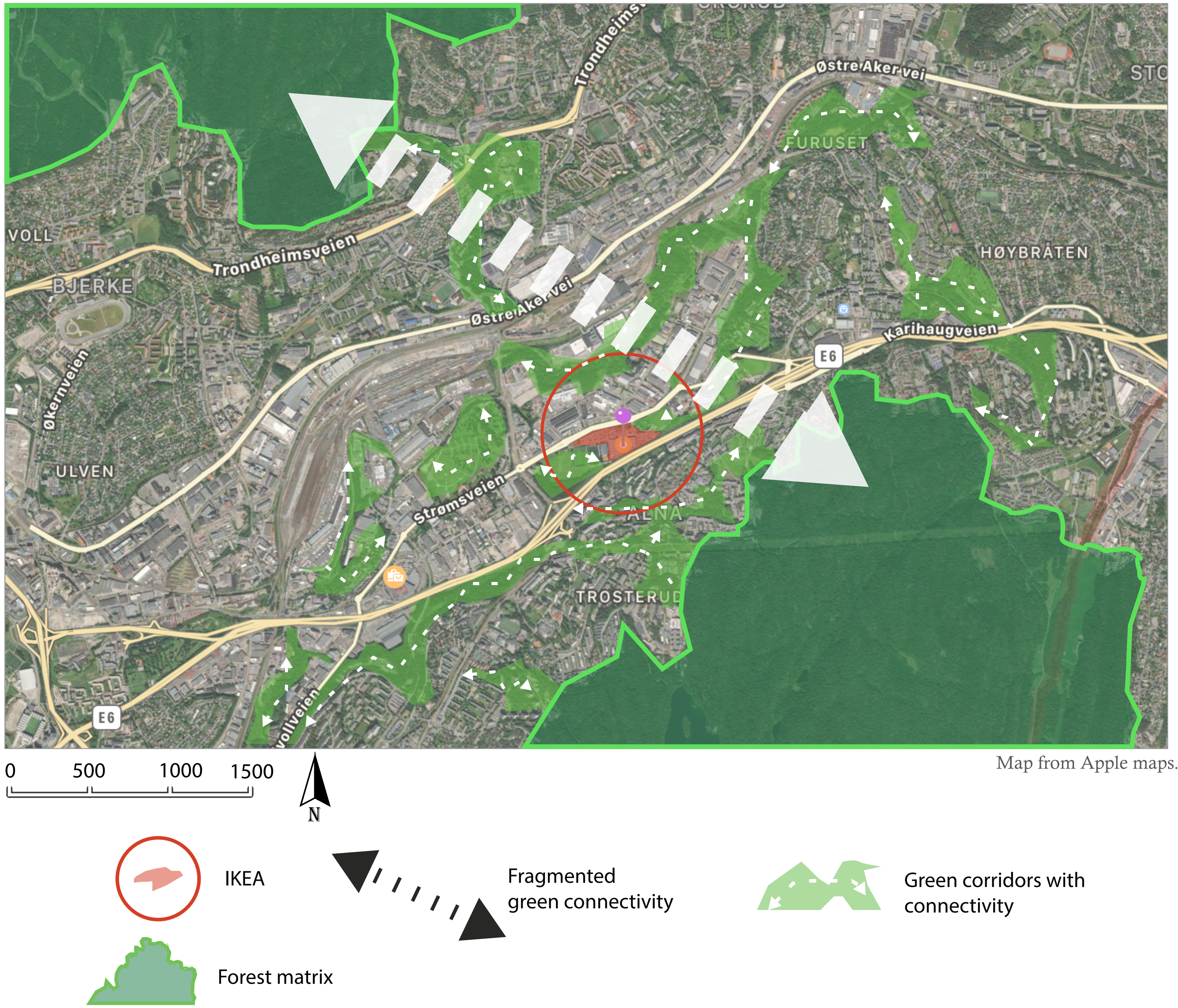
sub-urban land-use types

I industrial
II residential

IKEA Furuset - sub-urban industrial

MACRO-SCALE Landscape level

What is the matrix?
What are natural corridors?
How is the overall connectivity through the matrix?



Map from Apple maps.

Figure 3.34 of macro analysis on the landscape level.

ANALYSIS

- **Matrix**

Sub-urban surrounded by forest matrix.

- **Regional level of green connectivity**

Low/medium.

- **Land-use heterogeneity**

Medium. Multiple land-uses and activites.

- **Land-use**

Industrial, commercial, business, transport, residential.

- **Infrastructure**

Network of roads, railways, green corridors and buildings.

- **Fragmentation level**

High due to infratrcutre and land-use heterogeneity.

IKEA Furuset - sub-urban industrial

MESO-SCALE Landscape level

What are the patches, barriers, corridors and stepping stones?

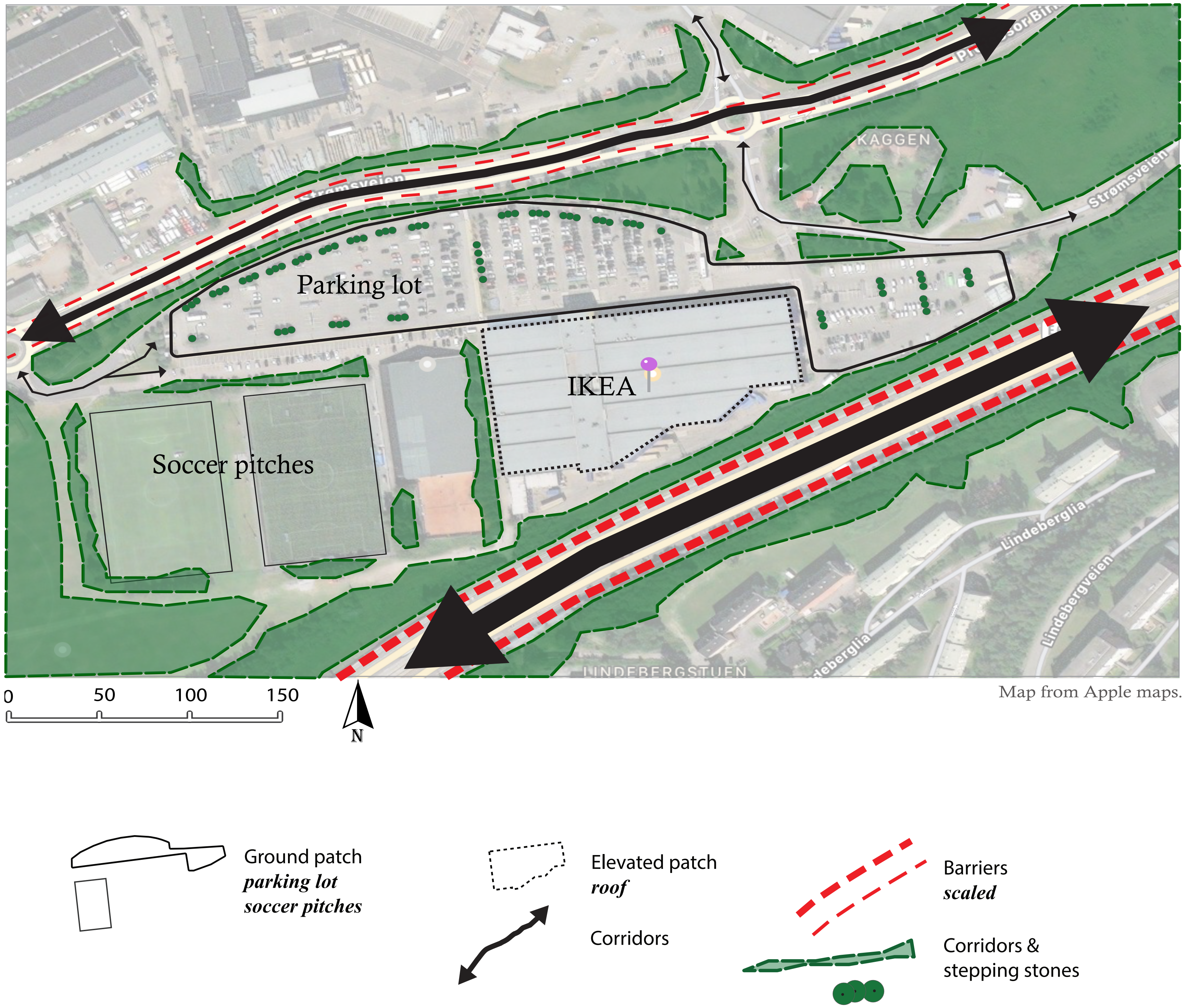


Figure 3.35 of meso analysis on the landscape level.

ANALYSIS

- **Patches**

Parking lot, IKEA roof, sports arenas.

- **Patch quality – heterogeneity**

Homogenous patches of different ground coverage being asphalt, concrete and artificial turf.

- **Green corridors and stepping stones**

Tree rows along smaller road and in parking lot patch..

- **Movement corridors**

Roads and highway.

- **Barriers**

Roads and highway.

- **Edge-interior quality**

Higher edge quality in parking lot patch than interior patch. Green edges of tree rows, some green stepping stones in interior of the parking lot but mostly oriented on the sides.

Source and sink elements

Following are suggested analyses results of the site with elements that function as sources or sinks. This is done based on the source and sink table (table 3.3) and the following source-sink gradient (table 3.4).

In these suggestions the gradients will be mapped in accordance to the present elements and landscape metrics' functioning.

The red areas show what elements that dont function i.e. hinder ecosystem health.

The green show what elements that contribute i.e. promote ecosystem health.

These mapped gradients can help visualise where the biggest need to make improvements are, and might provide some sort of prioritation scale.

Source-sink gradient (table 3.2)

- Strong source
- Weak source
- Weak sink
- Strong sink

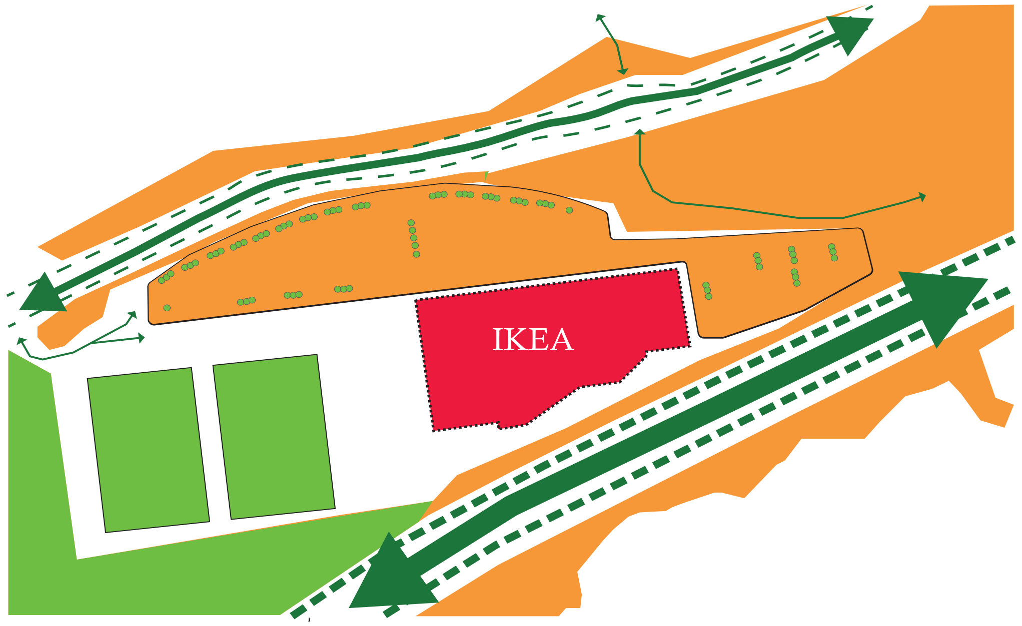
Analyses results - IKEA Furuset

What elements function as sources and sinks?

SOCIAL

Sources
- Roads enable mobility.
- Road-fences provide safety.
- Stepping stones make a greener edge on the parking lot, providing shade and some recreational value.
- Sports arenas offer social value of recreation, together with the public green field in west.

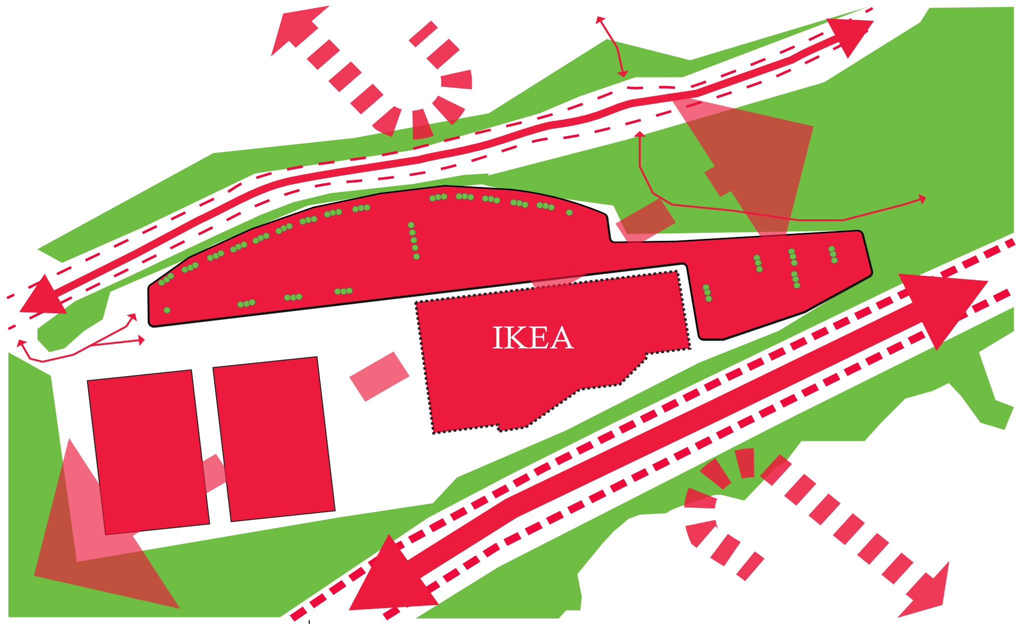
Sinks
- IKEA only provides commercial activity and the roof lacks sources for all systems
- The parking lot provides parking, has impermeable ground cover and some green.
- The surrounding green corridors along road and northeast of the parking is not publicly available and has low quality due to many disturbances (e.g. noise, traffic, lights).



ECOLOGICAL

Sources
- Green corridors along roads and green patches west and northeast of the parking lot.
- Stepping stones.

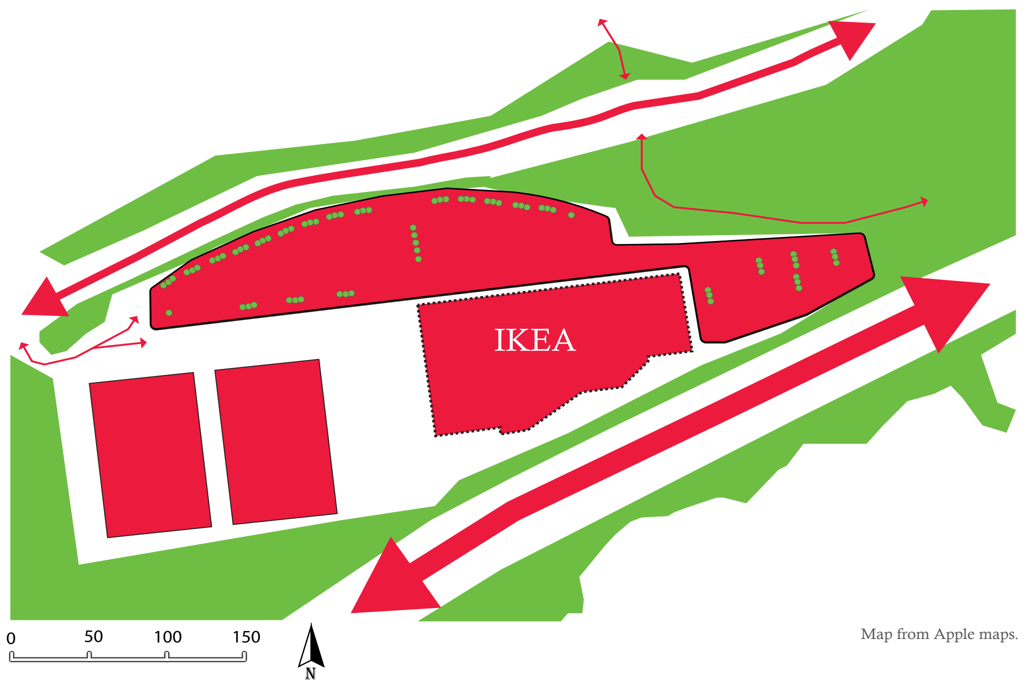
Sinks
- IKEA and parking lot has impermeable cover and no ecological function or value.
- Roads with traffic and disturbances..
- Fences have barrier-function.
- Many disturbances (i.e. pollution) from traffic and infrastructure present of lights, fences and noise.
- Artificial turf.
- Fragmented overall landscape connectivity.



ENVIRONMENTAL

Sources
- Green corridors and patches of lawn and trees that provide some ecosystem services that benefit the microclimate (e.g. carbon sequestration).
- Stepping stones of trees.
- Permeable, vegetated ground cover of lawn.

Sinks
- Traffic and infrastrucutre that provides pollution (e.g. lights and noise).
- Impermeable ground cover.
- Artifical turf.



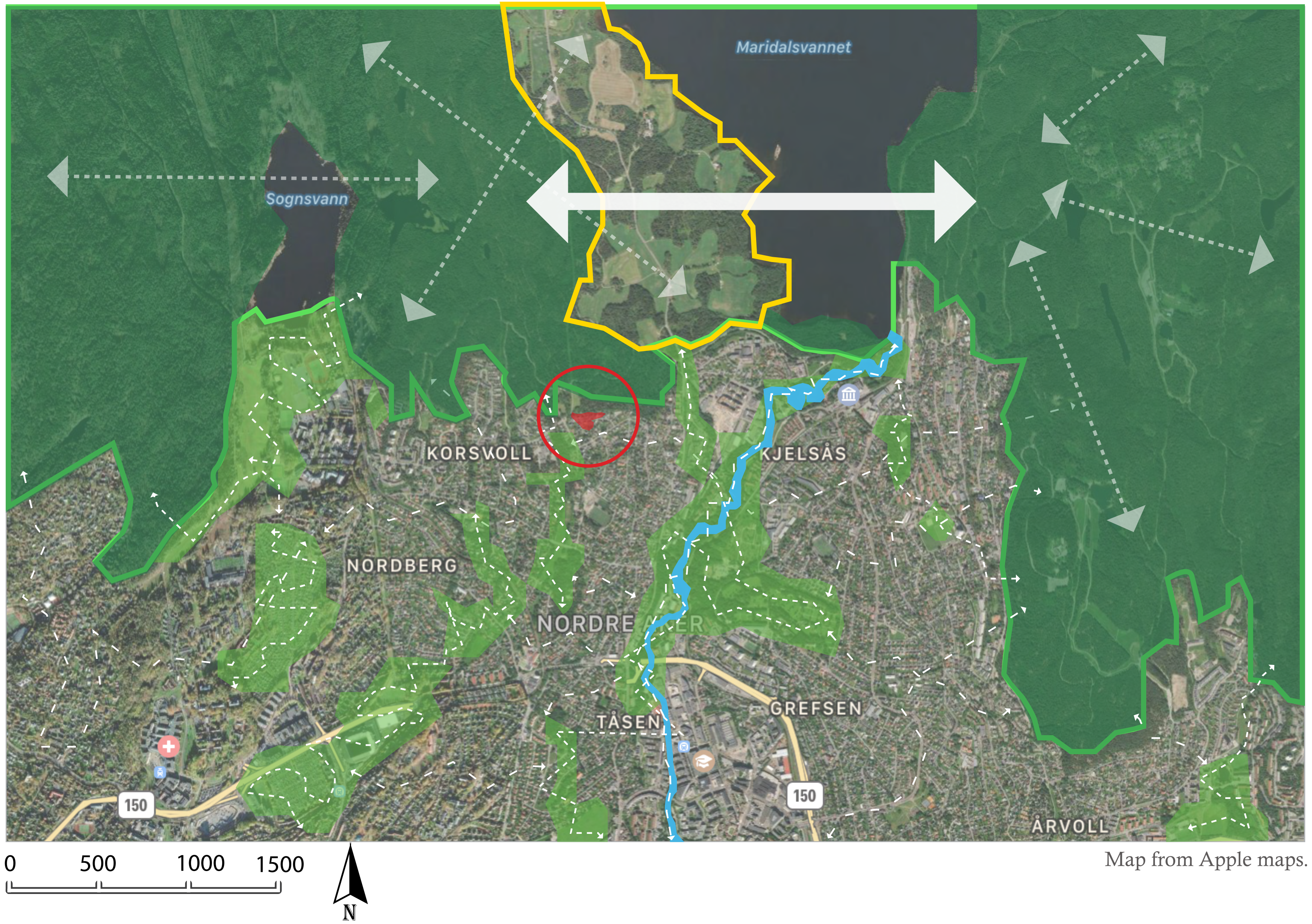
Figures 3.36 A-C of from top to bottom of micro analyses on the site level.

Map from Apple maps.

Korsvoll - suburban residential

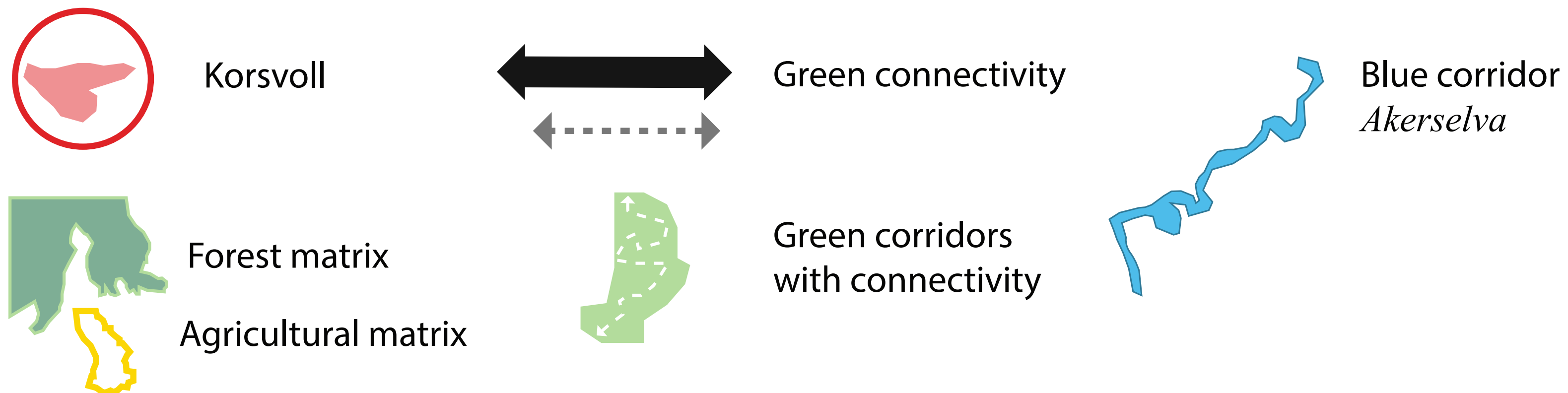
MACRO-SCALE Landscape level

What is the matrix?
What are natural corridors?
How is the overall connectivity through the matrix?



Map from Apple maps.

Figure 3.37 of macro analysis on the landscape level.



ANALYSIS

- **Matrix**

Sub-urban facing forest matrix.

- **Regional level of green connectivity**

Good.

- **Land-use heterogeneity**

Low.

- **Land-use**

Mainly residential and recreational, some commercial and industrial activity.

- **Infrastructure**

Network of roads, public transportation, blue-green corri-dors and buildings.

- **Fragmentation level**

High due to infratrcutre and land-use heterogeneity.

Korsvoll - suburban residential

MESO-SCALE Landscape level

What are the patches, barriers, corridors and stepping stones?

Map from Apple maps.

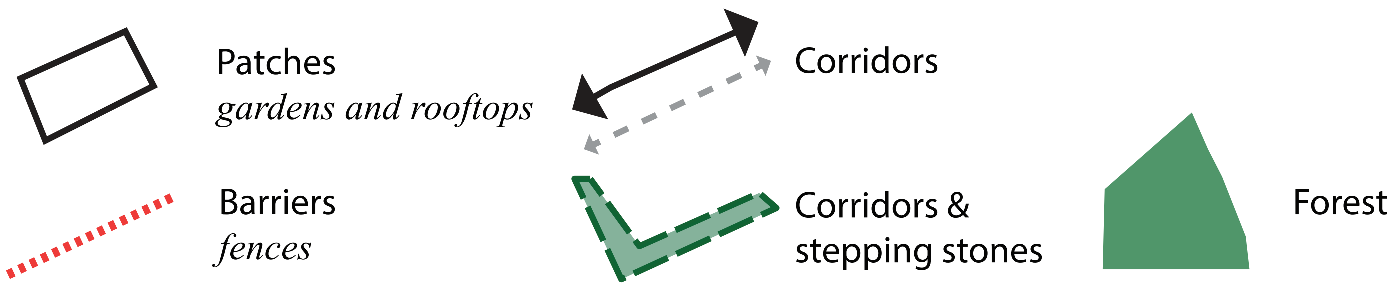


Figure 3.38 of meso analysis on the landscape level.

ANALYSIS

- **Patches**

Private gardens and single-houses.

- **Patch quality - heterogeneity**

Mostly homogenous garden patches of similar vegetation: lawn, some shrubs or fruit-trees. Some heterogeneity depending on garden design (vegetation, maintenance, structure). Homogenous grey roofs.

- **Green corridors and stepping stones**

Garden patches function as stepping stones. Depending on permeability between gardens and their surrounding matrix/ patch they can function as corridors.

- **Movement corridors**

Smaller roads, trails and hiking routes.

- **Barriers**

Fences. To some extent the roads.

- **Edge-interior quality**

Depends on garden design. Gardens with natural fences of shrubs and homogenous vegetation e.g. finely cut lawn can have a higher edge than interior quality. Gardens with heterogenous vegetation and artificial fences will have a higher interior than edge quality.

Source and sink elements

Following are suggested analyses results of the site with elements that function as sources or sinks. This is done based on the source and sink table (table 3.3) and the following source-sink gradient (table 3.4).

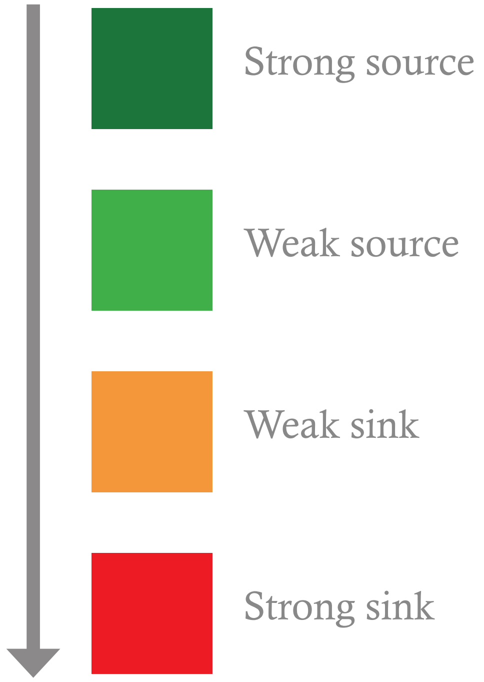
In these suggestions the gradients will be mapped in accordance to the present elements and landscape metrics' functioning.

The red areas show what elements that dont function i.e. hinder ecosystem health.

The green show what elements that contribute i.e. promote ecosystem health.

These mapped gradients can help visualise where the biggest need to make improvements are, and might provide some sort of prioritation scale.

Source-sink gradient (table 3.2)



Analyses results - Korsvoll

What elements function as sources and sinks?

SOCIAL

Sources

- Roads, trails and shortcuts enable mobility.
- Surrounding forest provide ecosystem services that improve the microclimate while providing recreational and hiking activity.
- Gardens have recreational value. Depending on the unique garden design they can provide different function, e.g. foraging berries and fruits, play, recreation, barbecue, aesthetical values. Heterogenous garden patches provide multiple services and activites.
- Permeability beween gardens and surrounding gardens (open fences or no fences) can enable more interaction between neighbours (i.e. limited barriers).

Sinks

ECOLOGICAL

Sources

- Surrounding, heterogenous forest.
- The unique garden designs define their quality and function.

Heterogenous garden patches with diversity in layout, structure and vegetation with a limited amount of barriers can function as sources.

- Green permeability to cross garden patches and enable connectivity.

Sinks

- Fences that hinder flow of movement.
- Homogenous garden patches with little diversity in layout, structure and vegetation with more barriers can function as sinks.
- Disturbance from streets of vehicles, bikes, pedestrians and pets.

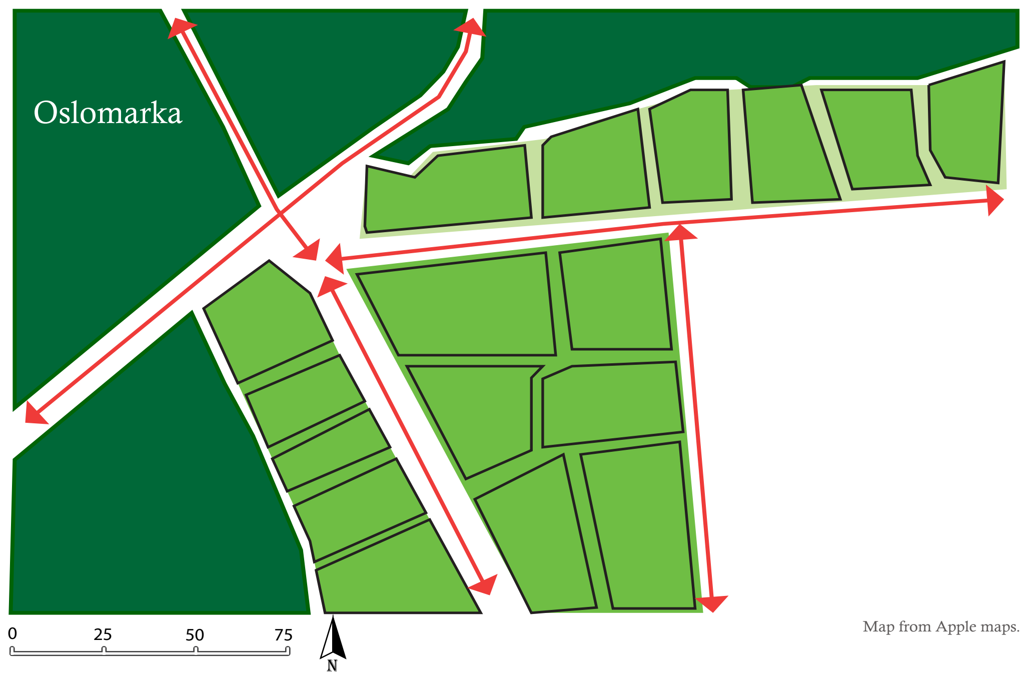
ENVIRONMENTAL

Sources

- Surrounding forest with strong provision of ecosystem services that benefit the microclimate and global climate e.g. carbon sequestration, carbon storage. Green corridors and patches of lawn and some trees.
- Garden patches with vegetated, permeable ground cover benefit the microclimate.

Sinks

- Traffic and infrastrucutre that provides pollution (e.g. lights and noise).
- Impermeable ground cover on streets.



Figures 3.39 A-C of from top to bottom of micro analyses on the site level.

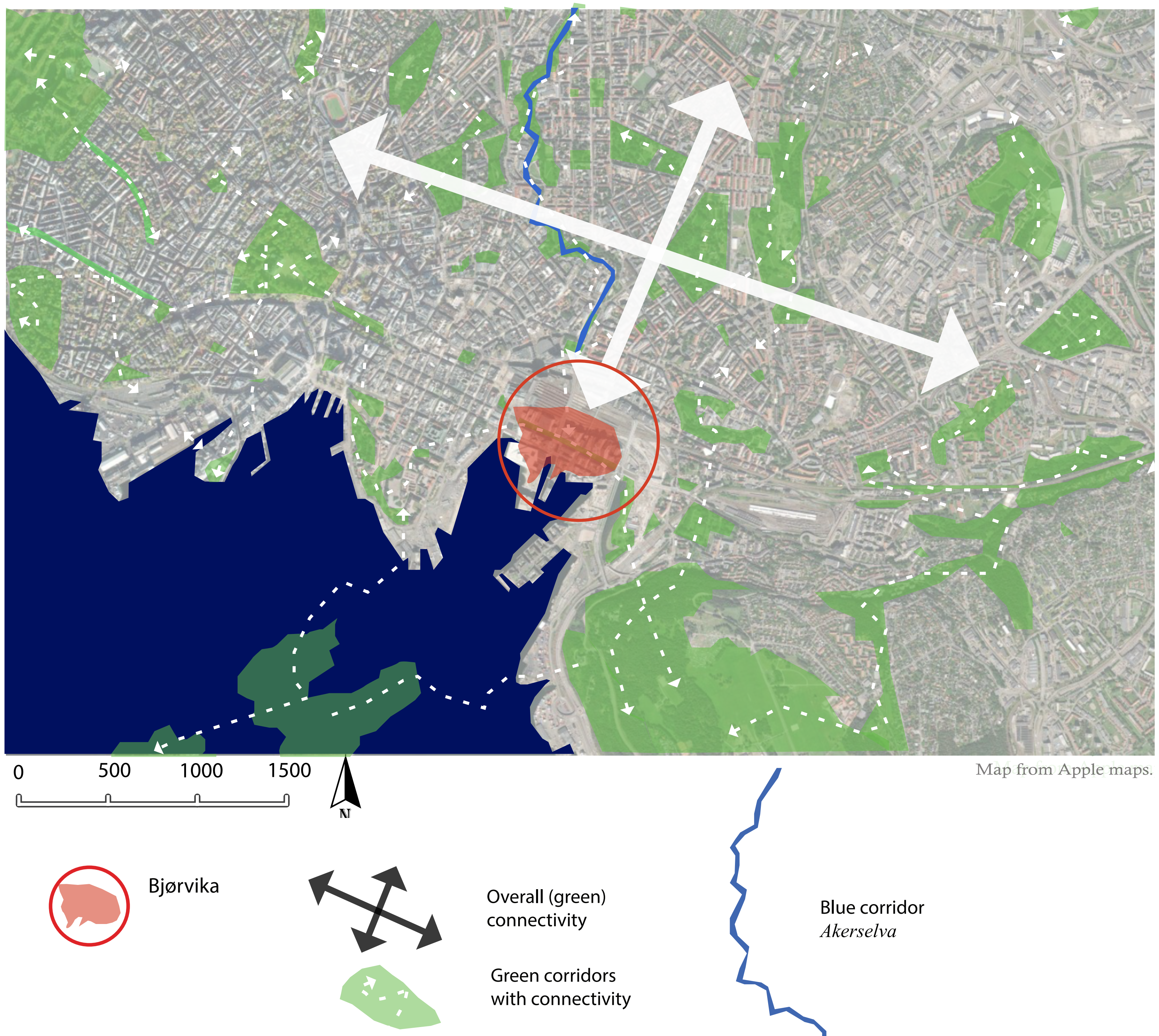
urban land-use types

II industrial
IV residential

Bjørvika - urban industrial

MACRO-SCALE Landscape level

What is the matrix?
What are natural corridors?
How is the overall connectivity through the matrix?



Map from Apple maps.

Figure 3.40 of macro analysis on the landscape level.

ANALYSIS

- **Matrix**

Urban facing ocean matrix.

- **Regional level of green connectivity**

Low/medium.

- **Land-use heterogeneity**

Medium. Multiple land-uses and activities.

- **Land-use**

Industrial, commercial, business, gastronomic, residential, cultural and recreational.

- **Infrastructure**

Network of roads, pedestrian pavements, biking lanes, tram tracks, railways, green and blue corridors, roofs, grey squares and buildings.

- **Fragmentation level**

High due to infratrcutre and land-use heterogeneity.

Bjørvika - urban industrial

MESO-SCALE Landscape level

What are the patches, barriers, corridors and stepping stones?

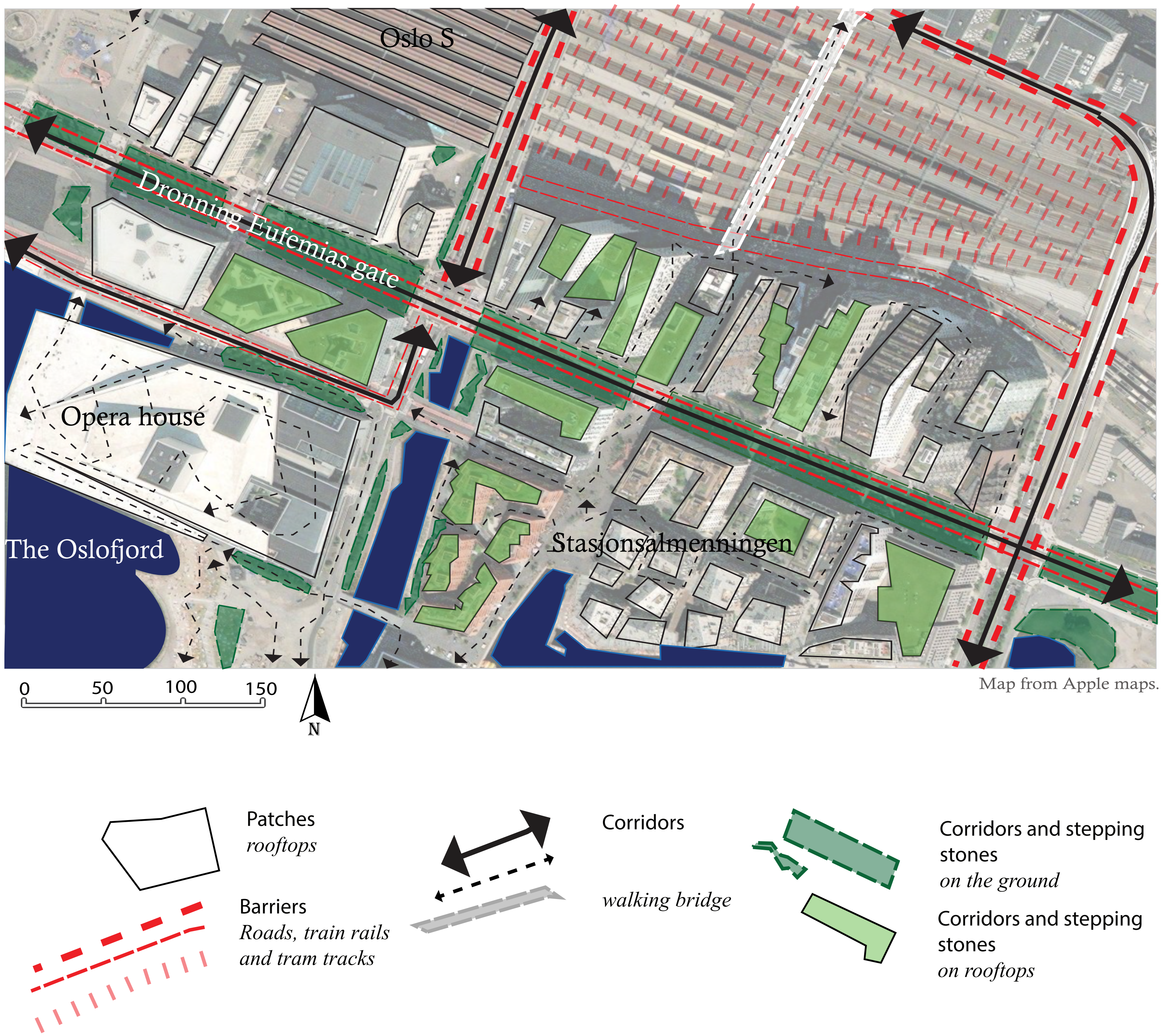


Figure 3.41 of meso analysis on the landscape level.

ANALYSIS

- **Patches**

Rooftops and ground level streetscape like the square Stasjonsalmenningen.

- **Patch quality – heterogeneity**

Homogenous rooftop patches of different ground coverage, grey and green. Heterogenous streetscape with green vegetation and the waterfront amongst grey squares and streets.

- **Green corridors and stepping stones**

Tree rows and vegetation on the ground in small parks, squares, streets and rooftops.

- **Movement corridors**

Roads, public transportation network, pavemenrs and biking lanes. In general the streetscape facilitates pedestrian movement.

- **Barriers**

Main road (Dronning Eufemias gate), train station (Oslo S) and tram tracks.

- **Edge-interior quality**

Edge quality in streetscapes with green corridors of tree rows. Interior quality in green patches.

Source and sink elements

Following are suggested analyses results of the site with elements that function as sources or sinks. This is done based on the source and sink table (table 3.3) and the following source-sink gradient (table 3.4).

In these suggestions the gradients will be mapped in accordance to the present elements and landscape metrics' functioning.

The red areas show what elements that dont function i.e. hinder ecosystem health.

The green show what elements that contribute i.e. promote ecosystem health.

These mapped gradients can help visualise where the biggest need to make improvements are, and might provide some sort of prioritation scale.

Source-sink gradient (table 3.2)

- Strong source - promotes ecosystem health
- Weak source
- Weak sink
- Strong sink - hinders ecosystem health

Analyses results - Bjørvika

What elements function as sources and sinks?

SOCIAL

Sources

- Roads and streetscape in general enable mobility to vehicles, bikes and pedestrians.
- Green corridors along trafficated street provide ecosystem services (e.g. noise buffering, air filtering, aesthetical value).
- Stepping stones on the ground provide ecosystem services and are available to all.
- Green roof patches provide ecosystem services limited to those with access.
- Opera roof provides cultural and recreational values.
- Waterfront provides recreational value.

Sinks

- Facades provide little aesthetical value and urban heat island effects
- Grey rooftops forces the urban heat island effect and no recreational value
- Traffic and trainstation provides disturbances (e.g. pollution and noise)

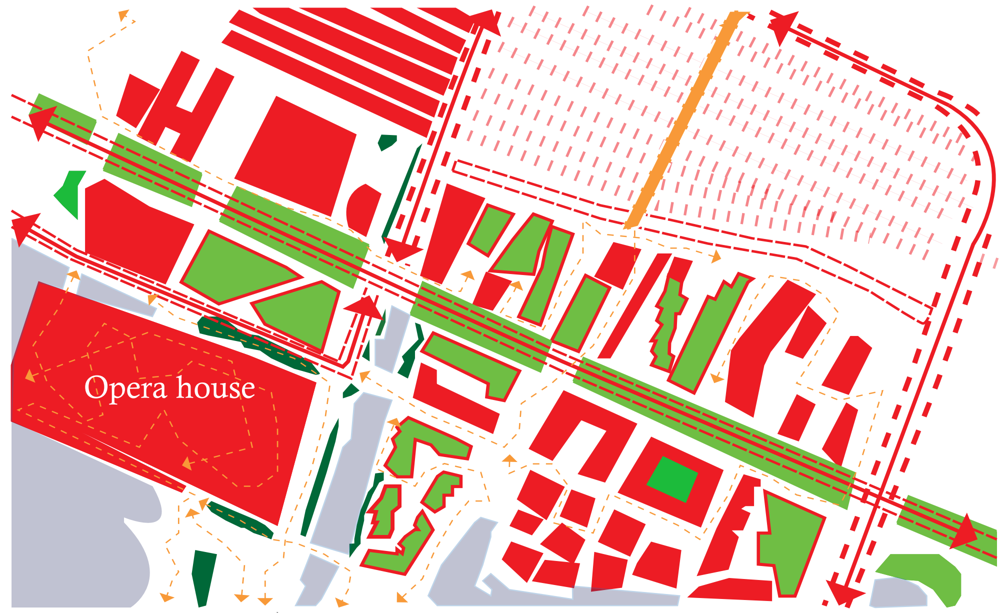
ECOLOGICAL

Sources

- Green rooftops available to avian organisms.
- Stepping stones on the ground available to all.
- Waterfront can provide ecological value to marine organisms but that is outside the scope of this analysis.

Sinks

- Facades with glass can lead to collissions with birds.
- Traffic and trainstation hinder flow of movement.
- Disturbances from streets of vehicles, infrastructure (e.g. light) public transportation, bikes, pedestrians and pets.
- Enabled connectivity but with lacking quality patches as destinations.



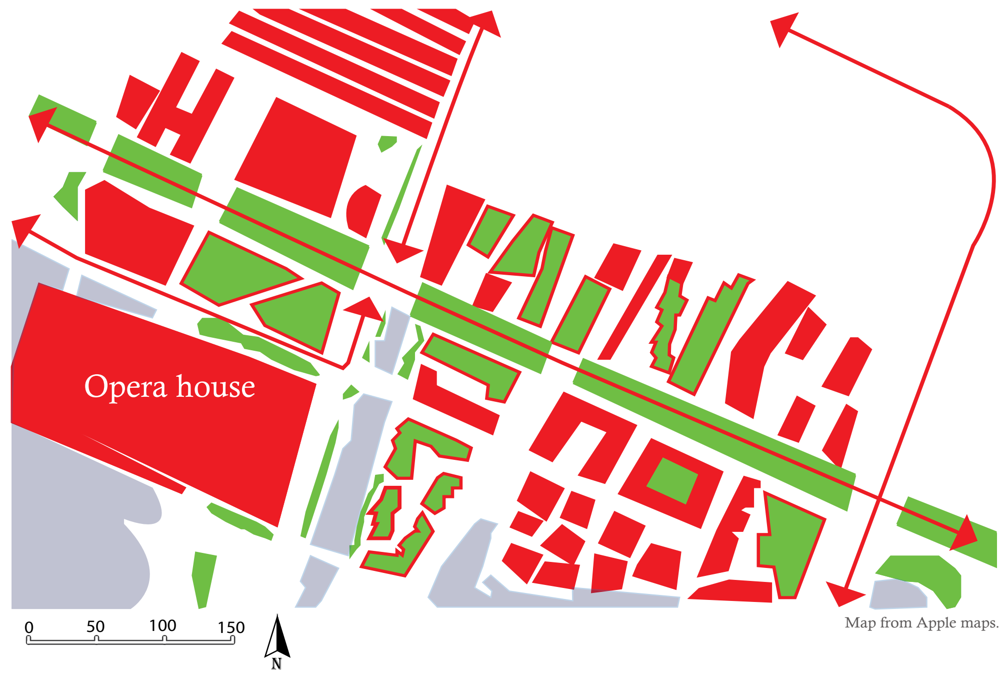
ENVIRONMENTAL

Sources

- Green patches, corridors and stepping stones on roof and ground provide ecosystem services that improve the microclimate. Source quality depend on vegetation heterogeneity and quality.

Sinks

- Traffic emits pollution.
- Surplus of grey surfaces increases the urban heat island effect and thus decreases microclimatic conditions.
- Grey rooftops dont utilize the available resources e.g. solar panels.



Figures 3.42 A-C of from top to bottom of micro analyses on the site level.

Frogner - urban residential

MACRO-SCALE Landscape level

What is the matrix?
What are natural corridors?
How is the overall connectivity through the matrix?

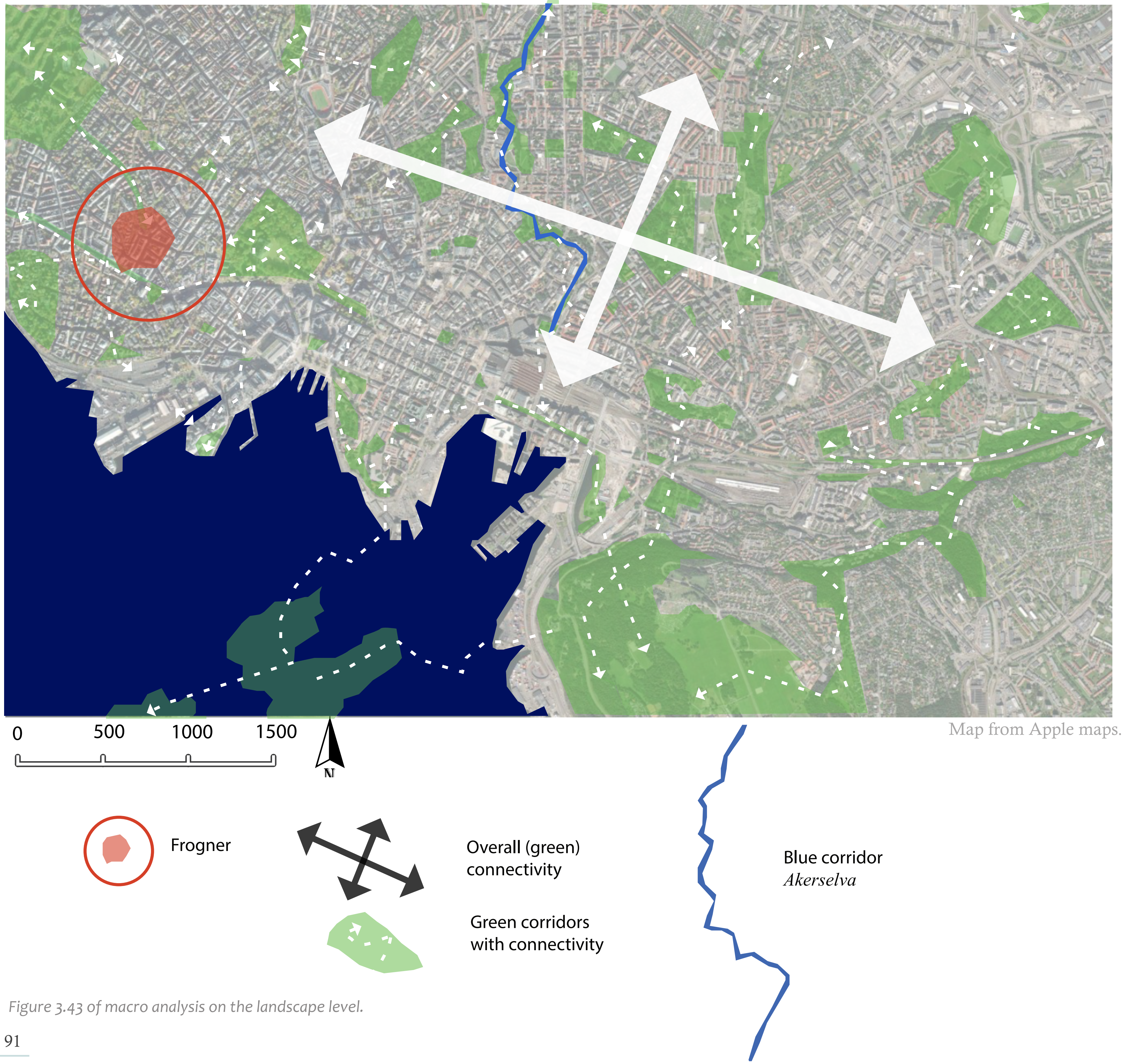


Figure 3.43 of macro analysis on the landscape level.

ANALYSIS

- **Matrix**

Urban

- **Regional level of green connectivity**

High

- **Land-use heterogeneity**

Low, residential mix

- **Land-use**

Residential, educational, recreational, gastronomic and some commercial activity

- **Infrastructure**

Network of small streets, pedestrian pavements and biking lanes, tram tracks, green and blue corridors, schoolyards and buildings

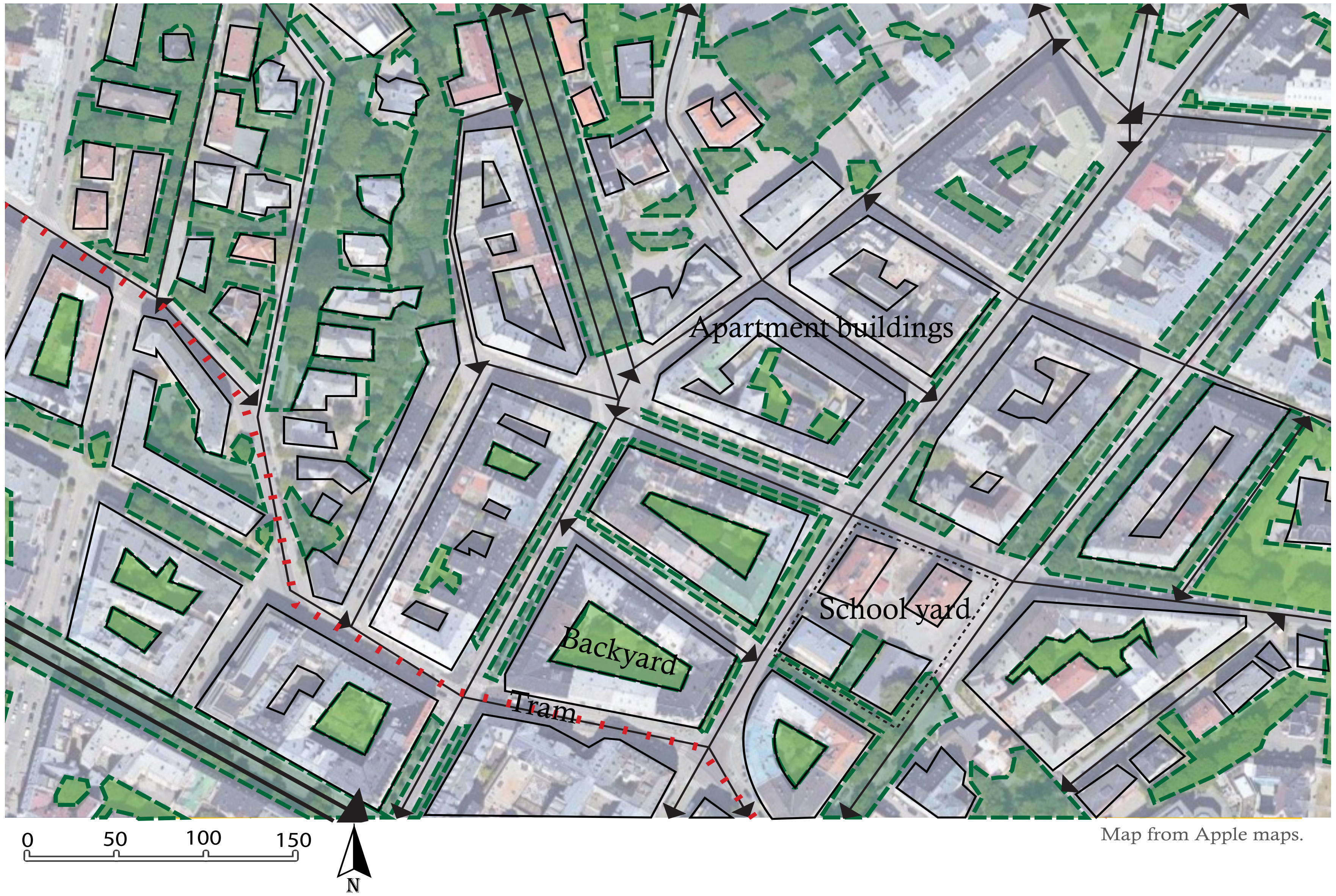
- **Fragmentation level**

Low due to high level of green connectivity in the background matrix

Frogner - urban residential

MESO-SCALE Landscape level

What are the patches, barriers, corridors and stepping stones?



Map from Apple maps.

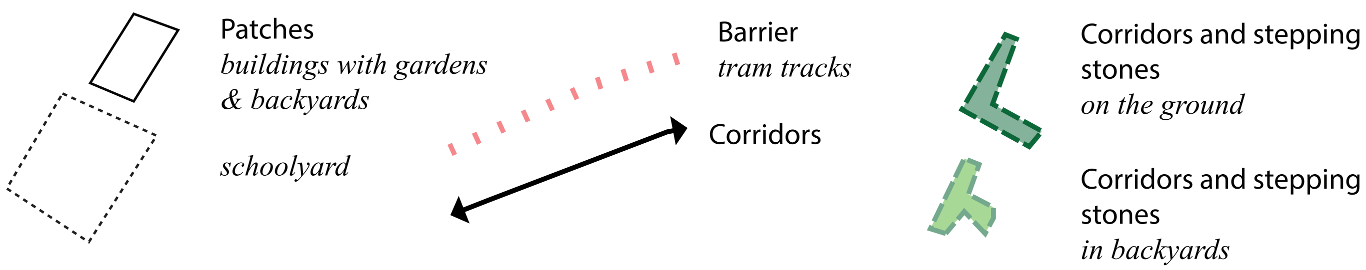


Figure 3.44 of meso analysis on the landscape level.

ANALYSIS

- **Patches**

Buildings with backyards and gardens in streetscape

- **Patch quality – heterogeneity**

Homogenous grey rooftop patches. Heterogenous streetscape with green vegetation amongst grey squares and streets

- **Green corridors and stepping stones**

Tree rows and vegetation on the ground in streets, squares, parks, gardens and backyards.

- **Movement corridors**

Streets, public transportation network, pavements and biking lanes. In general the streetscape facilitates pedestrian movement.

- **Barriers**

Bigger road (Bygdøy Allee) and tram tracks (Frognerveien)

- **Edge-interior quality**

Edge quality in streetscape with green corridors (tree rows) and patches (frontgardens). Interior quality in green patches in streetscape or backyards and gardens. Building patches with front gardens have edge quality.

Source and sink elements

Following are suggested analyses results of the site with elements that function as sources or sinks. This is done based on the source and sink table (table 3.3) and the following source-sink gradient (table 3.4).

In these suggestions the gradients will be mapped in accordance to the present elements and landscape metrics' functioning.

The red areas show what elements that dont function i.e. hinder ecosystem health.

The green show what elements that contribute i.e. promote ecosystem health.

These mapped gradients can help visualise where the biggest need to make improvements are, and might provide some sort of prioritation scale.

Source-sink gradient (table 3.2)

- Strong source
- Weak source
- Weak sink
- Strong sink

Analyses results - Frogner

What elements function as sources and sinks?

SOCIAL

Sources
- Green patches and corridors available to the public.
- Front gardens of buildings publicly available.
- Backyards and private gardens weaker source function.
- Schoolyard source.
- Overall connectivity and enabled mobility in the streetscape for vehicles, public transportation, pedestriands and bikers. .

Sinks
- Grey facades, rooftops and backyards wihtout vegetation.

ECOLOGICAL

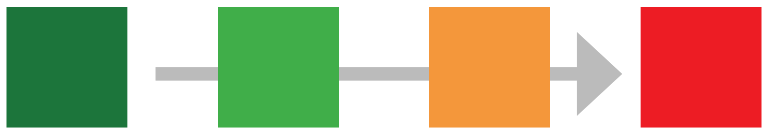
Sources
- Green patches and corridors available on the ground to all.
- Limited access to private vegetation in gardens and backyards.

Sinks
- Impermeable groun cover in streetscape.
- Traffic disturbances.
- Grey rooftops and backyards.

ENVIRONMENTAL

Sources
- Green patches, corridors and stepping stones on roof and ground provide ecosystem services that improve the microclimate and global cliamte (e.g. carbon sequetration and storage). Source quality depends on vegetation heterogeneity and quality.

Sinks
- Traffic emits pollution.
- Surplus of grey surfaces (e.g. glass and concrete) increase the urban heat island effect and thus decreases microclimatic conditions.
- Grey rooftops dont utilize the available resources e.g. solar panels.



Figures 3.45 A-C of from top to bottom of micro analyses on the site level.

3.3.6 Interventions

Demonstration of alternative improvements for elements to function as sources rather than sinks.

Suggestions

For the following part, suggestions for how to improve the ecosystem health dynamics by making sinks function as sources and sources function even stronger. The aim of this part is to show that this can be done by simple interventions. Improvements for the red elements identified in the site-scale of the land-use analyses dont neccessarily require new or advanced expertise to become green. Landscape archtiects already have a whole set of developed tools and ways to mititgate negative impacts and improve sites.

To meet the different challenges and contexts present some alternatives will be presented by simple sketches. They will be presented in a gradient for better alternatives that can be selected by the options available for site improvement, budget and scale for the interventions. Some of the positive impacts will be mentioned, but the suggestions are all based on the present tables on source and sink elements and the gradient that explains the functioning of different elements to the three selected sub-systems within the ecosystem. The suggestions are not a complete list of alternatives that can improve the ecosystem health but is a follow up from the previous tables and analyses of ecosystem health functions.

Following the table are some site-specific suggestions for how they can be implemented in the case study sites or suggestions that can fit several places.
The aim with such improvements are to achieve a majority of source function for all systems and the identified sinks from the analyses results are leading the improvements.

Some of the sinks detected in the source-and sink maps were grey surfaces on the ground, walls and roofs, broken landscape connectivity and garden design. Weak sources like gront gardens or street trees or green edges can get stronger source functions and the sinks can with suggested improvements get a source function. Additionally, by looking at the common sinks and sources for the three systems it can become even clearer what improvements that can be done without risk and with the biggest potential. Homogenous, grey surfaces is one example.

The aim is to change the sink functions into source functions and thereby changing the source dynamics in the sites. The mapping of sources and sinks easily point out source and sink- functions in sites, what have the same function to all systems and what has unique functions to some of the systems. This was it becomes easier to identify where improvements should be focused and what effect they will have. Or, what function on desired for a site and thereby addressing what elements hinder or promote that in the site within the different systems.

I have selected elements in each case study site that function as sinks or weak sources. I present some (of many) alternative ways to change their function to become sources. Many of the alternatives that enhance a source function for one system will have correlating positive effects to the other systems as healthy ecosystems are able to provide ecosystem services that benefit the whole ecosystem of people, nature and climate. An environmental source function of urban cooling will improve the microclimate of the site that also benefits the social and ecological system of more comfortable summer temperatures and conditions.

The following should be seen as examples of site-improving interventions and not a completed list of ways to improve the ecosystem health. As I only present some suggestions per site there are more alternatives that could be added in all for all the sites, and many of the suggestions are applicable to the other case study sites. The idea behind the case-study sites is to present typical situations in novel ecosystems that can be found anywhere and therefore the idea is that the suggestions have the potential to be applied in a multitude of sites with different land-uses and matrix context.

Gradient of better alternatives

I will present alternative suggestions with an increasing source function (illustrated by the gradient to the right). The gradient is based on literature on source and sink elements (Table 3.3, 3.4 and Appendix 1) and a persoanl evaluation.

The main purpose of presenting several better alternatives is not to define what separates "better" from "best" as that demands another scientific work in itself and is outside the scope of this thesis. It is rather is to present different alternatives and stress their increasing positive effect as sources to the ecosystem health of the social, ecological and environmental system. Simple, site-scale interventions are emphasized as they hold much potential in improving the ecosystem health of the sites.

IKEA Furuset
sub-urban industrial

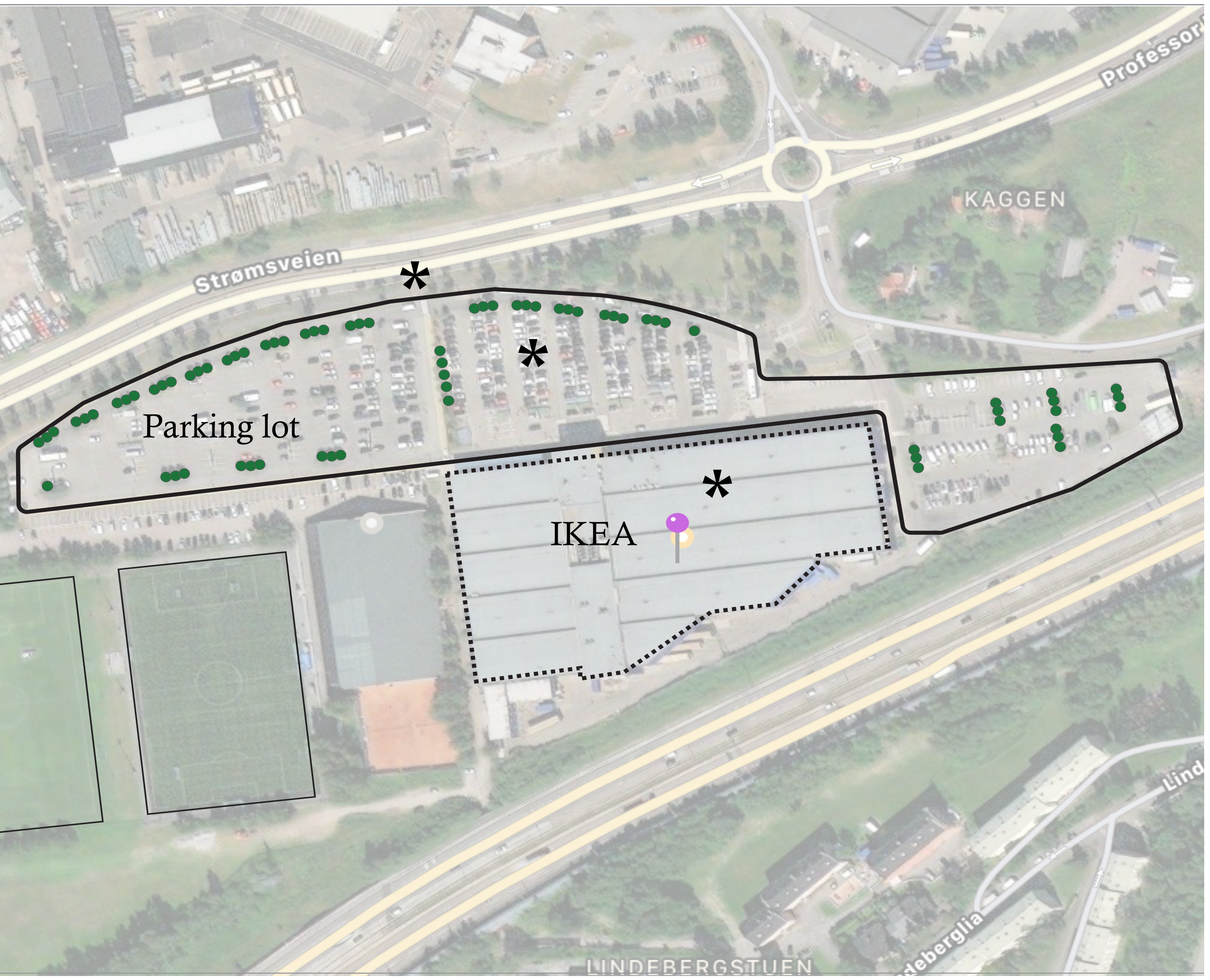


Figure 3.46. Map of IKEA with places for suggested interventions marked with stars.

ELEMENTS

The following are some suggestions for present elements that impact the source-sink dynamics of the site. Additional suggestions can be green facades, limited outdoor lighting and permeable ground cover.

* IKEA roof

The given land-use and contextual pre-conditions of the building, the placement and typical activities make the roof an unattractive place for recreation or other activities. Nonetheless, the undesired area for the social system opens up for undisturbed land-use (in the given context of other disturbances on the site like traffic noise and light). The roof holds potential to provide green energy with e.g. solar panels. Or, the roof can get an ecological function as habitat, nesting-site for ground nesting birds or as resource for biodiversity (e.g. pollinating insects, stop-over for migratory birds). Therefore a priority to the environmental or ecological system should be given to site-improvements for the roof.

* Parking lot

The parking lot accomplishes what it's set up to do, providing parking space for the customers of IKEA. However, the characteristics of the homogenous patch are boring to the human eye with little aesthetic value except for the groups of trees in the edges. The vast impermeable ground cover hinders efficient stormwater management and to the ecological system the patch might be considered a grey desert of sink functions. Given that the same amount of parking needs to be sustained the social system is prioritised. The social system would benefit from a greener and more heterogenous patch with more aesthetic value, and so would the ecological and environmental system. These systems often function in correlation to each other, and what is a source to one often is a source to another. The same goes for this site.

For the ecological system the best option for maximized source function might be to rip up the impermable ground cover and replace the parking lot with a little forest. This would also benefit the environ mental system of storm water retention, carbon sequestration and storage, air filtering and cooling. If the land-use of the parking lot could be redistributed to reduce the amount of parking to better meet the needs of all systems it could provide a source function of more ecosystem services like aesthetic value, function with recreational "island" for people to rest at or walk their dog, support biodiversity and be more energy efficient. However, with the present priority to the social system the aim is to find solutions that can combine source function for all systems within the frames of the site.

* Edges

The edges of the parking lot towards the road provide multiple ecosystem services already like noise buffering and aesthetic value, function as stepping stones or corridors to biodiversity and have an environmental function of cooling and air filtering to mention some of the effects. However, the relative distribution of green in the edges compared to the vast, grey interior is small. By enforcing the edges their function as sources would be increased and might manage to match the source function of the interior. More vegetation in the edges would provide more noise buffering, more shade for warm summer days, more aesthetic value and become a more human- and nature friendly site. It would provide more resources and habitat options to the ecological system, however this also depends on the species

Suggestions
IKEA roof

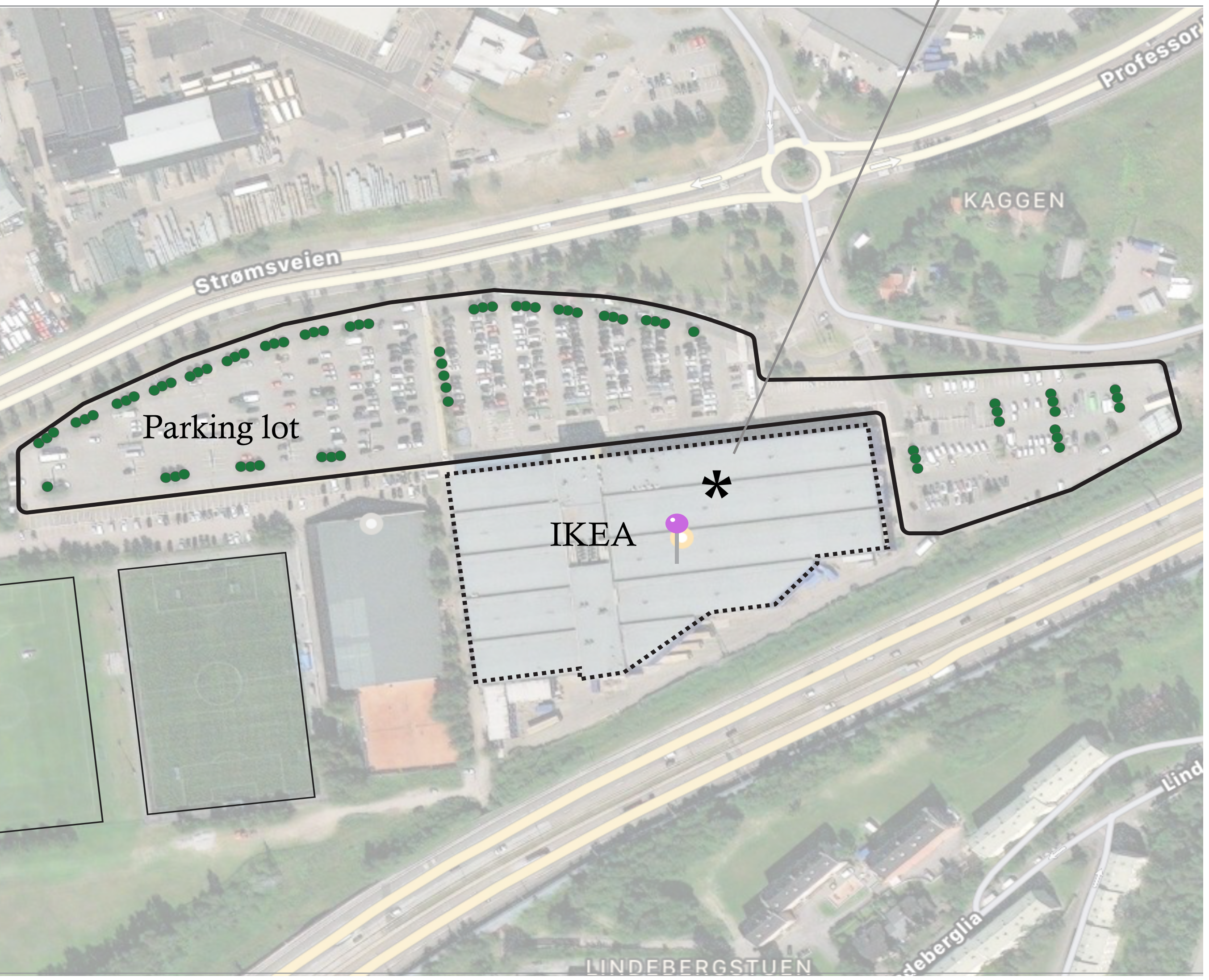
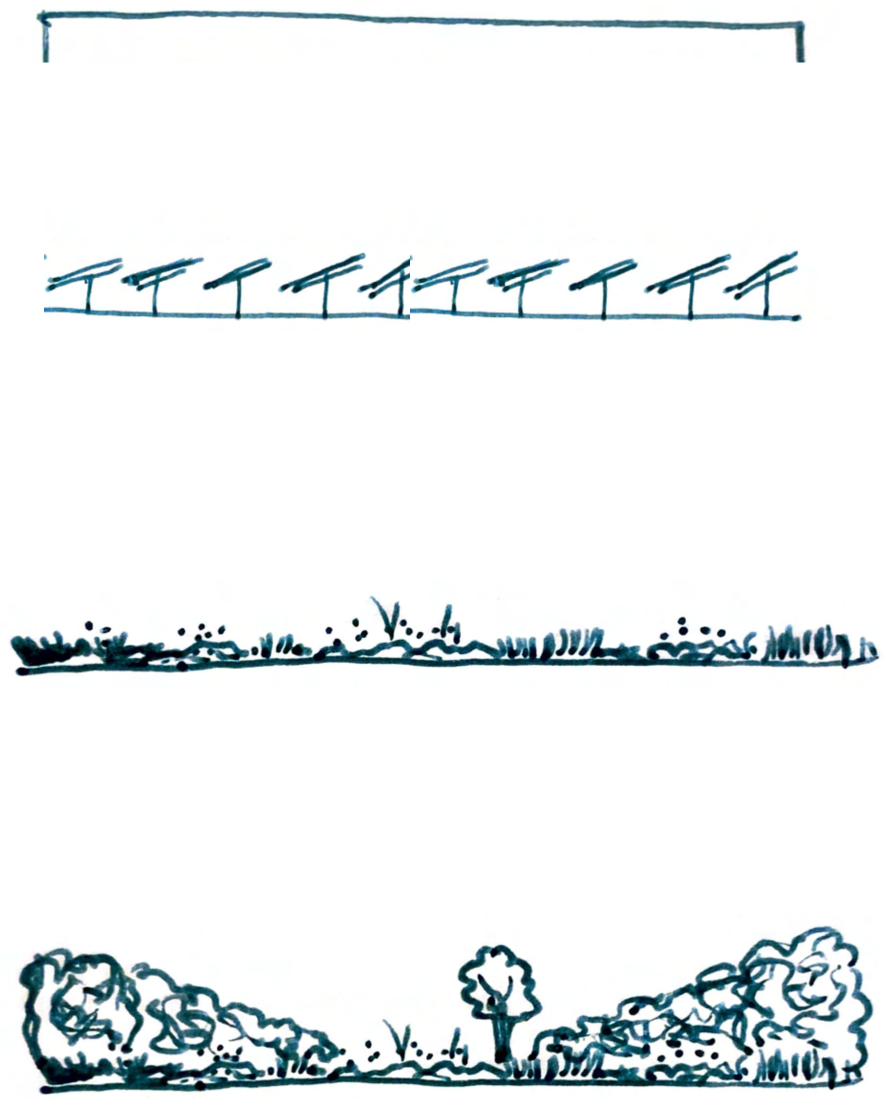


Figure 3.46 A. Map of IKEA with places for suggested interventions marked with stars.

Figures 3.47 A-D to the right with sketched suggestions.



as is:
Grey roof without social, ecological or environmental function.

suggestion I:
Solar panels for environmental source function.

suggestion II:
Homogenous ground vegetation for environmental and ecological source function.

suggestion III:
Heterogenous vegetation in all layers for maximised ecological and environmental source function.

Source functions

The benefits of green roofs with heterogenous vegetation (both vegeation types and strucutres/layers) are ecological source function of providing resources like pollen, habitat, nesting-sites or stepping stone function to migratory birds. For the environmental system heterogenous vegetation in all layers increases the provision of ecosystem services like air filtering of particulate matter, flood risk mitigation, carbon sequestration and storage and cooling. Even though this type of vegetated roof is not facilitated for use of the social system these source functions in the natural system benefit the social system indirectly of improved microclimates and for instance increasing abundance of wildlife.

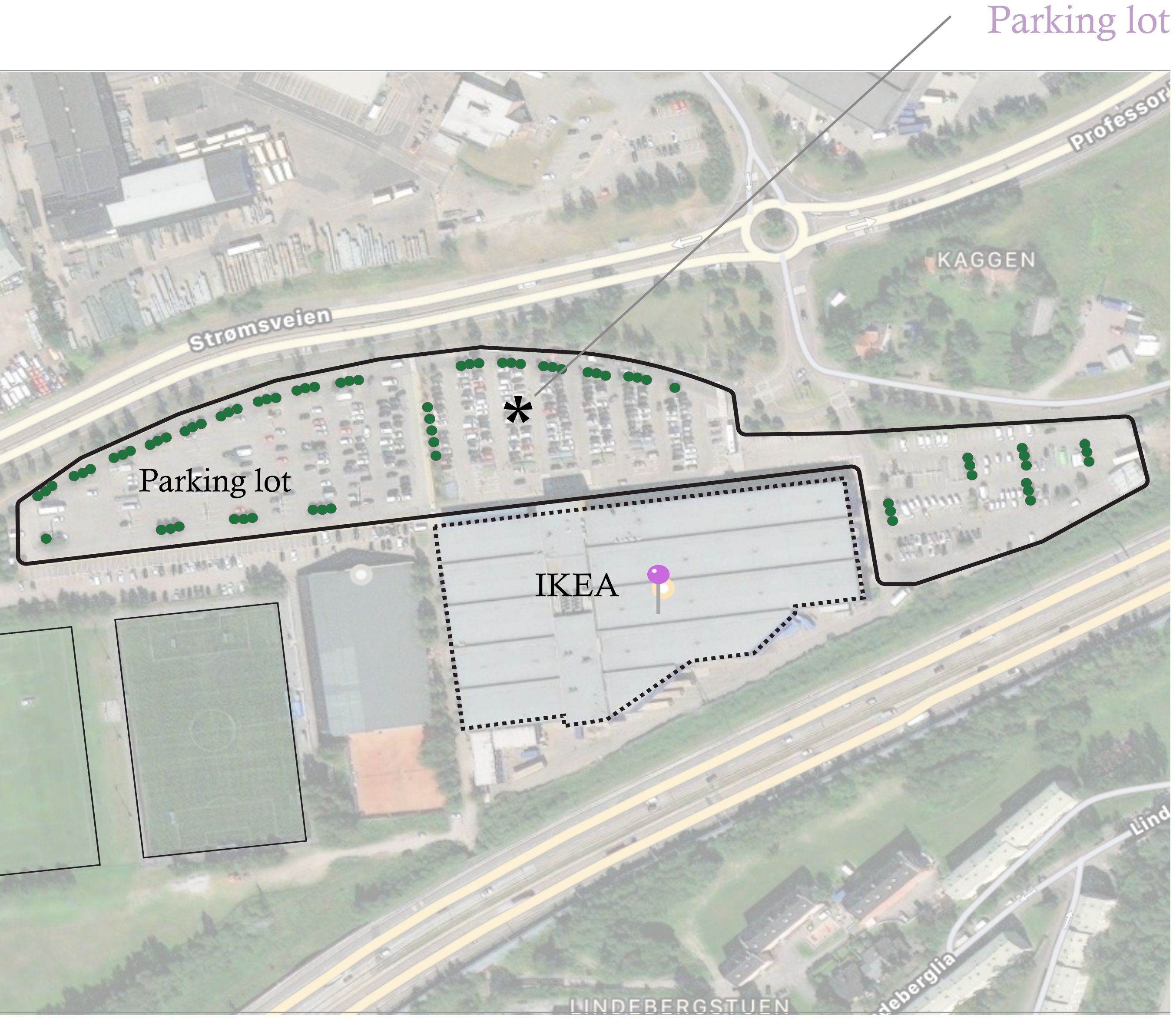
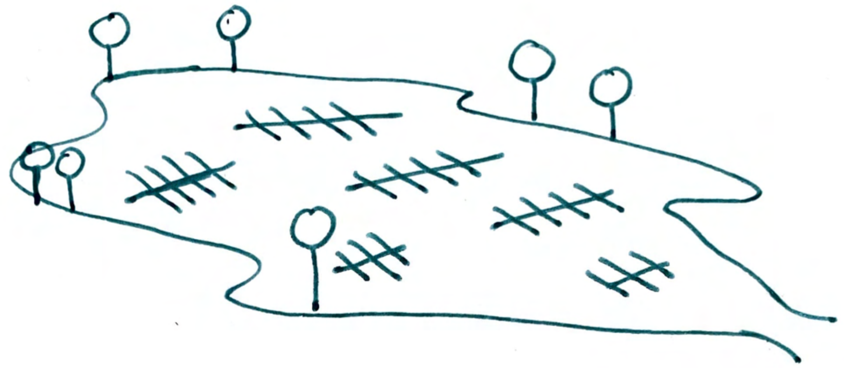


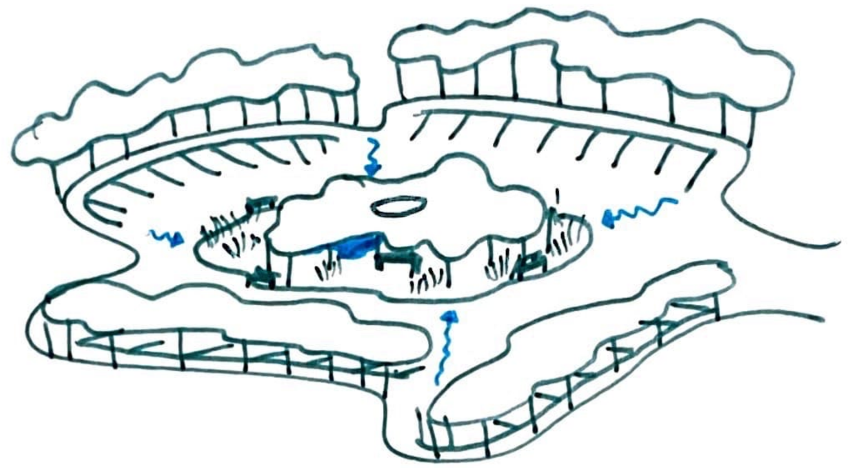
Figure 3.46 B. Map of IKEA with places for suggested interventions marked with stars.

Figures 3.48 A-C to the right with sketched suggestions.



as is:
Geen edges, homogenous grey interior.

suggestion I:
Green interior with ecological, environmental and social source function.



suggestion II:
Reinforced green edge together with green "island" that also tackles stormwater and rainwater runoff. Source function to all systems. Can also add in groups of trees in between to reinforce connectivity and green distribution across the whole parking lot.

Source functions

The benefits of more heterogenously distributed parking lots that combine social and natural function are increased aesthetic value, recreational experiences in busy commercial areas as sitting on a bench, in the shade of a tree or enjoying the calming sounds of birds, water or wind in the leaves. With less grey, impermebale surface replaced by green, permeable surfaces there a number of ecosystem services provided that indirectly benefit the social system like cooling. The ecological system gets an increase in natural resources and habitat valuable to biodiversity. With a heterogenous distribution of different green elements there is a higher support to more species that are adapted to itnerior or edge qualities. The higher the distribution and heterogeneity of green is, the higher the distribution of ecosystem services from the environmental system is if the growth condtitions are adequate.

Suggestions
edges

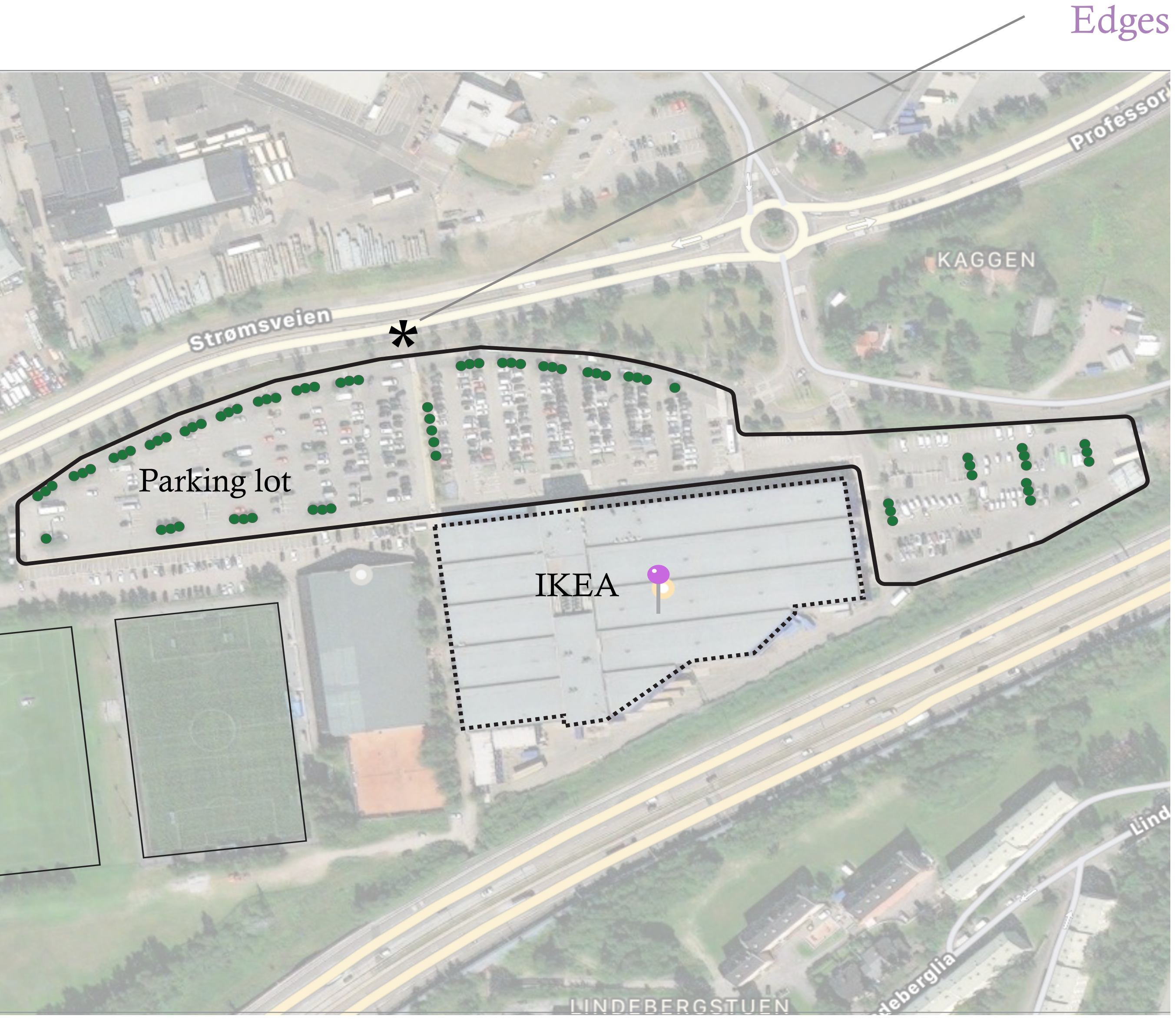


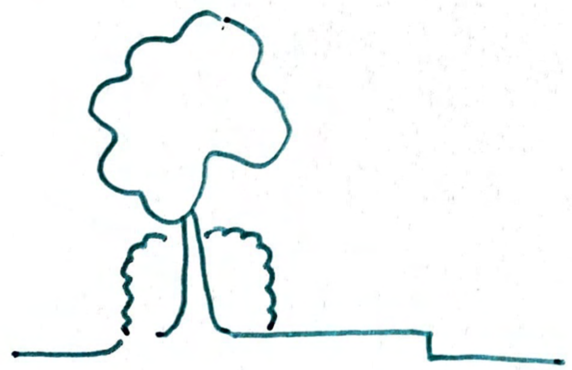
Figure 3.46 C. Map of IKEA with places for suggested interventions marked with stars.

Figures 3.49 A-E to the right with sketched suggestions.

as is:
Green edge of trees on asphalt.

suggestion Ia:
With ground cover vegetation.

suggestion Ib:
With herbaceous vegetation.



suggestion Ic:
With shrub vegetation.

suggestion II:
With heterogenous vegetation in all layers.

Suggestions
edges

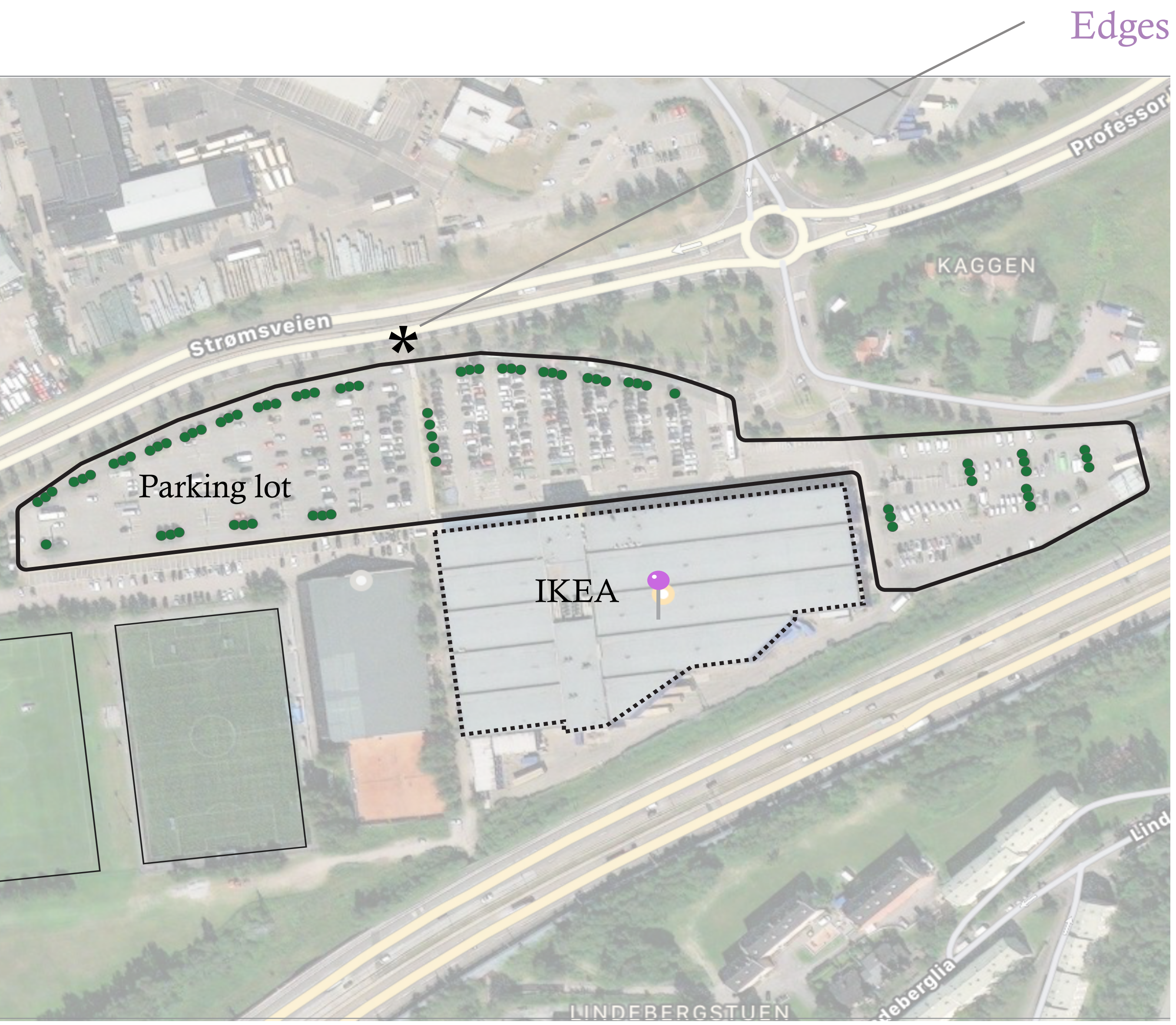
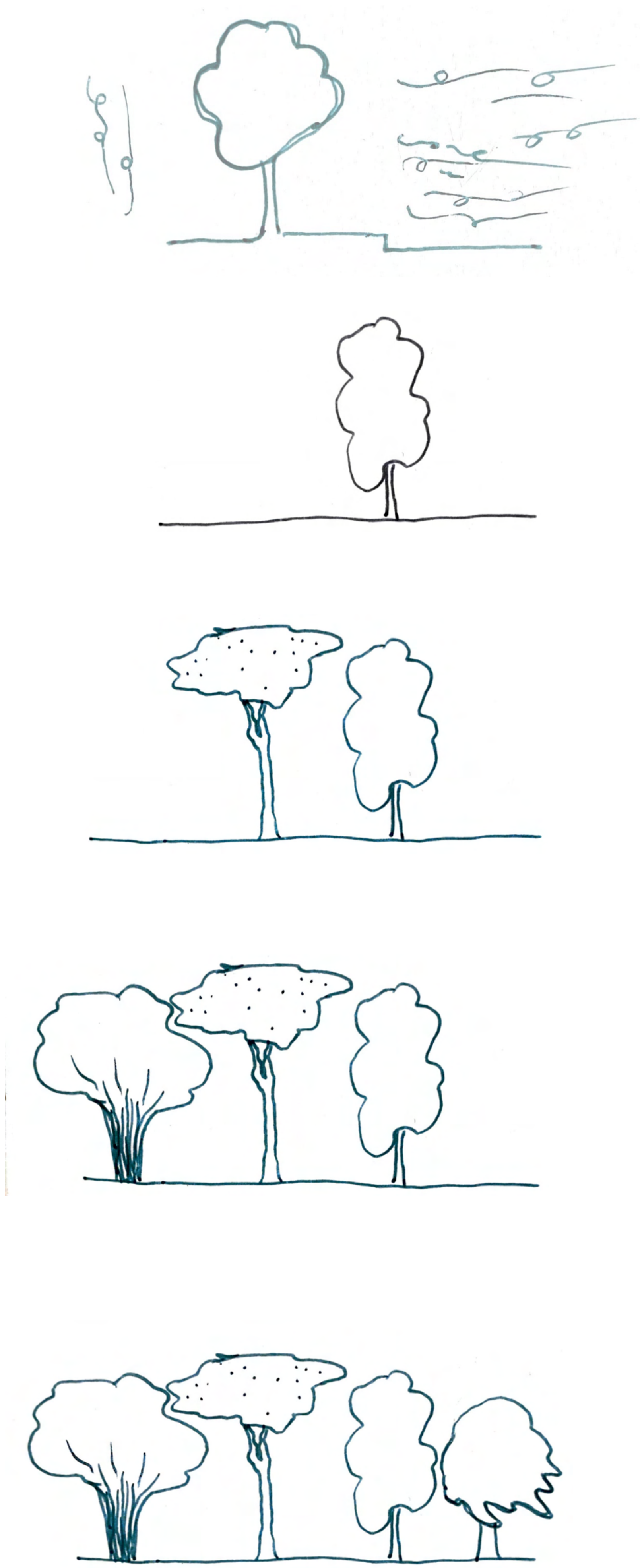


Figure 3.46 D. Map of IKEA with places for suggested interventions marked with stars.

Figures 3.50 A-E to the right with sketched suggestions.



as is:
Green edge of one tree species.

compositional heterogeneity:
More tree species will give a bigger contribution i.e. source function to all systems as different species have different qualities for ecosystem service provision (habitat, carbon sequestration, aesthetic value), requiremenets for growth condition and resilience.

As a heterogenous forest is stronger to withstand threats will trees in novel ecosystems.

In addition, their aesthetic contribution will increase with more variation.

Source functions

Two alterations of heterogeneity are configurational (i.e. spatial arrangement, vegetation in different layers) or compositional (i.e. types of land cover, using different species for a tree row instead of one).

Structural heterogeneity

With heterogenous vegetation in all layers (ground-, herbaceous, shrub and canopy layer) the ecological and environmental function could be maximised. It could provide increased aesthetic value and noise buffering function beneficial to the social system.

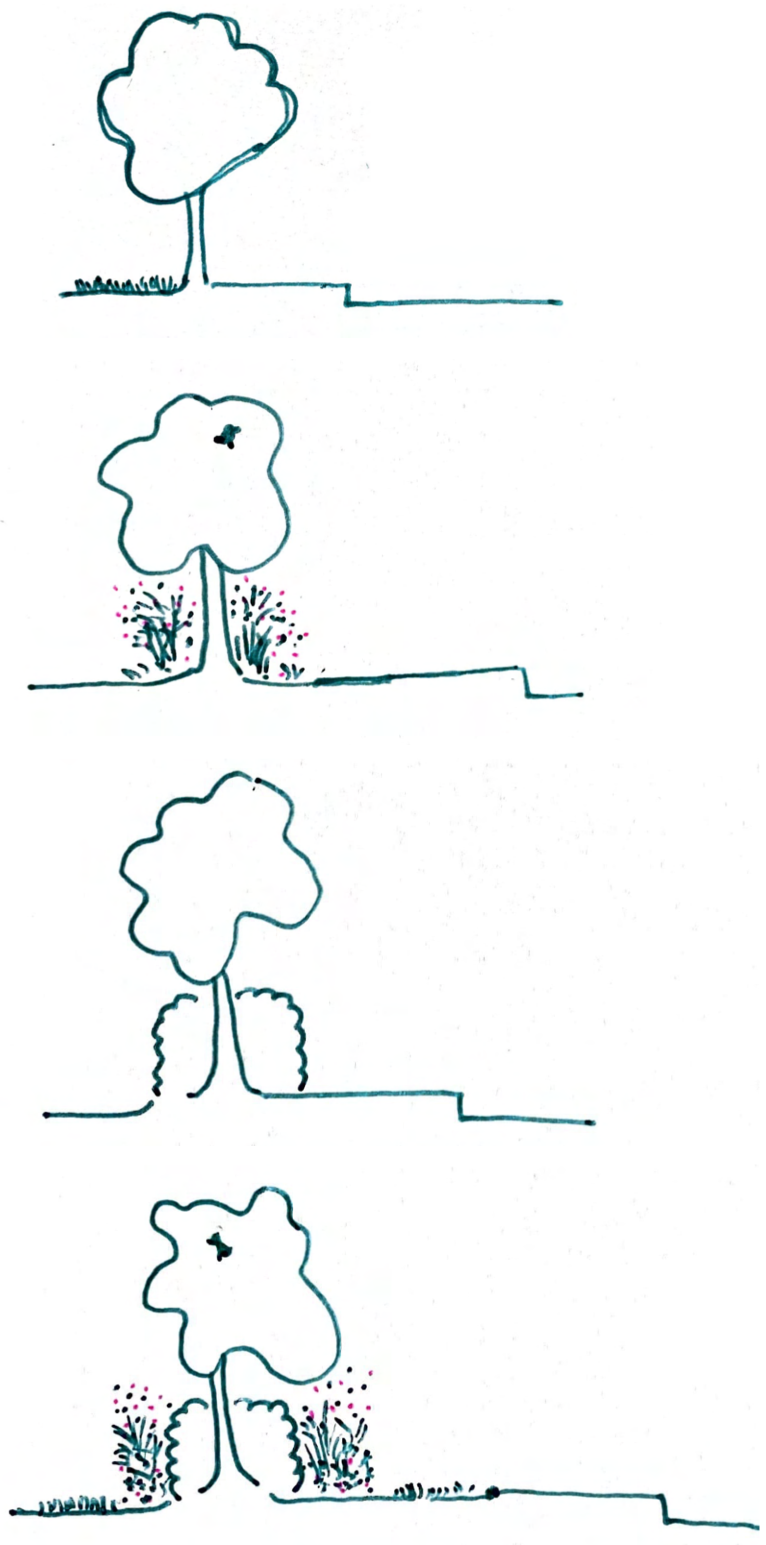
Species heterogeneity

With heterogenous species there would be a bigger array of aesthetics. The social function of this could be a more diversified aesthetic expression that would be subjectively evaluated, some might think it messy, others exciting.

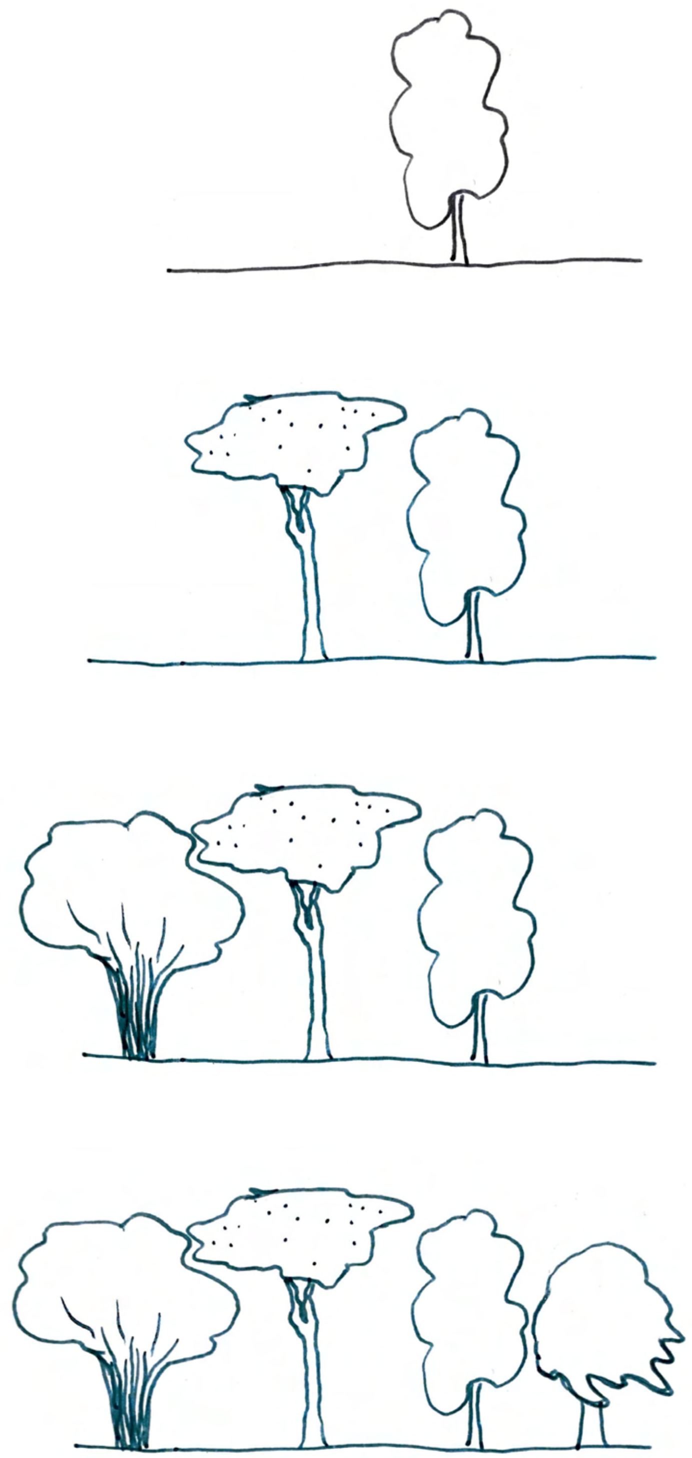
More heterogenous vegetation could provide e.g. more resources available to biodiversity, more habitat, nesting sites and biodiversity. Heterogenous vegetation could provide more ecosystem services that benefit the environmental system of e.g. air filtering and stormwater retention. The social system could also benefit from an increased provision of ecosystem services like noise buffering and aesthetic value that can soften the homoegenous look of the parking lot and make it more human- and nature friendly. Combined or separately integrating heterogenous vegetation could improve the source function of the site.

Figures 3.49 B-E to the left and 3.50 B-E to the right with sketched suggestions.

Configurational heterogeneity



Compositional heterogeneity



Korsvoll
sub-urban residential

Figure 3.51. Map of Korsvoll with places for suggested interventions.

ELEMENTS

These elements are not site-specific but elements that are present or applicable to all garden patches. Additional suggestions for this site are green roofs or facades, permeable ground cover and street vegetation. Suggested sites are just examples of where the improvements could be done.

* Fences

Fences are typically abundant elements in residential neighbourhoods with multiple intentions. Fences can however function as a sink for the ecological system as barriers that hinder flow of energy. This sink function can also l the social system and prevent kids play between neighbours, however this sink effect is low. Fences can have different design and vegetation as fences offer source functions to the ecological and environmental system. The amount of fences in residential areas is vast and they can hinder ground-moving animals from dispersal and survival.

* Messy gardens

Garden design and maintenance can impact their source function to the ecological and environmental system. The social system is a more subjective matter of preference and therefore it is hard to suggest better or worse alternatives for what maximizes the source function of aesthetic value and use of the gardens. For the natural systems the heterogeneity of the gardens with species variation and layering. Even though a messy garden might be perceived negatively in the social system it can provide strong source function to the ecological system of pollinators and other.

* Outdoor lighting

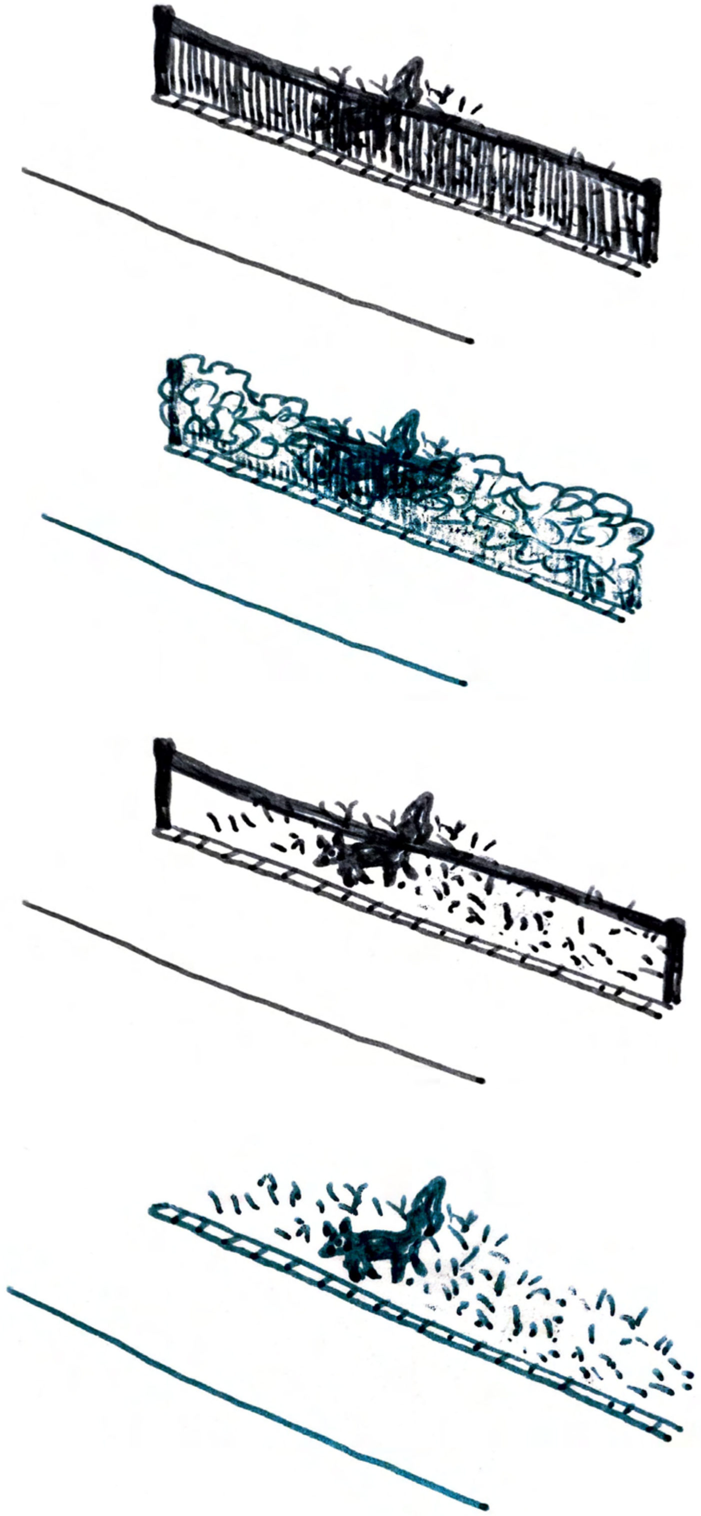
Outdoor lights are abundant in all residential and industrial areas. Outdoor lighting have a negative sink function for the ecological system as a distraction or disturber of natural processes for wildlife. For the social system lighting is associated with safety and for streetscapes it is an important element to ensure the feeling of safety and use. Outdoor lighting also includes lit houses and facades, porches and even lights on vegetaion. By increased use of lights on more elements than simply streets their sink function to the ecological system increases vastly.

In sites like these there is a higher abundance of wildlife due to the proximity to the forest matrix. The objective should be to find the balance between minimizing outdoor lighting with sink function to the natural systems and providing safety to the social system.

Suggestions
fences

Fences

Figure 3.51 A. Map of Korsvoll with places for suggested interventions marked with stars.



suggestion I:
Artificial fencing that hinder flow of energy i.e. barrier to ground moving animals.

suggestion II:
Natural fencing that function as a barrier for humans but that is permeable i.e. it allows some passing of animals.

suggestion III:
Permeable fencing with a weaker barrier function that have a more symbolic function.

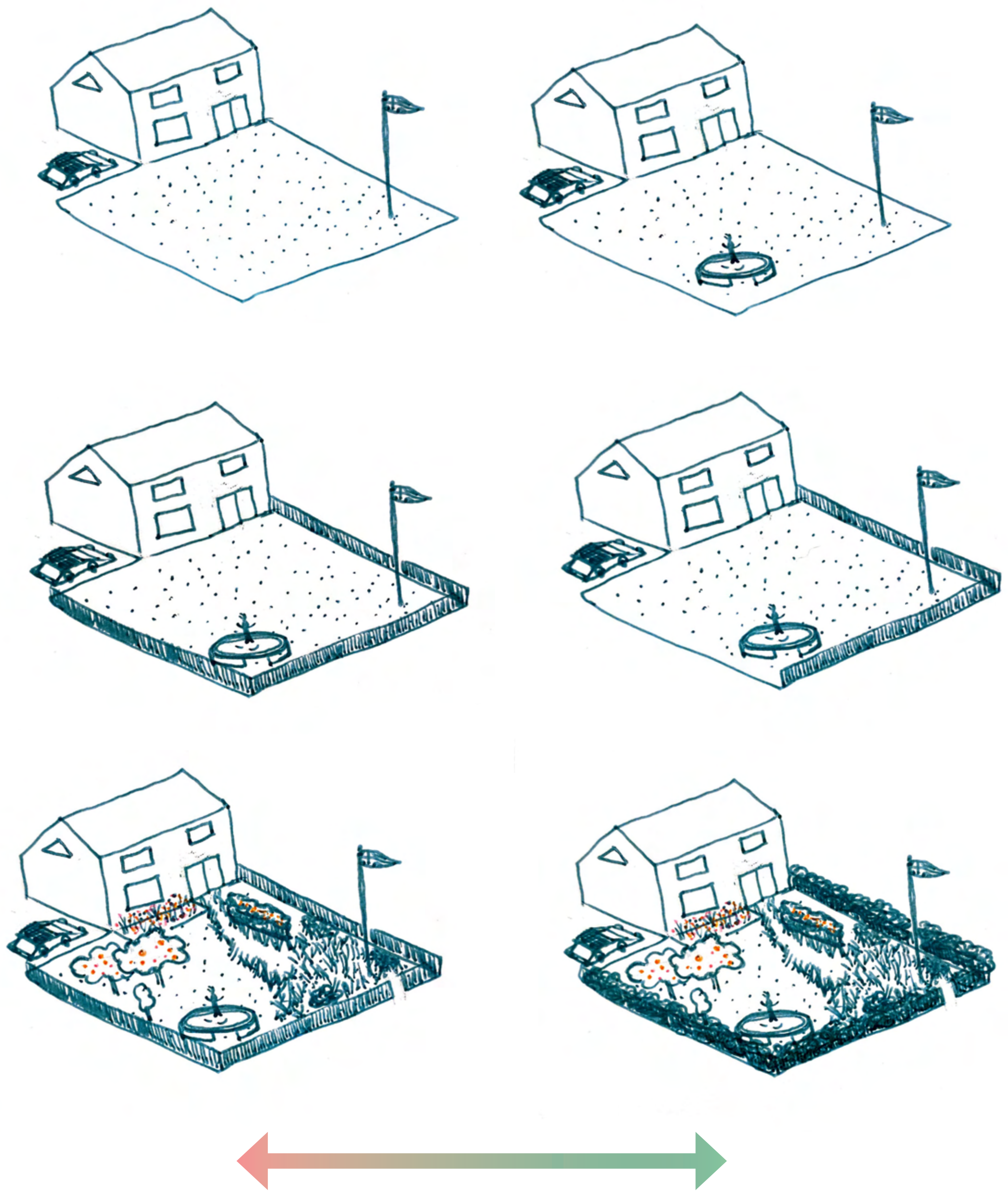
suggestion IV:
No fence i.e. no barrier

Figures 3.52 A-D with sketched suggestions.

Source functions

Permeable or no fences enable free movement for ground-moving animals as well as humans. These are source functions to the ecological and social system. The benefits of vegetation as fences are environmental source functions, in addition to prossible habitat or movement corridors for wildlife. Permeable fences with a more symbolic function for the social system can work to mark an edge without functioning as barrier. The ecological system is strongest affected by fencing so priority should be given to find solutions that enable source function to all systems.

Figure 3.51 B. Map of Korsvoll with places for suggested interventions marked with stars.



suggestion I:
Homogenous garden of homogenous vegetation and use.

suggestion II:
Fully fenced (left) or partly fenced (right) to enable movement in some edges.

suggestion III:
Artificial fencing (left) around heterogeous garden patch with a messy corner and an openig in the fence. Natural and permeable fencing (right).

Figures 3.53 A-F with sketched suggestions.

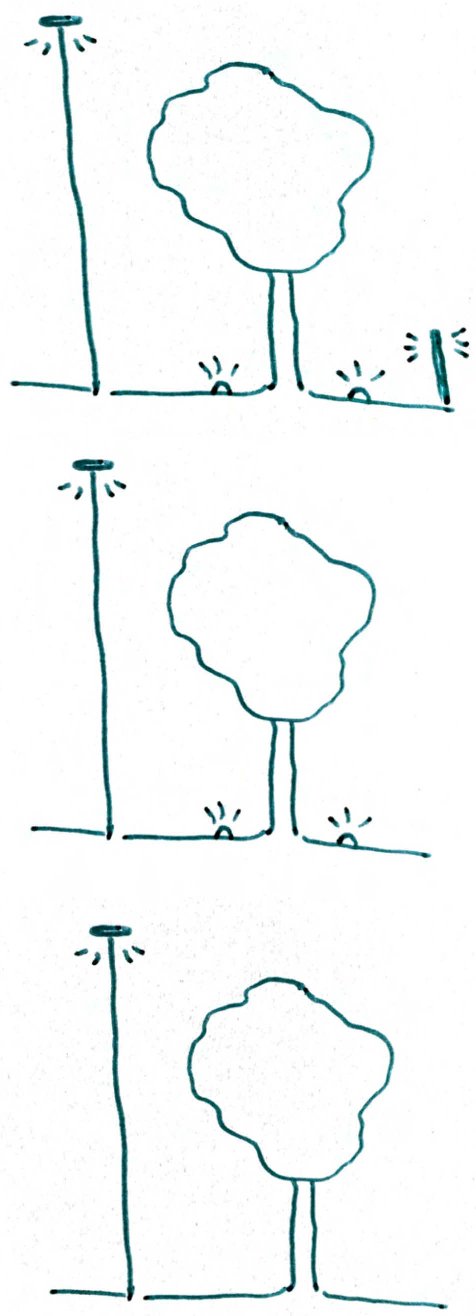
Source functions

By breaking up the homogenous garden patch with different vegetation and function for use the source function increases to all systems. Heterogenous vegetation will provide seasonal variation, aesthetic and foraging possibilities for the social system. In addition, by either limiting artificial fencing to have one open edge to enable movement of ground moving animals or by replacing the fence with a shrub or vegetated fence the source function increases further for the ecological system. The social system will in addition get more insight limitation with a vegetated fence if it is left to grow tall, in addition to other ecosystem services the vegetation provides. By leaving a messy corner in the garden where the maintenance is limited so the vegetation can grow to provide resources to the ecologica system the source function further increases and a more naturalistic look might be prefereable to some.

Suggestions
outdoor lighting

Lights

Figure 3.51 C. Map of Korsvoll with places for suggested interventions marked with stars.



Figures 3.54 A-C with sketched suggestions.

worst case scenario:
Outdoor lighting in multiple layers of vegetation with strong sink function.

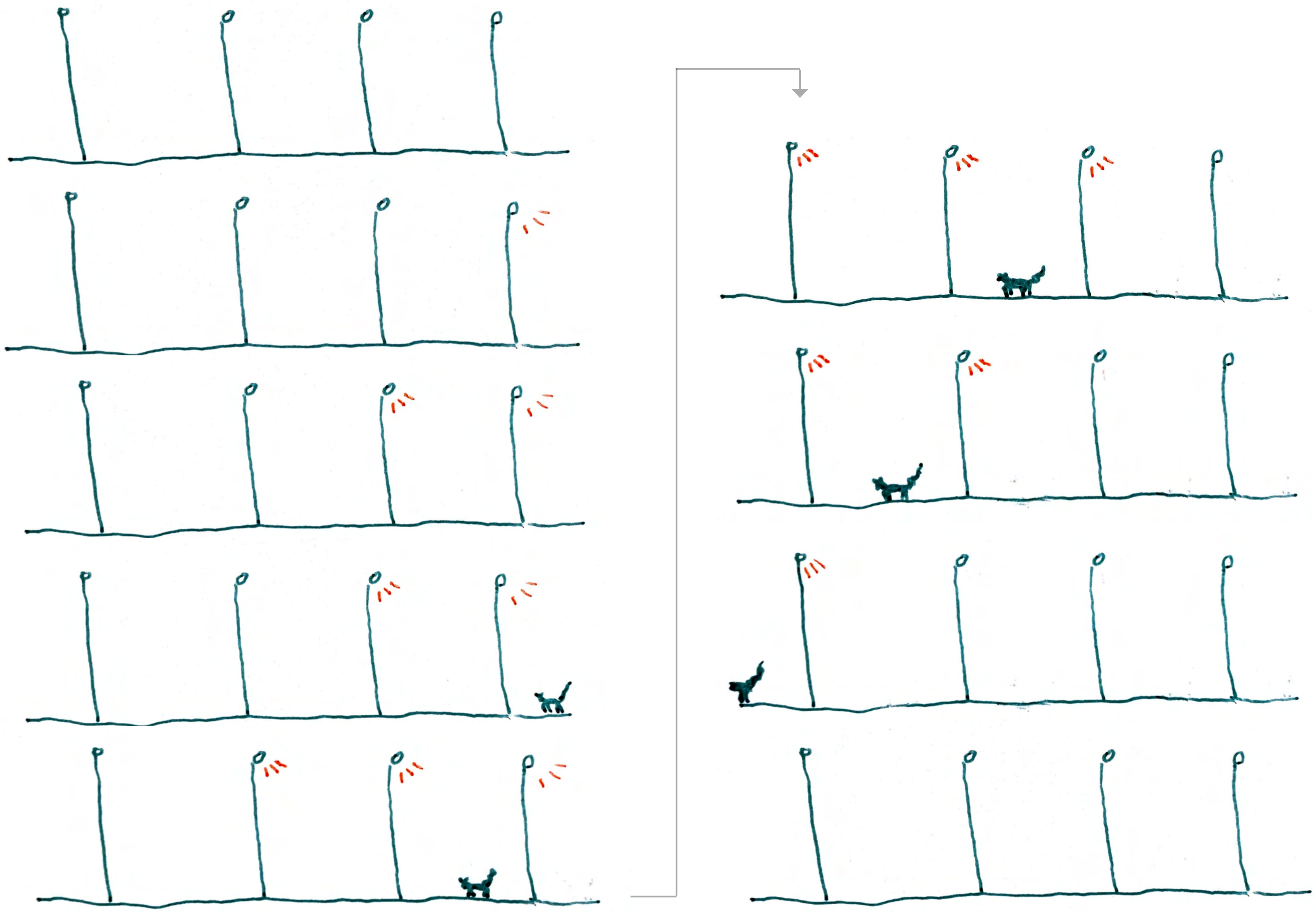
Limiting number of light sources will decrease the sink function.

better:
Outdoor lights in streets or where absolutely neccessary limits the sink function.

Source functions

Outdoor lighting can have a sink function for the ecological system of vegetation, trees and wildlife. Therefore limiting the outdoor vegetation to the minimum of what is required to enable a feeling of safety for the people is important. Outdoor lighting on buildings can have an equally negative impact as lighting of vegetation and it should be avoided to limit the sink function to that system. This will indirectly affect the environmental source functioning of the vegetation as outdoor lighting can negatively impact vegetation function and growht. Minimizing outdoor lighting will also benefit the social system of reduced light pollution.

Suggestions
outdoor lighting with sensors



Figures 3.55 A-I with sketched suggestions.

Source functions

An alternative to limit the sink function of outdoor ligthing that can benefit all systems is using sensors on the lights so they only activate when there is movement registered. If possible, requiring movement from humans or bigger vehicles for the lights to turn on would reduce the negative impact they can have for biodiversity and wildlife. Insects and small animals would then be undisturbed by the lights and vegetation would not be affected. Sensors would also ensure the feeling of safety and view for the social system. This type of alternative have to be thought through and only placed at sites where it does not increase a feeling of unsafety or criminal activity.

Bjørvika
urban industrial

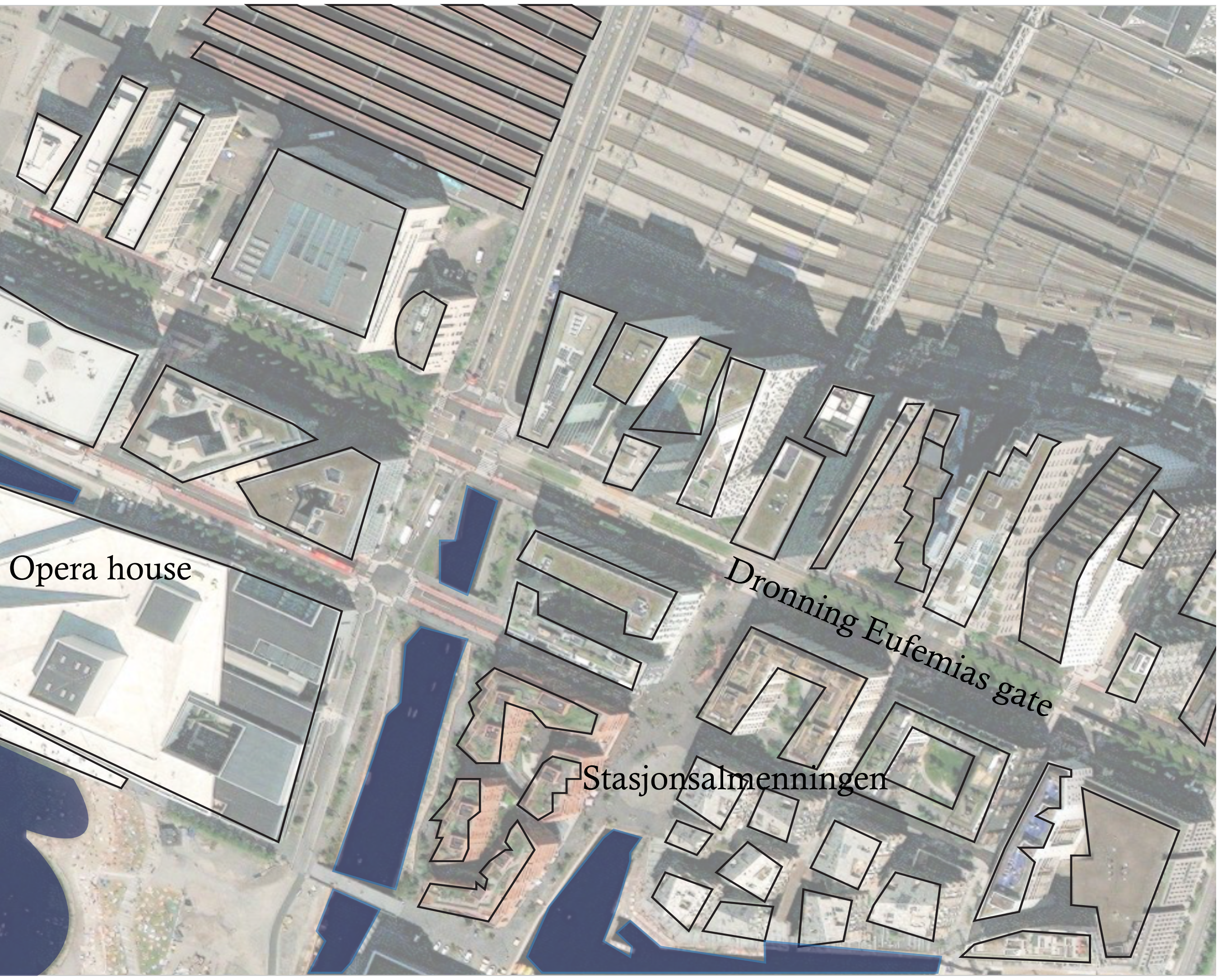


Figure 3.56. Map of Bjørvika with places for suggested interventions.

ELEMENTS

The elements in the urban matrix are not restricted to certian sites as they are general and widely distributed in the site. Stars are suggested sites for theinterventions. Additional suggestions for this site can be street trees, green edges, limited outdoor lighting.

* Urban roofs

The contextual pre-conditions of the urban high-rises are weather exposed outdoor rooms unavailable to the public. However, these roofs are increasingly designed as recreational spaces with a bigger social function to those with access. These roofs are often more facilitated for the social than ecological systems and their functions follow. The special conditions on the roofs being strongly ecposed to weather and especially wind, sun and droguth make them challenging habitats and growth places for the ecological system. Due to their typical, contextual placemenet in an urban matrix their potential to support the ecological system is limited and naturally the social system is prioritized. However, it is possible to combine ecological and source function.

* Facades

The buildings in this land-use site often compose of hard structures like glass or concrete facades with little function to the social system outside of the office (i.e. the public) and to the ecological system. The strong sink functions of these materials in high-rise developments worsen the micro-climatic conditions of e.g. increased wind speed, urban heat island effect and noiese echoing in addition to having negative impacts on the ecological system. The biophilia hypothesis that suggests a human preference to natural and vegetated surfaces with soft curves supports the social source function green walls could have. In addition this would provide environmental source functions of microclimatic regulations and ecological benefits of resources and habitat.

* Ground cover

Ground cover has multiple effects as source and sink due to for instance ground cover permeability that affects the environmental source function of ecosystem service provision like stormwater mangement or urban cooling. Permeable and vegetated ground cover provides a number of ecosystem services that benefit the social, ecological and environmental system. The ecological system of microbiological communities that are supported by live and humus-rich soils again beneftis the social system through fighting pests and diseases and providing health stimulating bacterias. Impermeable surfaces dont provide any desired ecosystem services but undesired ones like urban heat island effect. For an urban matrix the abundance of permeable, vegetated surfaces is very limited.

* Human friendly streetscapes

A continuation of the biophilia hypothesis is the aspect of scaling on strucutres that is human-friendly. Oversized high-rises can feel intimidating and unfriendly to the social system. Only grey surfaces on the ground with little variety creates homogenous ecosystems that are little stimulating to the human mind and similarly for the ecological system. The source function of the environmental system is limited in these types of streetscapes. By breaking them up, adjusting them more to a human scale and adding in as much green and heterogeneity in the elements the streetscape can achieve more source functions to all of the sub-systems.

Suggestions
urban roofs

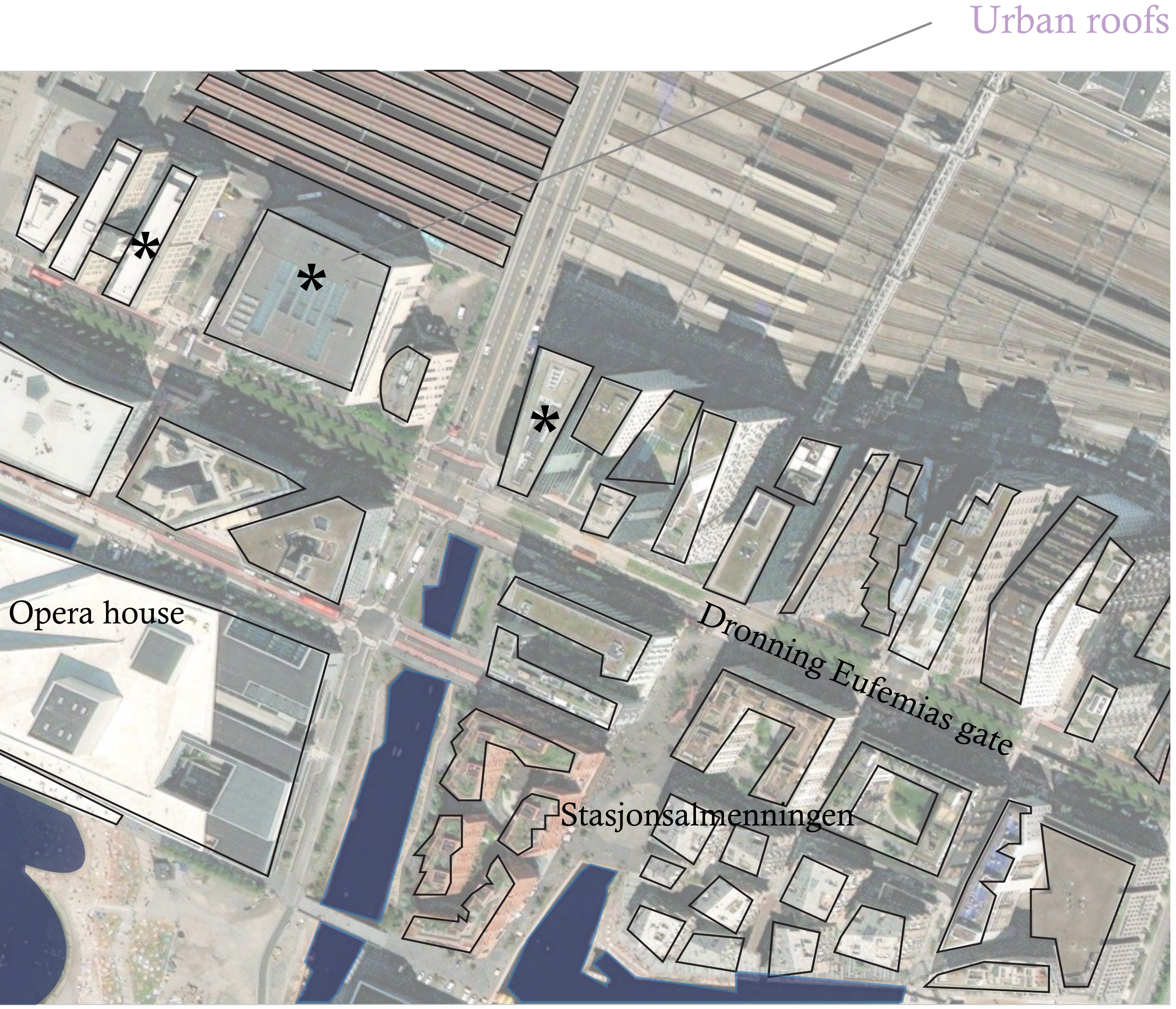
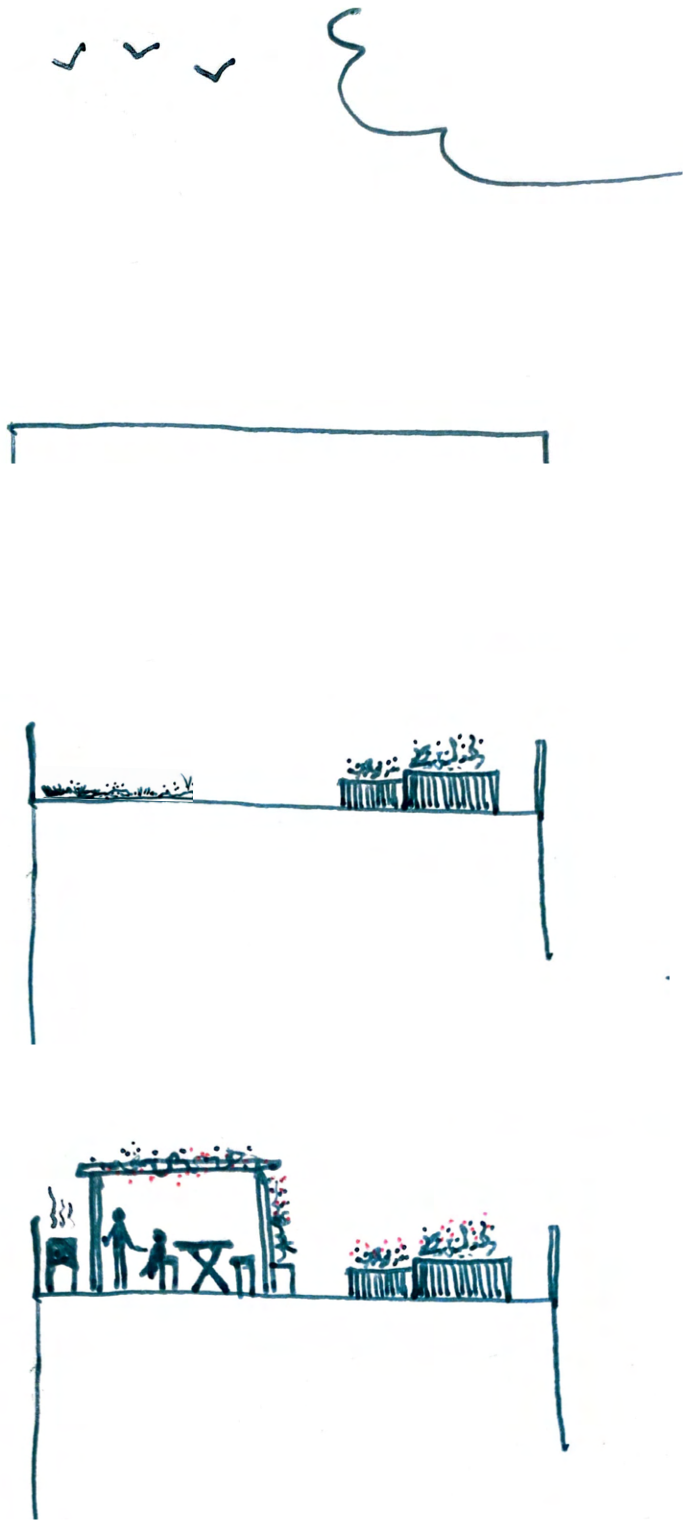


Figure 3.56 A. Map of Bjørvika with places for suggested interventions marked with stars.



as is:
Grey roof without social, ecological or environmental function.

suggestion I:
Some vegetation and facilitation for use for social and ecological source function.

suggestion II:
Heterogeneity in facilities for use increases the source function to the social system. The ecological system can gain some source function with adequate and heterogenous vegetation.

Figures 3.57 A-C with sketched suggestions.

Source functions

The benefits of multiple possibilities for use of the social system increases the possible source function with outdoor furniture, recreational facilities, possibilities to grow food and take care of plants. Heterogenous vegetation provides ecological source function with resources and nesting site for avian biodiversity and wildlfie. Due to the facilitation for the social syste the potential of the roof to function as habitat can be limited due to a higher disturbance load in roofs like IKEA. The environmental function is lower with a roof that has such limited distribution of vegetation and green, permebale cover. The characteristics of these roofs in Bjørvika are for instance their height that affects the accessibility for biodiversity and their source function to the ecological system.

Suggestions
urban roofs

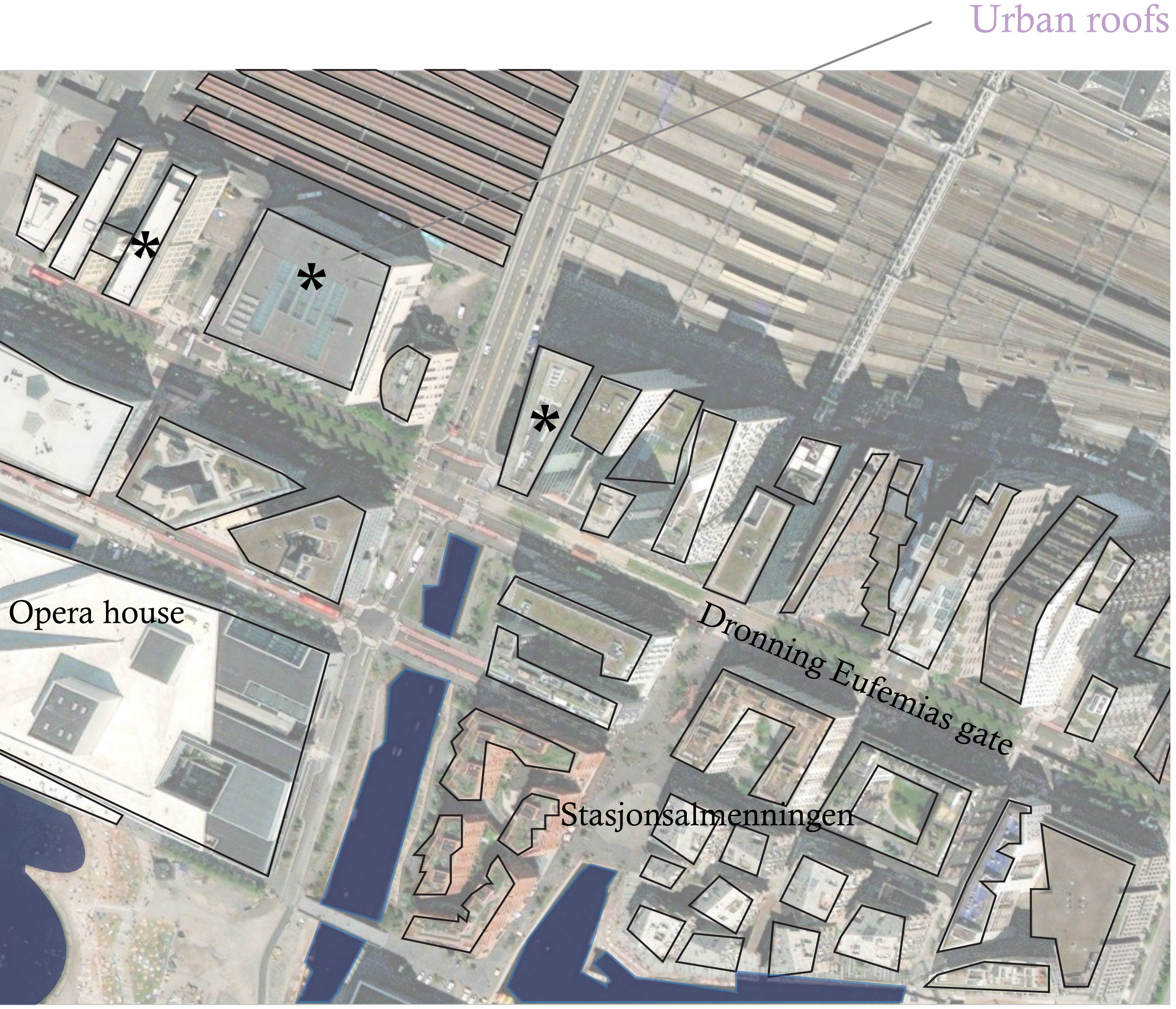
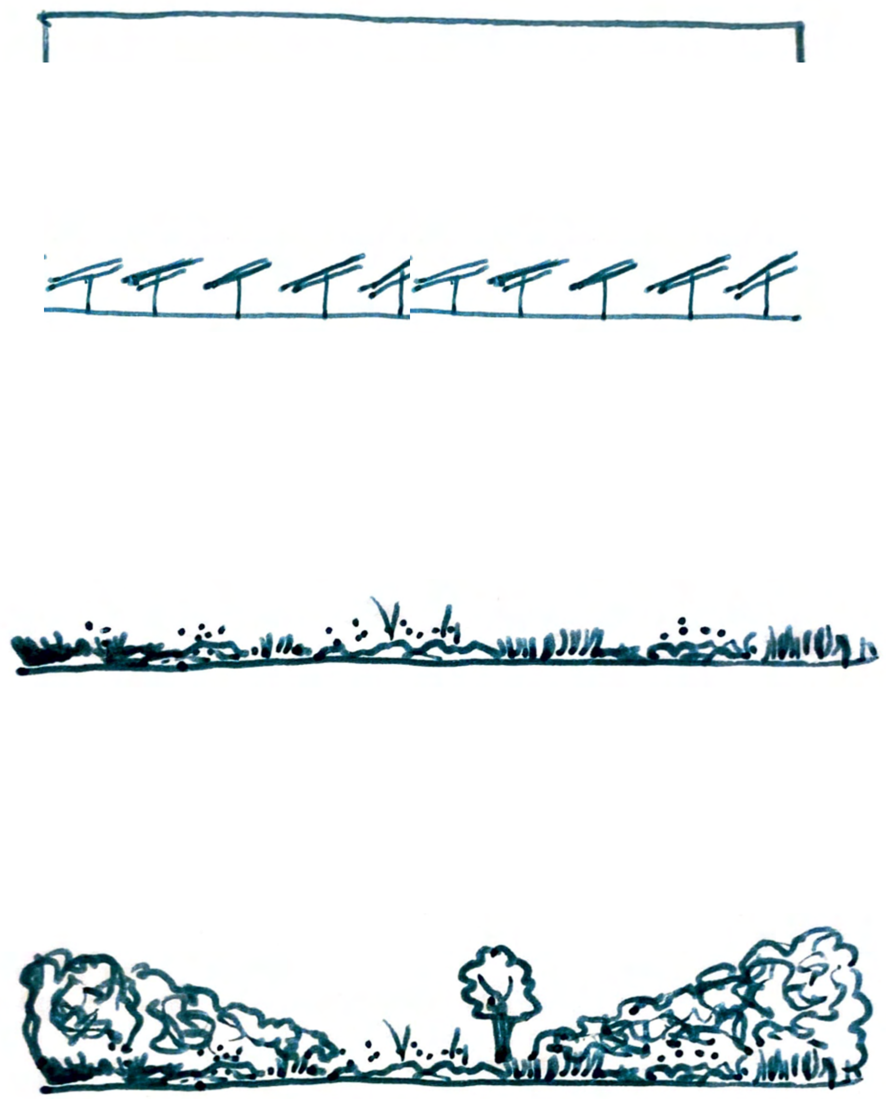


Figure 3.56 A. Map of Bjørvika with places for suggested interventions marked with stars.



Figures 3.58 A-D with sketched suggestions.

as is:
Grey roof without social, ecological or environmental function.

suggestion I:
Solar panels for environmental source function.

suggestion II:
Homogenous ground vegetation for environmental and ecological source function.

suggestion III:
Heterogenous vegetation in all layers for maximised ecological and environmental source function.

Source functions

The benefits of green roofs with heterogenous vegetation (both vegeation types and strucutres/layers) are ecological source function of providing resources like pollen, habitat, nesting-sites or stepping stone function to migratory birds. For the environmental system heterogenous vegetation in all layers increases the provision of ecosystem services like air filtering of particulate matter, flood risk mitigation, carbon sequestration and storage and cooling. Even though this type of vegetated roof is not facilitated for use of the social system these source functions in the natural system benefit the social system indirectly of improved microclimates and for instance increasing abundance of wildlife.

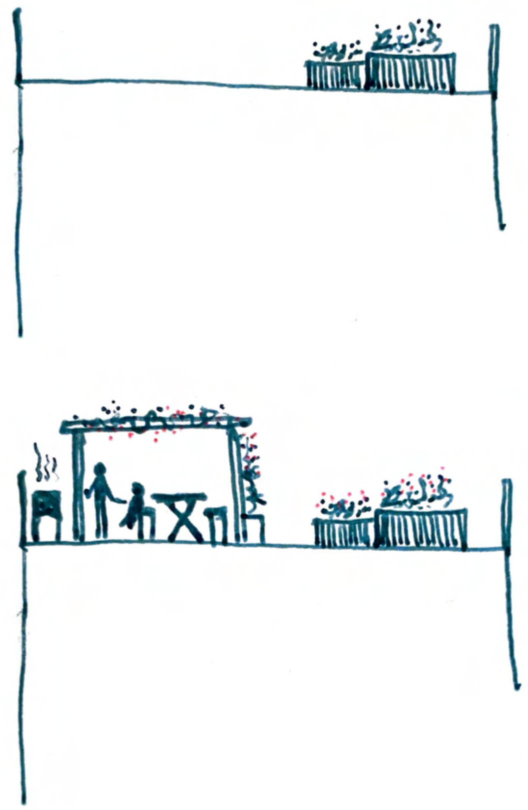
Source functions

Social priority
Where the social system is prioritized there will be a mixed-use and function by the social and ecological system of the roof. The environmental and ecological system will probably get a lower source function of a mixed-use roof than the social.

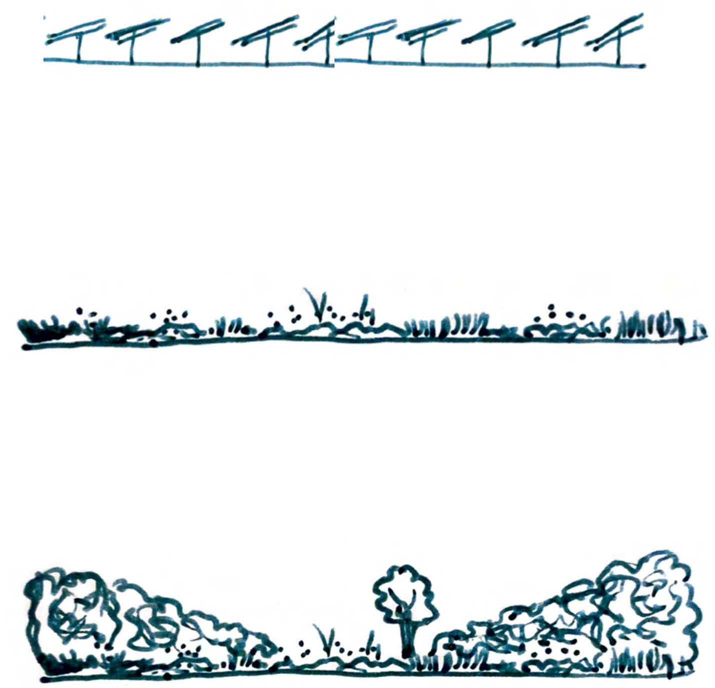
Environmental and ecological priority
Where the social system either is not prioritized or not possible to plan for the environmental system can be prioritized and provide green energy. By prioritizen for a mixed-use between the ecological and environmental system they would both be able to get a source function.

The social system would get a source function for those with access to the roof offering recreational possibilites like growing food, a place to host neighbourhood-community activities, barbecue or relaxing in green, semi-private environments away from the busy city life. A mixed use for the green system would provide resources, nesting-sites and habitat in addition to environmental source functions of urban cooling, air filtering and stormwater retention.

Social priority



Ecological and
environmental priority



Figures 3.57 B-C to the left and figure 3.58 B-D to the right with sketched suggestions.

Suggestions
green walls

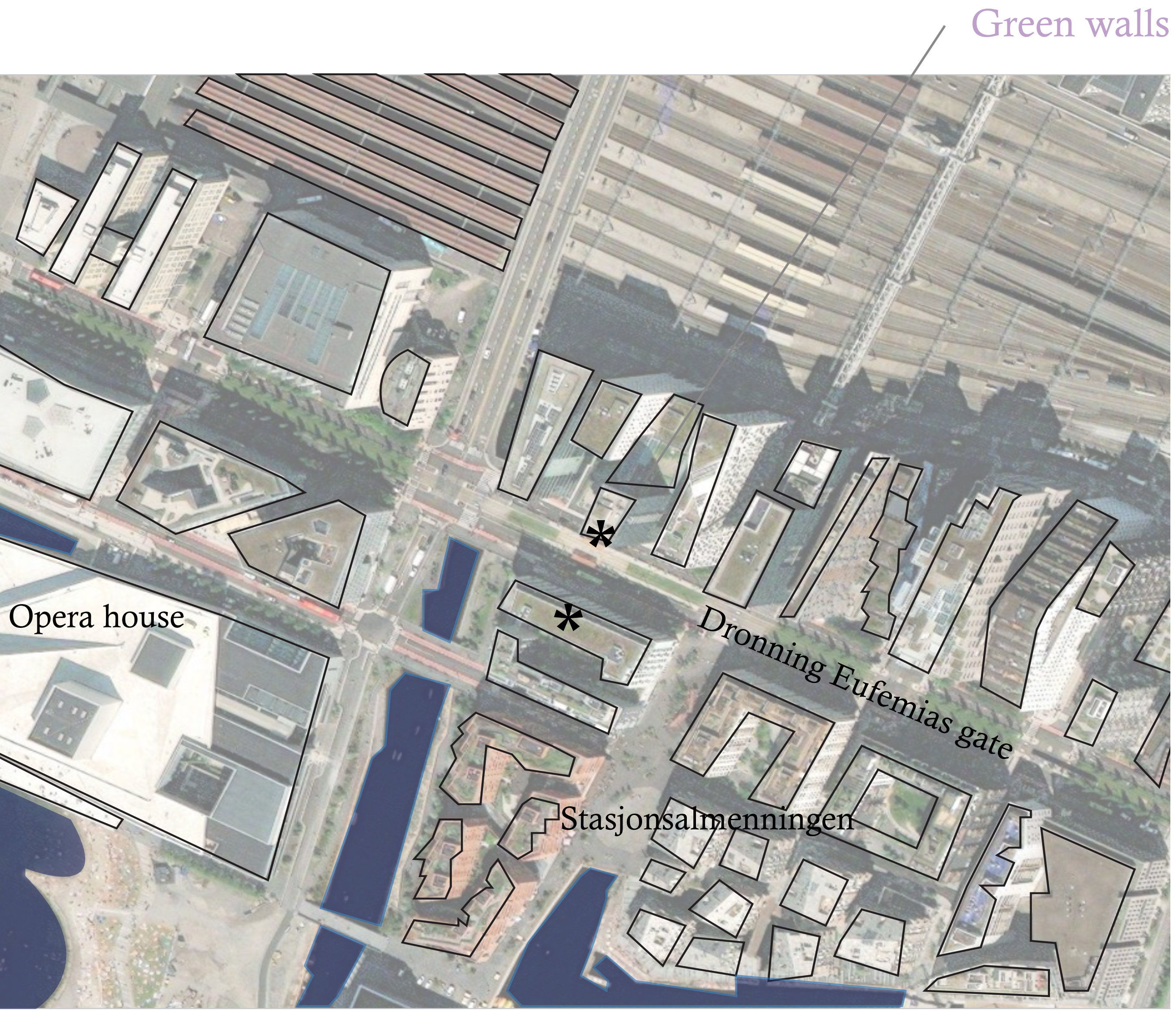
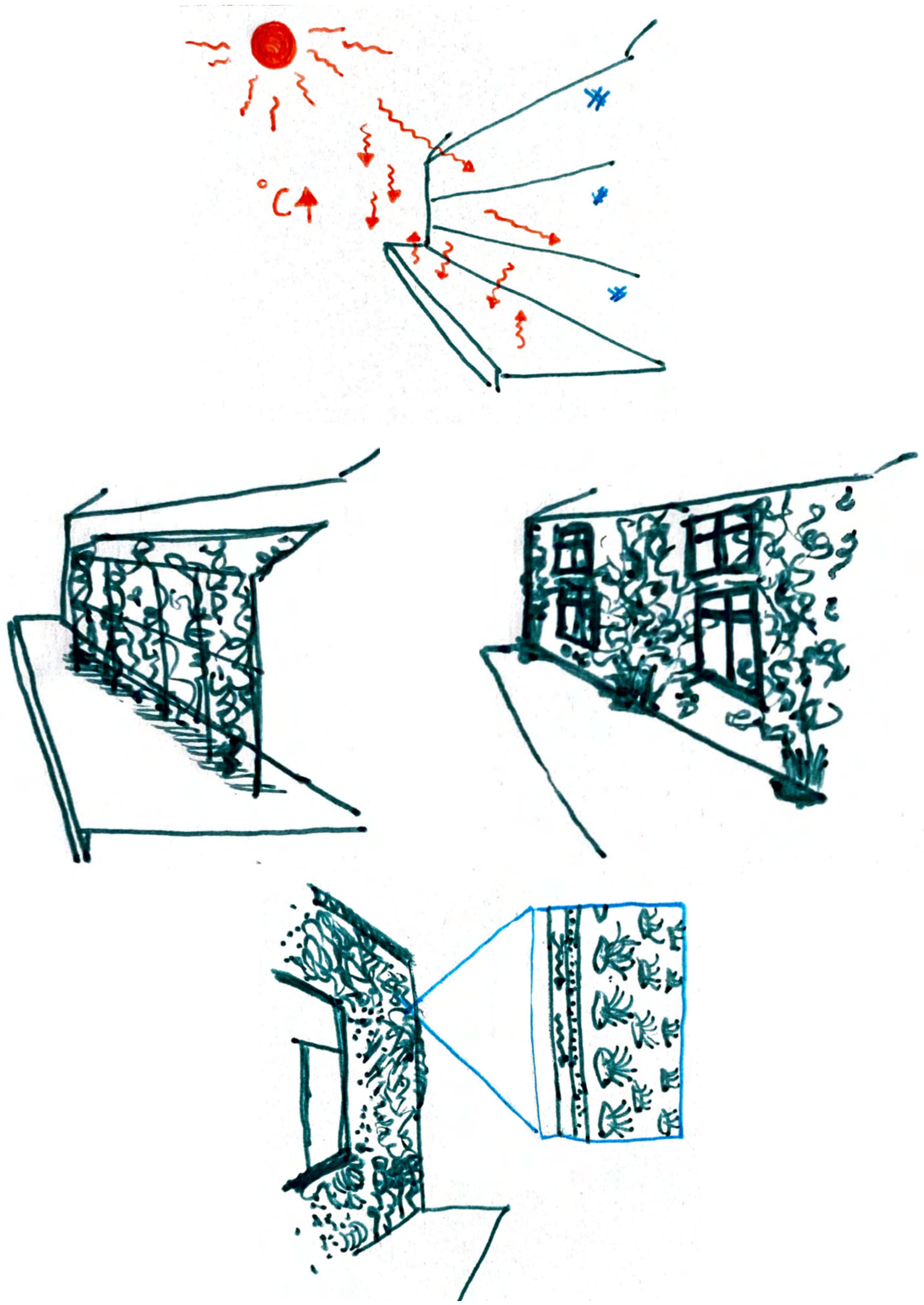


Figure 3.56 B. Map of Bjørvika with places for suggested interventions marked with stars.



as is:
Grey surfaces of glass, concrete, asphalt and similarly.

suggestion Ia:
To the left. External vegetation stands for creeper plants that cling to wires will provide source function to the social, environmental and to some extent ecological system.

suggestion Ib:
To the right. Climbing plants directly on walls with the same function. However climbing plants can destroy the wall with time and become a long-term sink.

suggestion II:
Panels with integrated substrate, plants and watering systems from the roofs. Stronger envrionmental and ecological function due to a bigger distribution of green.

Figures 3.59 A-D with sketched suggestions.

Source functions

The benefits of green walls for the social system are urban cooling of the streetscape and isolation of building interior, filtering of air and particulate matter with benefits to outdoor and indoor climate, aesthetic value and increased abundance of biodiveristy. For the ecological system the more heterogenous vegetation and seasonal value can increase the source function, as will the environmental source function. However for optimal growth, distribution and function the ground conditions are significant. With the integrated wall panels the possibilites to different types of vegetation arises, and mosses, sphagnum and other can be used in addition to more traditional plants. These can have a bigger seasonal value and therefore provide ecosystem services for a longer time-period. The bigger the distribution of green walls in Bjørvika is, the stronger source function they provide.

Suggestions
ground cover

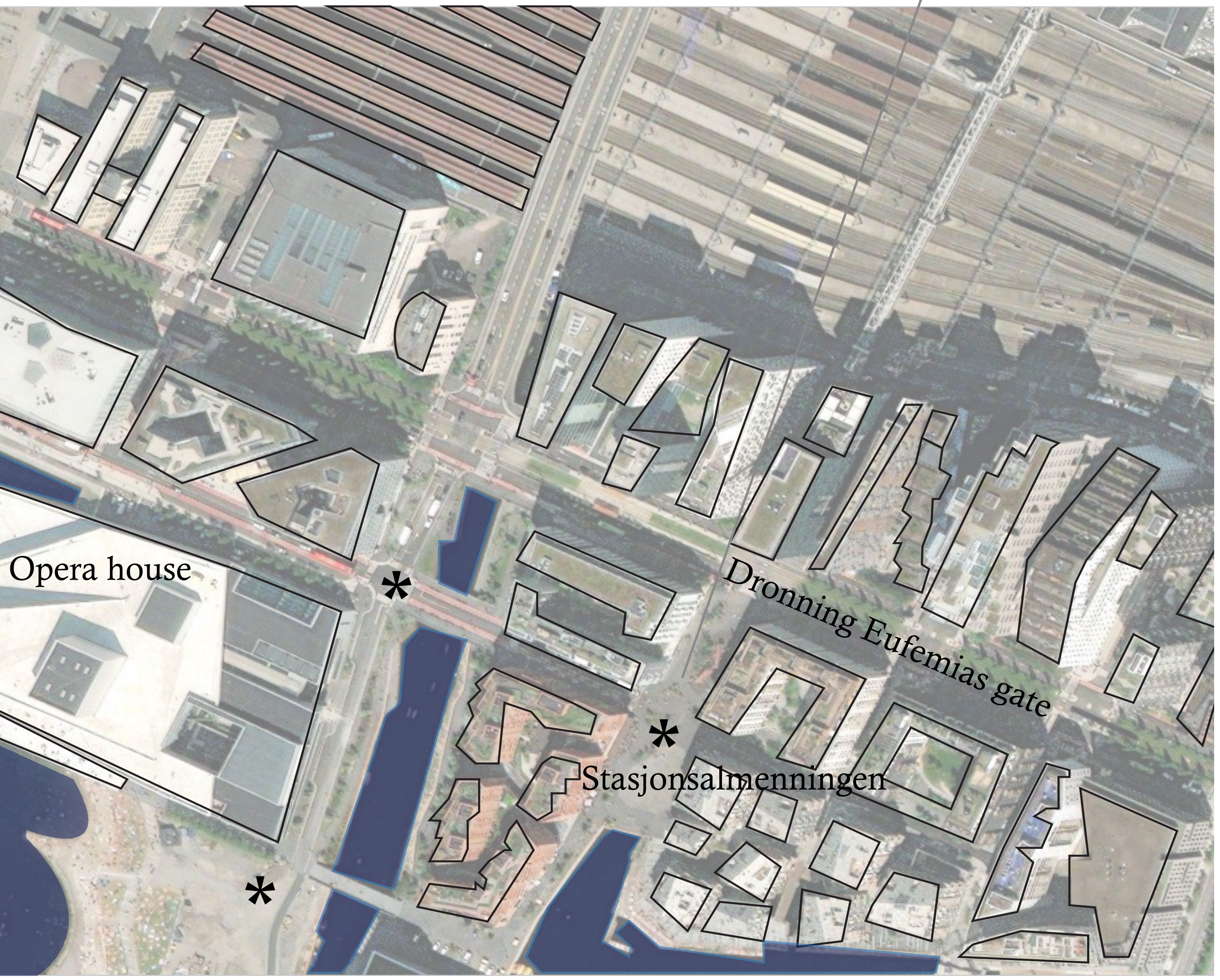
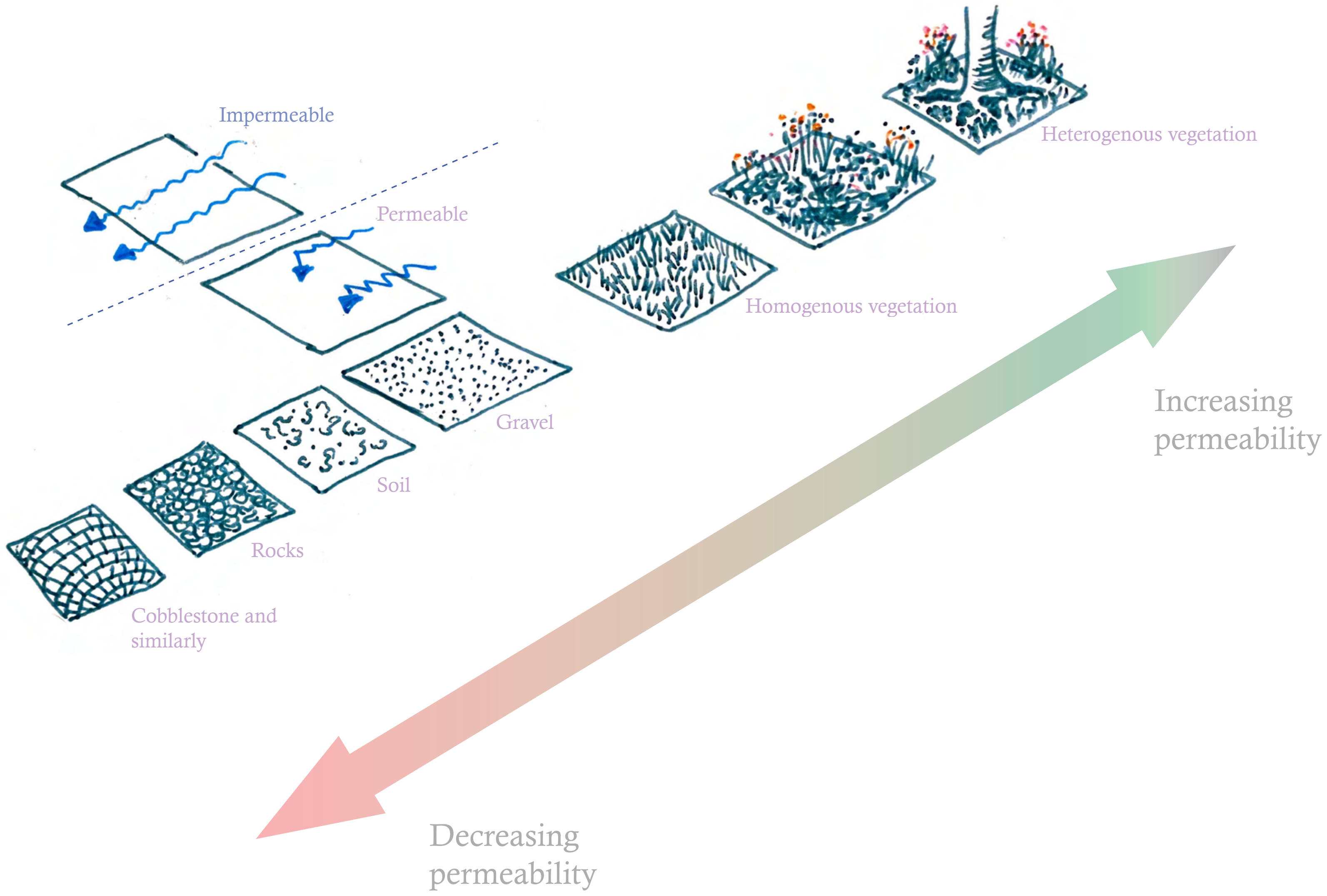


Figure 3.56 C. Map of Bjørvika with places for suggested interventions marked with stars.



Figures 3.60 with sketched suggestions.

Source functions

The ground cover determines the provision of desired and undesired ecosystem services like urban cooling and heating. The gradient shows the scaled functionality from vegetated permeable ground cover to un-vegetated. The gradient only shows the differences in permeability, but in addition a more heterogenous and vegetated ground cover will contribute to benefits to the social, ecological and environmental system except for stormwater management like noise buffering and air filtering. Increasing permeability automatically provides increasing provision of a number of ecosystem services like aesthetic value and biodiversity conservation. Breaking up the homogenous ground coverage of an urban matrix by patches, stepping stones or corridors of permeable and ultimately vegetated ground cover can increase the ground cover and site heterogeneity. Implementing permeable and vegetated ground cover could be done in places with less traffic like the squares and streets marked in the map as long as it does not hinder Univeral Design. Alterations could be to choose a smaller section of a street to provide Universal Design and a bigger section with heterogenous ground cover and vegetation like fragmentating a street with multiple functions.

Suggestions
human friendly streetscape

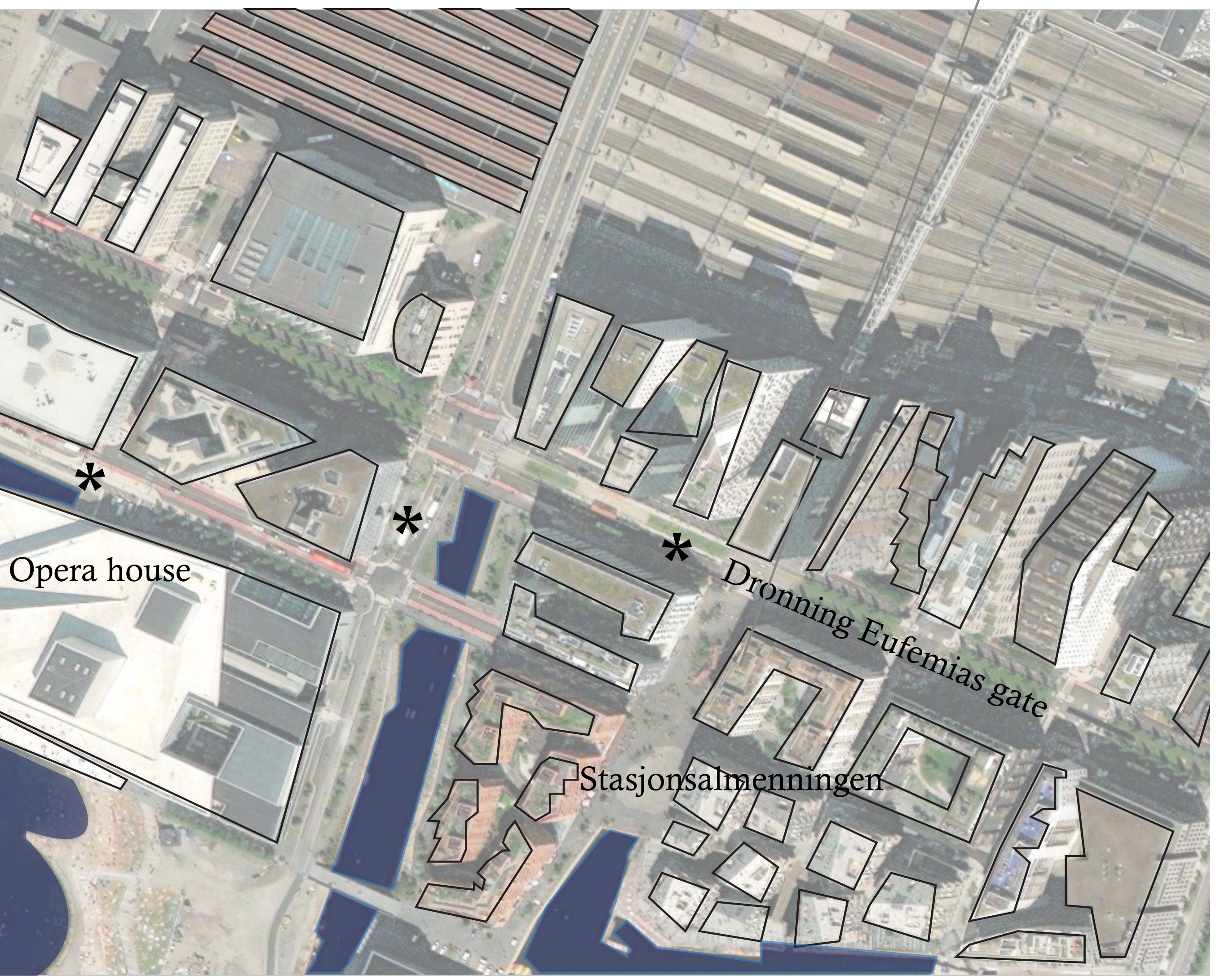
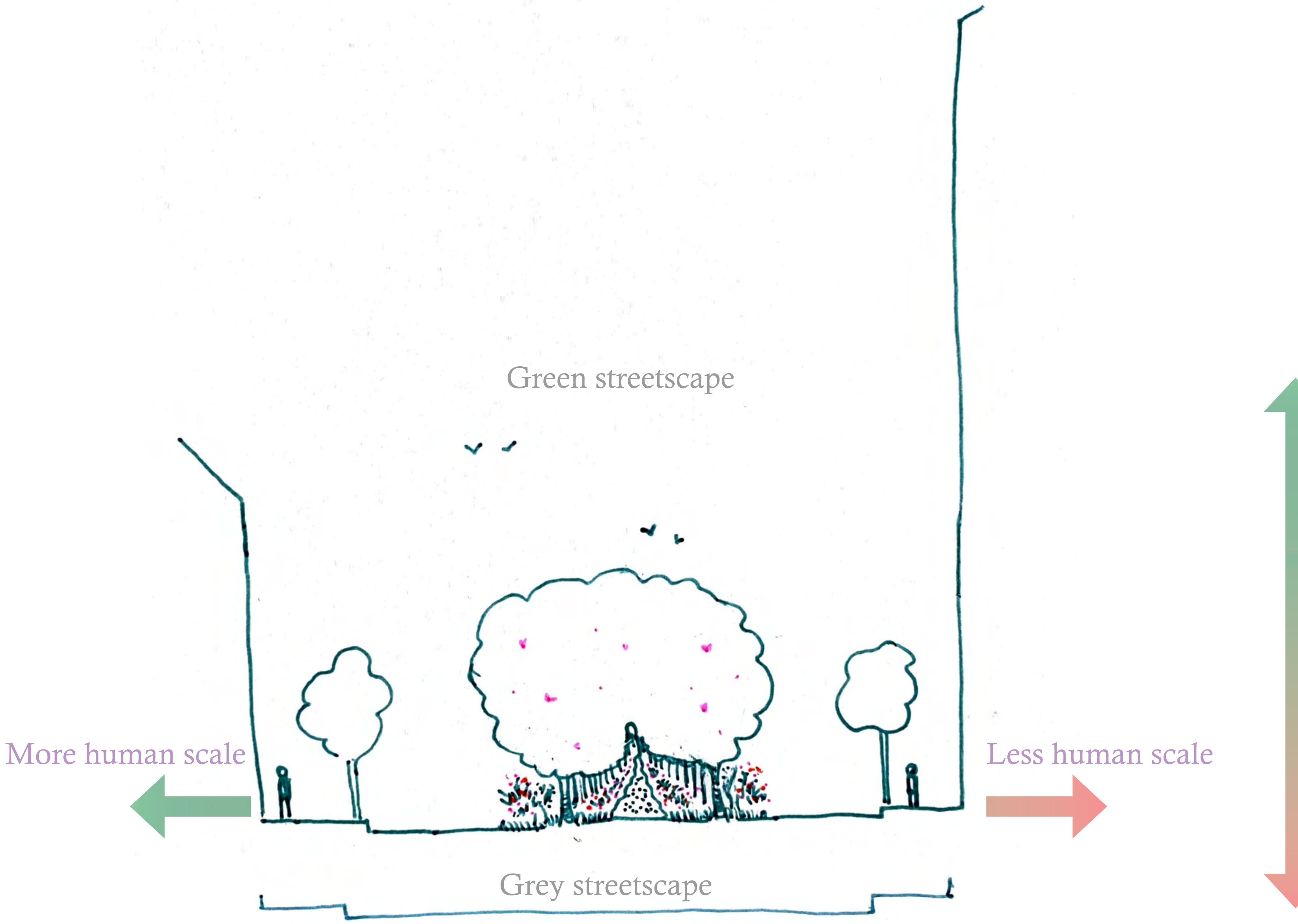


Figure 3.56 D. Map of Bjørvika with places for suggested interventions marked with stars.



Figures 3.61 with sketched suggestions.

Source functions

A more human scale of buildings and structures increases the human friendliness of sites that function as a source to the social system. A grey streetscape provides undesired ecosystem services of urban heating and increased flood risks while a green provides desired ecosystem services like aesthetic value, microclimate regulation, recreational paths and biodiversity supporting source functions. In Dronning Eufemias gate the middle section of the street is vegetated with lawn and some shrubs but this is where the tram goes. There is a great abundance of street trees on the sides, but if the green corridor in the middle would be more densely and heterogeneously vegetated it could have provided a great walking path with ecosystem services like aesthetic value, cooling, noise buffering, air filtering and pleasant room for a break. Moderations and alternatives could be implemented for several of the busier streetscapes

Suggestions
human friendly streetscape

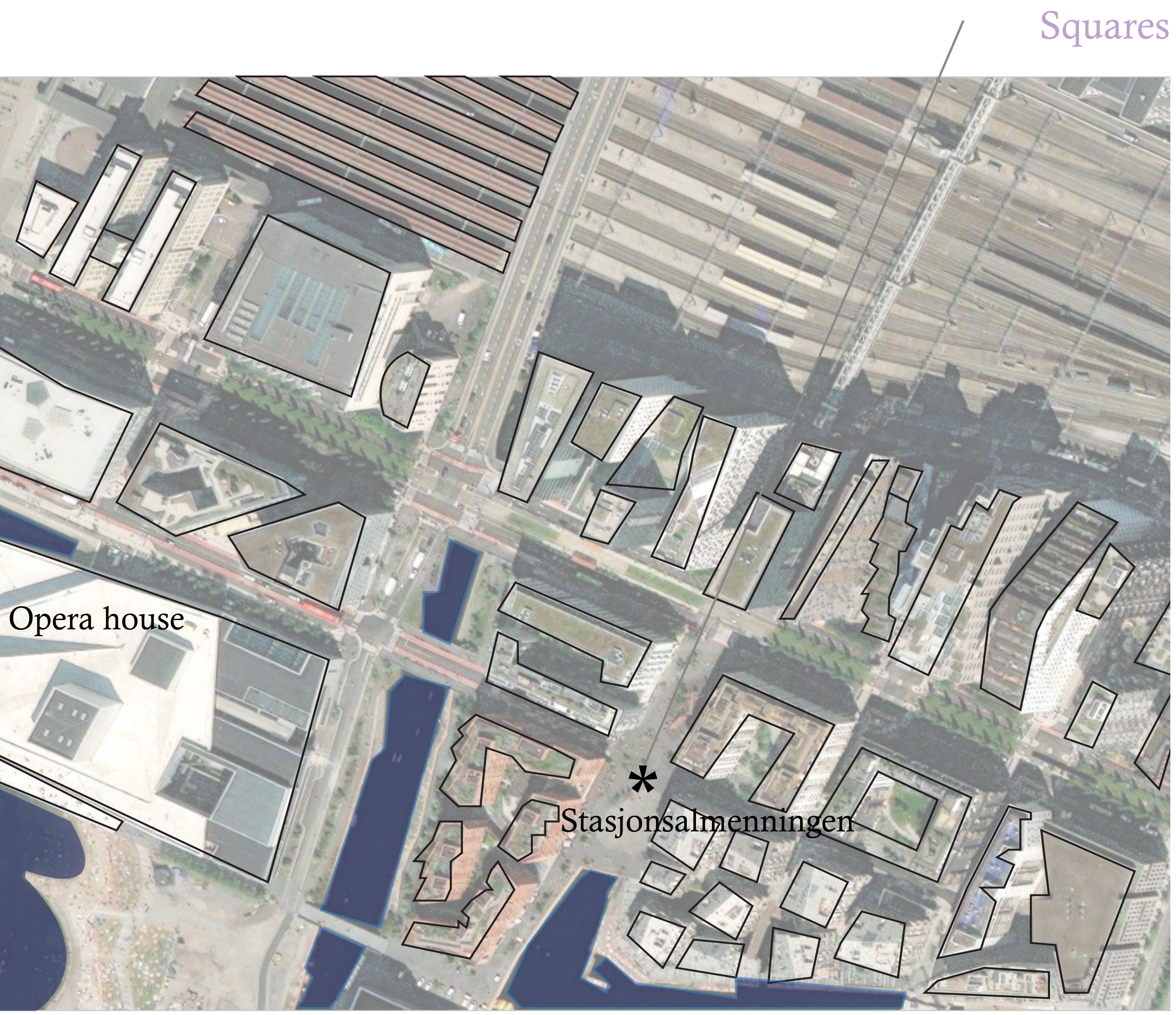
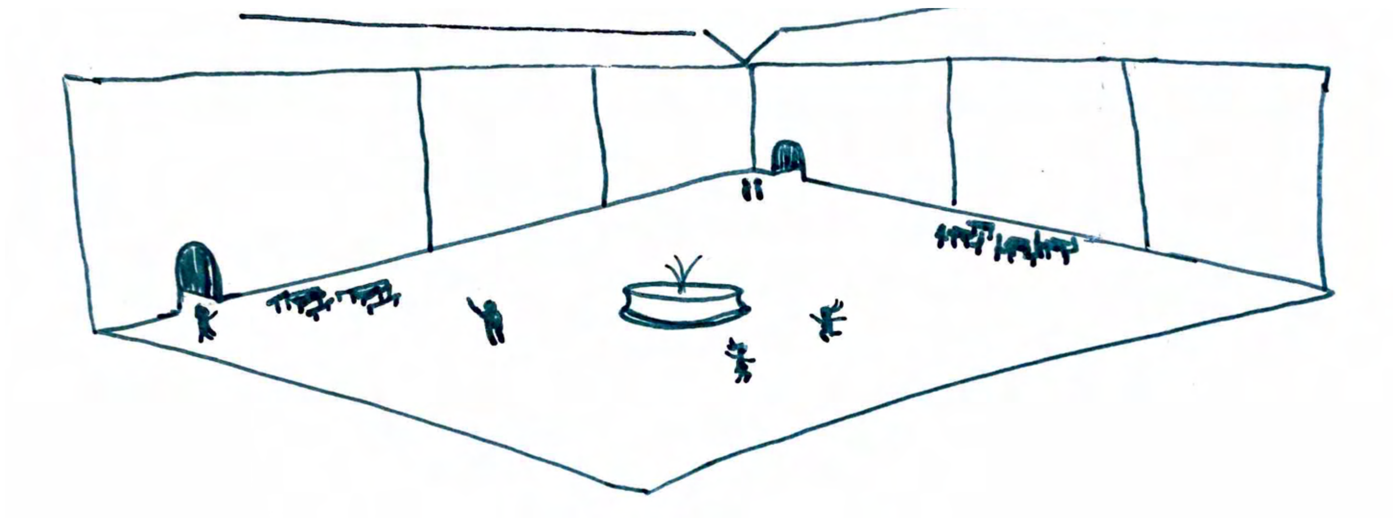
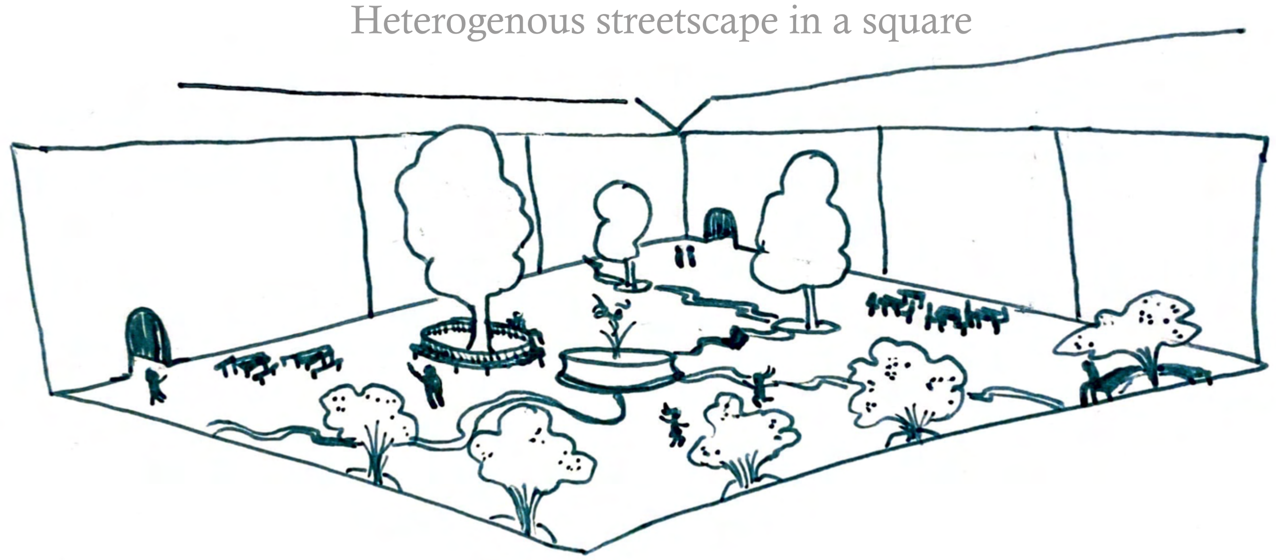


Figure 3.56 E. Map of Bjørvika with places for suggested interventions marked with stars.

Homogenous streetscape in a square



Heterogenous streetscape in a square



Figures 3.62 A-B with sketched suggestions.

Source functions

The more heterogenous streetscapes like in a square the more source function it can provide to the social system of adults, kids and elderly wih different needs and preferences for using a square. In addtion the mentioned effects of grey versus green surfaces are present and the ecological and environmental system would benefit equally from a more heterogenous streetscape design. For situations like Stasjonsalmenningen where there is no green coverage, considering different options to reduce freshwater waste with fountains and similarly should be considered to limit the sink function of the grey square. In addition a large grey square with only green edge can become unpleasantly warm during summer and more abundant tree-vegetation would provide more shade and possibly sustained use of the square. Vegetation would also slow stormwater runoff and mitigate flood risks.

Frogner
urban residential

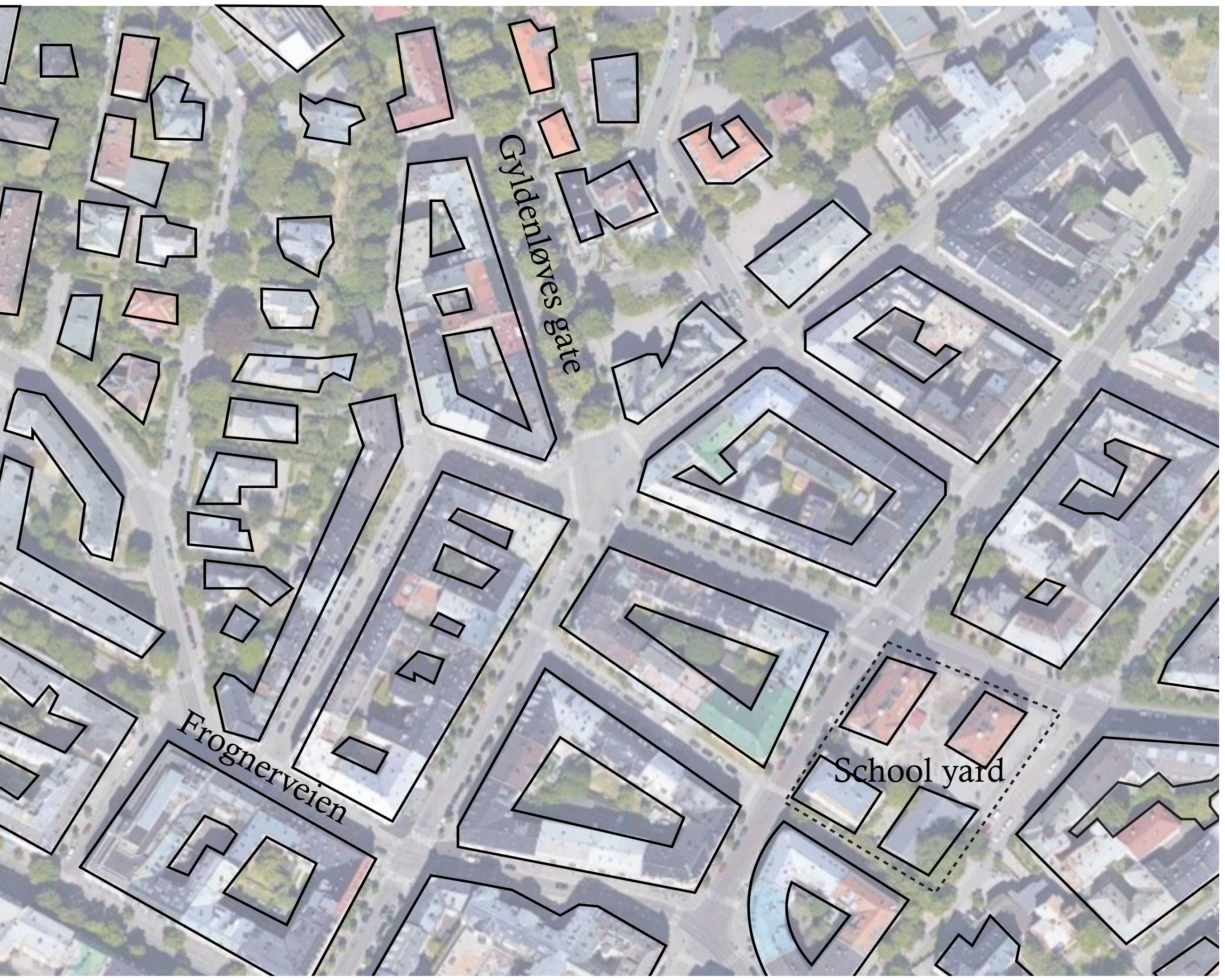


Figure 3.63. Map of Frogner with places for suggested interventions marked with stars.

ELEMENTS

Like in Bjørvika the elements are general and not site-specific so the suggested stars are examples of places where the solutions could be implemented. Additional suggestions for this site can be green roofs or facades, permeable ground cover and permeable fencing.

* Street trees

The distribution of street trees and the choices for tree species and structural heterogeneity are alternations found in Frogner. Some streets have street trees on the sides and an alley in the middle, like Gyldenløves gate. Other streets like Frognerveien dont have any while other have tree rows along the edges. The traffic in this area is less and slower in this area and the streets are wide. Even though the traffic is slower and less the grey sink functioning facades can benefit from source functions from street trees like urban cooling. Design alterations like density enhances the source function for all systems. Street trees enhance the streetscape and are publicly valuableas aesthetic value.

* Street tree ground cover

The ground cover of the street trees play a significant role both to the growth conditions and functioning of the trees, but also in other ways like permeability in ground cover, aesthetic value and ecological source function. Ground cover will be limited by street width and other factors but the more permeable and heterogenous vegetation there is the stronger the source function to all systems.

* Front gardens

In tune with street trees and their ground cover is the aspect of front gardens that are abundant in Frogner. The quality of the garden, i.e. the source or sink function they provide depends on their design. Heterogenous vegetation again maximizes the ecosystem services that serve as source function to all systems. These front gardens also play a role as publicly accessible aesthetic value that benefits not only the people living in the houses but the surrounding environment.

* Green backyards

Backyards are private greenspaces in an urban matrix but their quality and source function will increase with vegetation and heterogeneity in both vegetation and user function. The ecological system can be supported by less disturbed green areas but the limited accessibility only makes these green areas accessible to avian biodiversity. The social source function vegetation can have as identity marker or as a seasonal indicator for the people living in the building is great.

Suggestions
street trees

Street trees

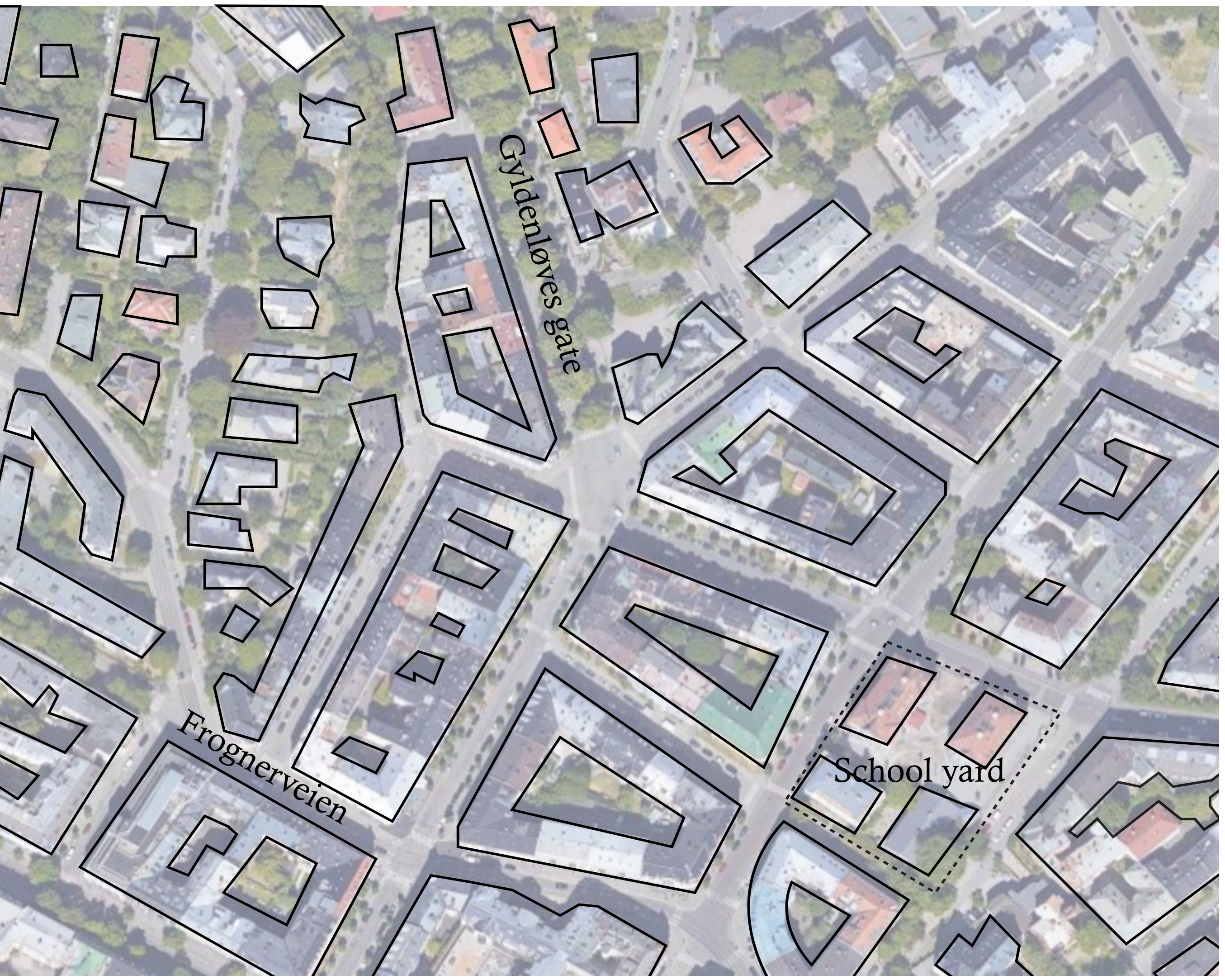
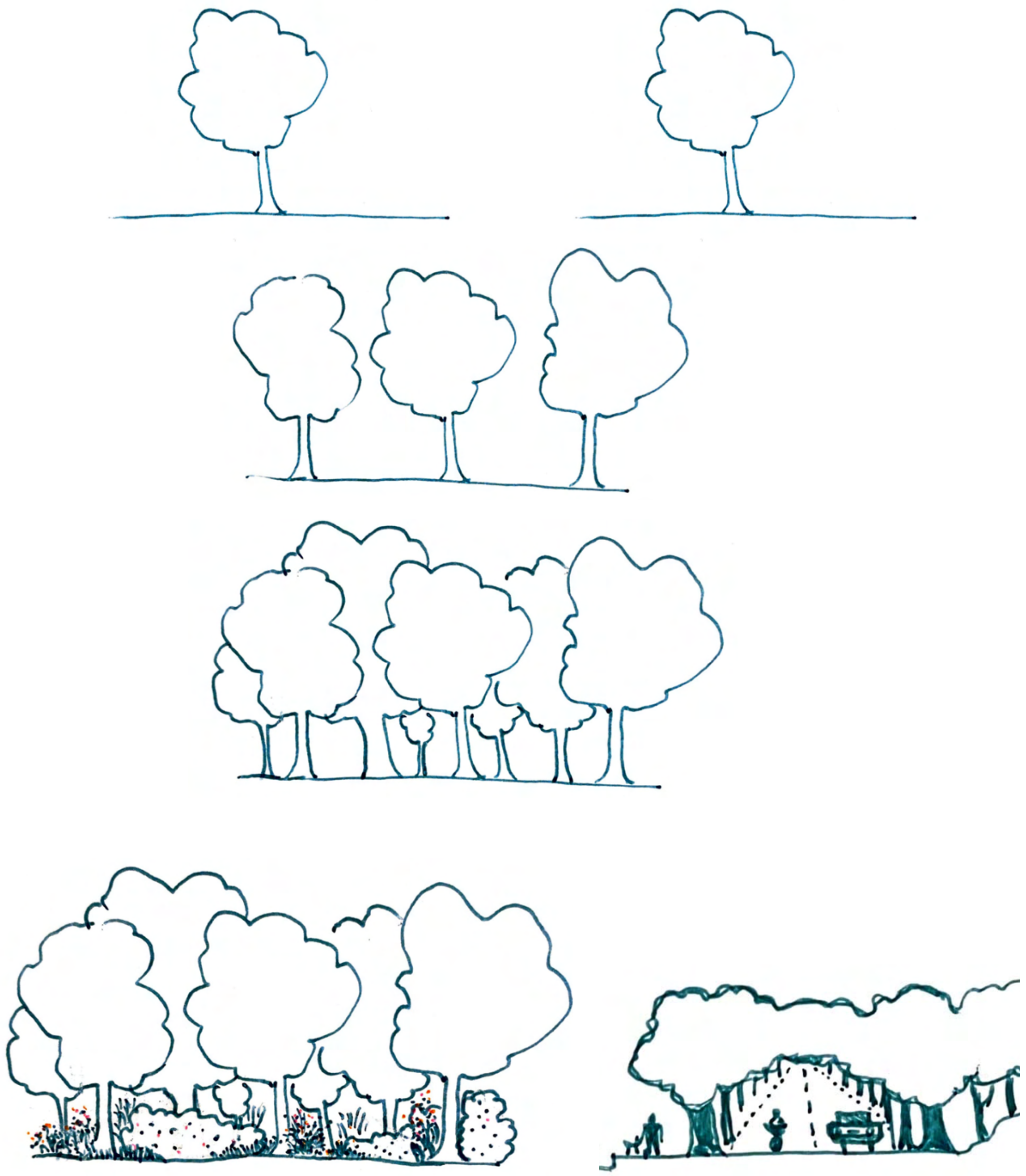


Figure 3.63 A. Map of Frogner with places for suggested interventions.



suggestion I
Sparsely distributed street trees.

suggestion II:
Densely distributed street trees that make tree rows. Increasing density increases the ecological source function as corridor and social source function.

suggestion III:
Wider belts of street trees or ”tree forests” with heterogeneity in species and structure. Increases the source function for all systems.

suggestion IV:
Wider belts with heterogeneous vegetation in all layers, (ground, understorey, shrub and canopy). Maximizes source function to all systems.

Figures 3.64 A-E with sketched suggestions.

Source functions

The more heterogenous and densely distributed street trees are the stronger the source function is to all systems. The social system will benefit from services like noise buffering, aesthetic value, urban cooling and shading, limited insight due to vegetation from the streets and abundance of biodiverse species like birds or insects. The ecological source function will increase with density as the street trees can function as corridors or stepping stones with increasing resources and habtitat possibility. The envrionmental source function increases and more ecosystem services can be expected with a denser vegetation of the streets. Planting trees along trafficated roads is particularly good for microclimatic regualation (e.g. air filtering and noise buffering) that indirectly benefits the social system. Where there are street trees already one could discover the possibilities to increase the vegetation density, and where there are no street trees like in Frognerveien the alternatives show different options.

Suggestions

street tree ground cover

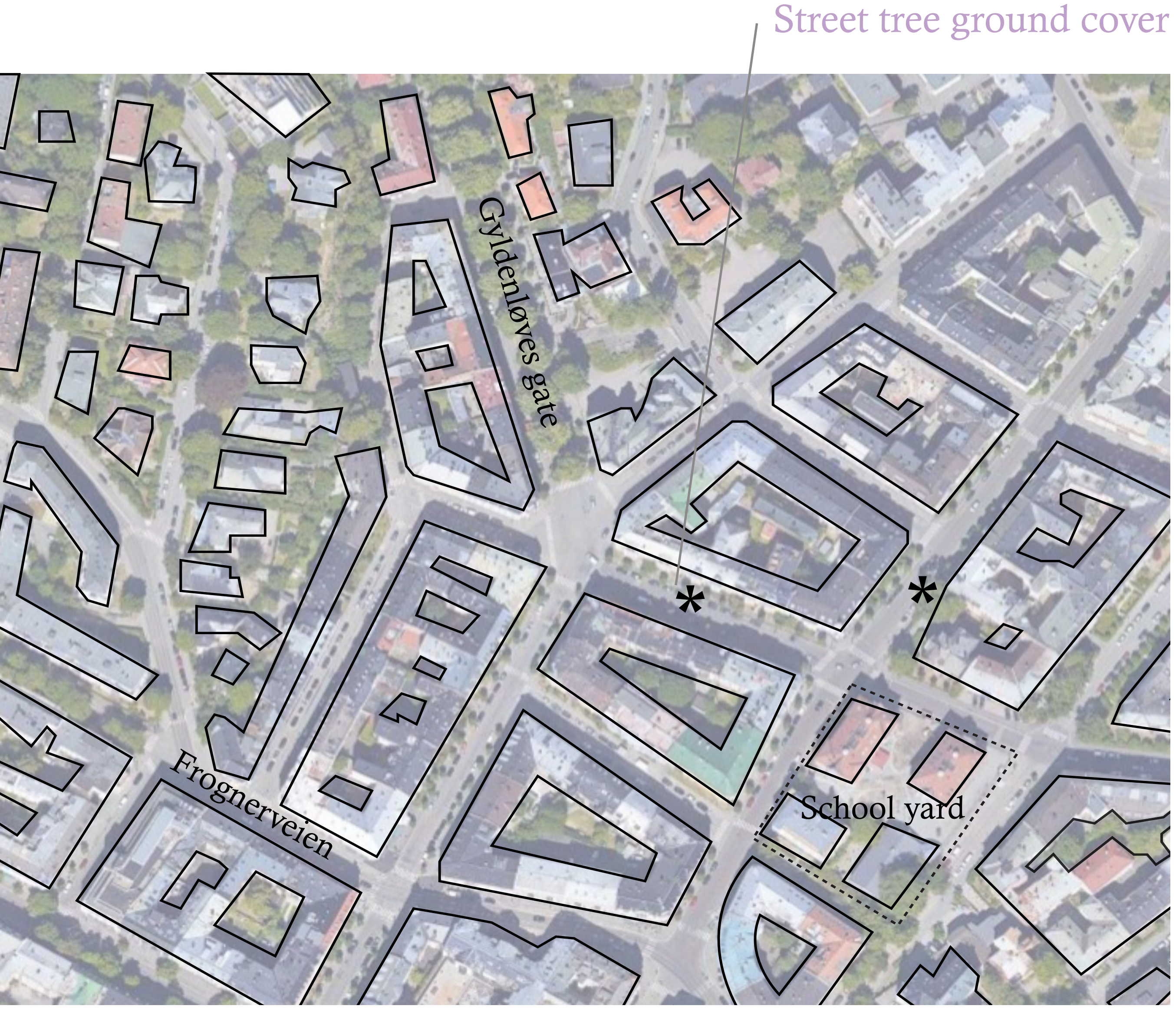
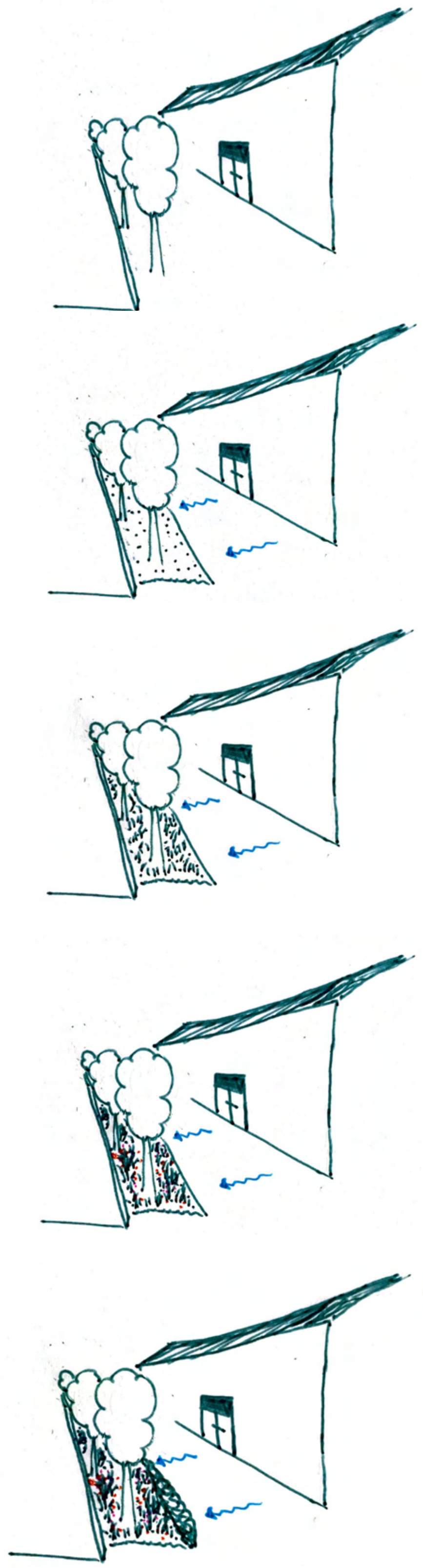


Figure 3.63 B. Map of Frogner with places for suggested interventions marked with stars.



Figures 3.65 A-E with sketched suggestions.

suggestion I:
Street trees staight on impermeable ground cover.

suggestion II:
Street trees on permeable ground cover of open soil.

suggestion III:
Street trees on permeable ground cover of ground vegetation.

suggestion IV:
Street trees on permeable ground cover of ground- and herbaceous vegetation.

suggestion V:
Street trees on permeable ground cover of heterogenous vegetation in all layers.

Source functions

The more vegetated and heterogenous vegetation in the ground cover the more source function the street trees get for all systems. More aesthetic value, more seasonal variation, possibilities for foraging if chosing fruit- or berry trees or shrubs, more noise buffering, air filtering and cooling that benefits the social system. The ecoligial system benefits from heterogenous vegetation with multiple resources and nesting sites in addition to humus and compost that will improve the soil and microbial activity. The heterogenous ground cover of trees with vegetation in all layers can also reduce the disturbance load for the plantings if a shrub is put as an edge towards the pavements. This could also be done towards the street to limit the disturbance load from pollutants to the interior of the planting. By making ”edges” to prevent disturbance the habtiat potential of these platnings increases and benefits the ecological system. The alternatives require more or less space in the streets/pavements and could for instance be implemented in Colbjørnsens gate or Skovveien.

Suggestions
front gardens

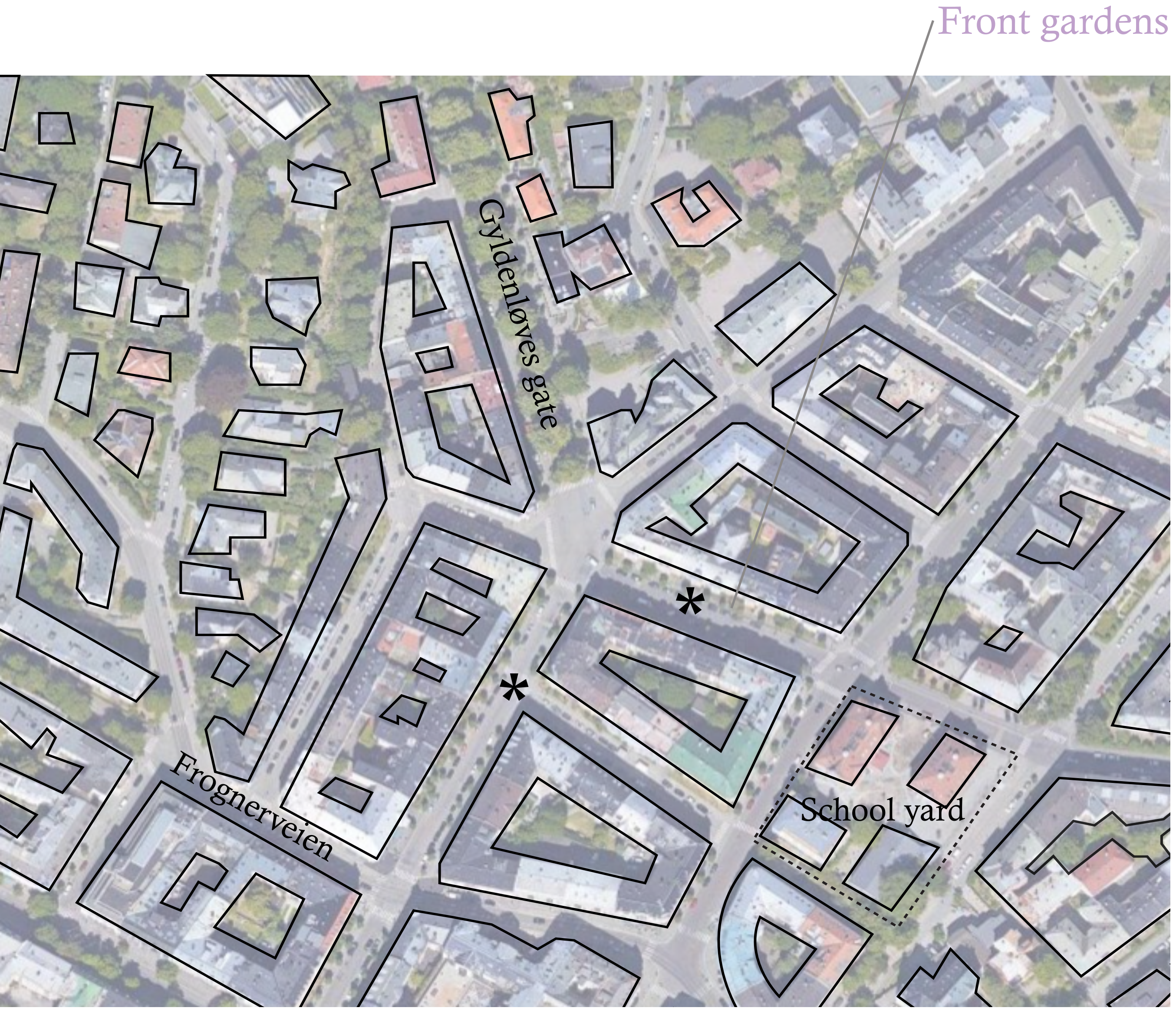
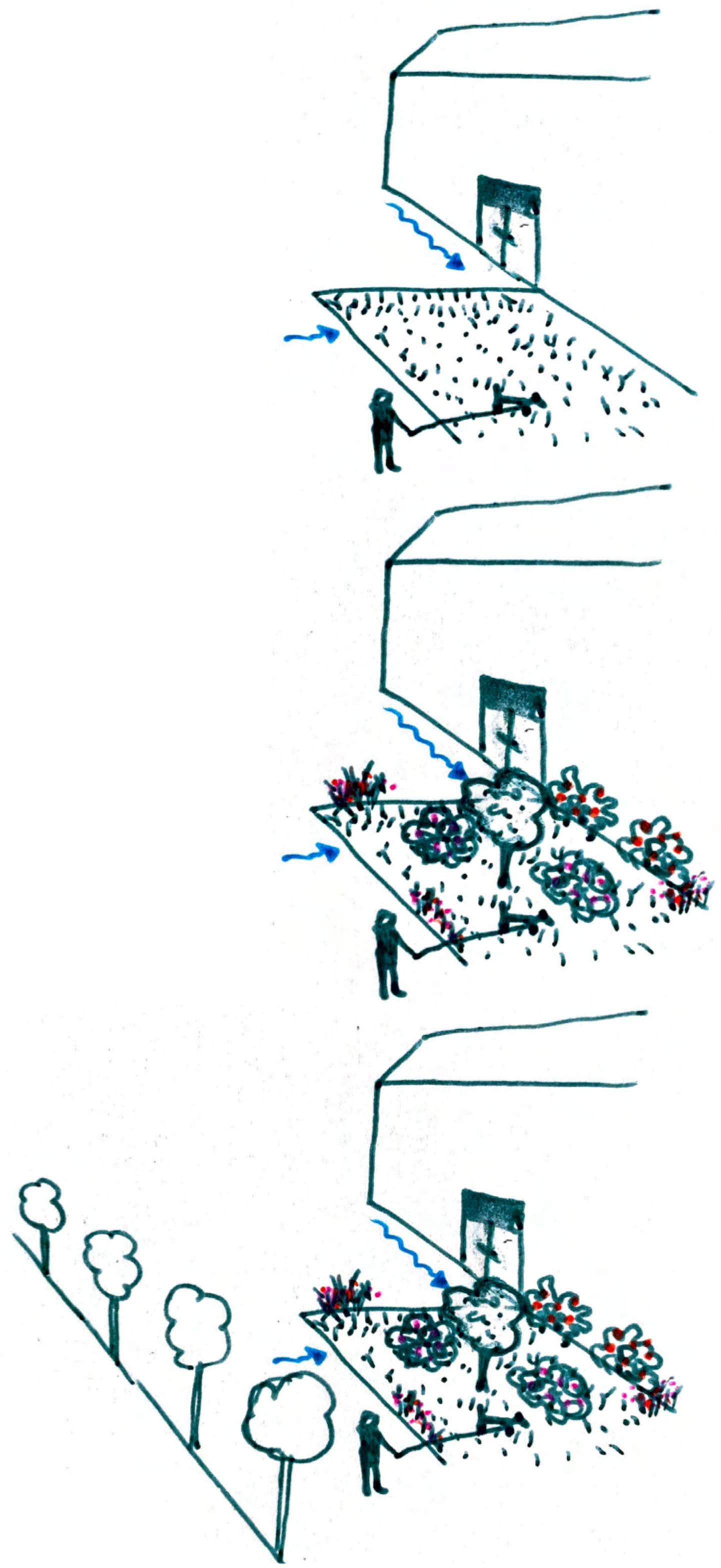


Figure 3.63 C. Map of Frogner with places for suggested interventions.



Figures 3.66 A-C with sketched suggestions.

suggestion I:
Permeable front garden of homogenous ground cover.

suggestion II:
Front garden with heterogeno-us vegetation in all layers.

suggestion III:
Front garden with heterogeno-us vegetation in all layers and street strees.

Source functions

The more heterogenous the front gardens are the more source function they provide to all systems. Aesthetic value for the public in the streets and for the residents inside the buildings facing the gardens, foraging possibilities with fruit- and berry vegetation, they provde places to watch the streetlife. The ecological source function increases with heterogenous vegetation but these green patches will have a high disutrbance load of pets if no fences are present. The environmental source function increases with the abundance and distibution of heterogenous green with direct and indirect benefits to the social system.

Suggestions
green backyards

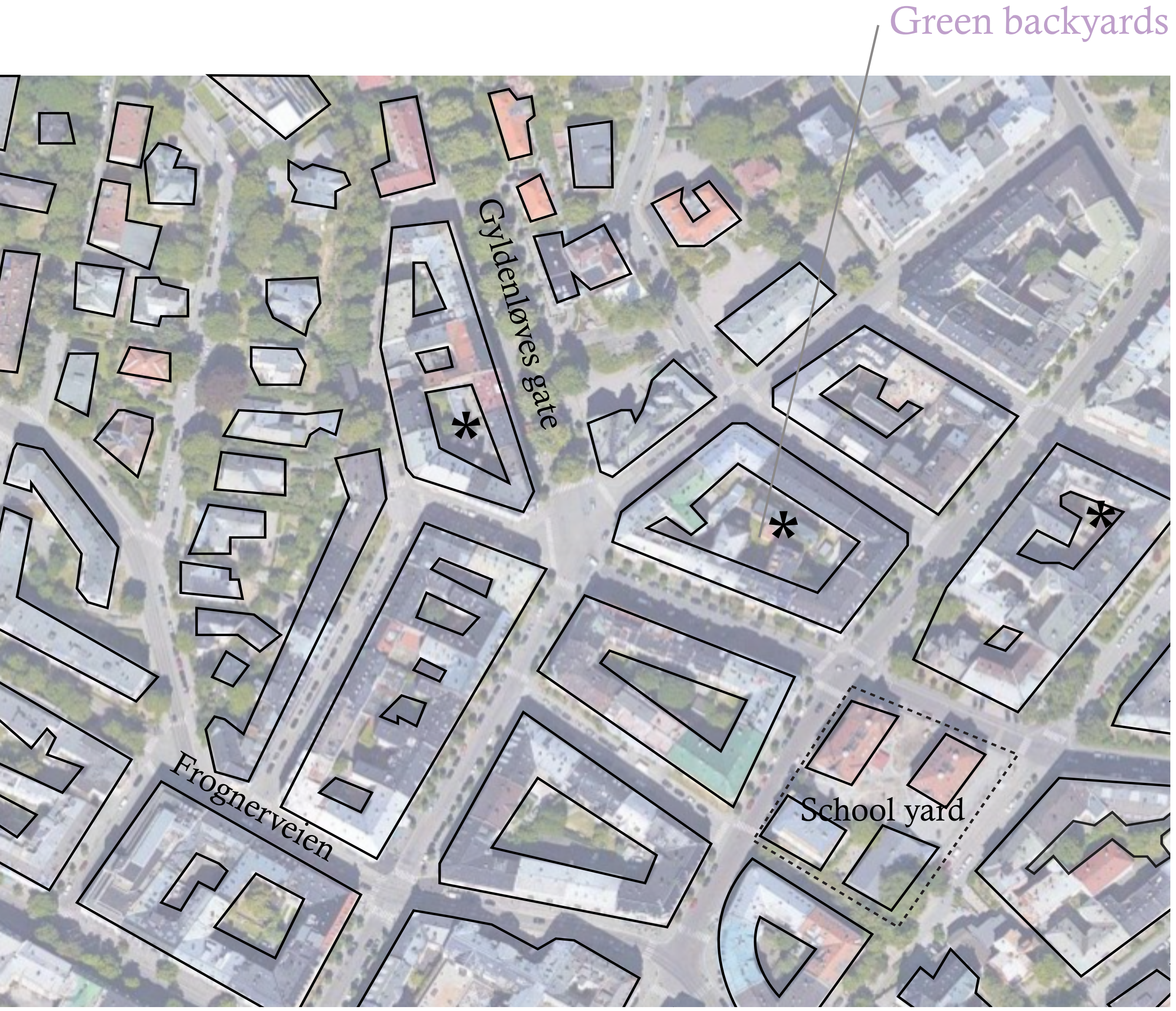
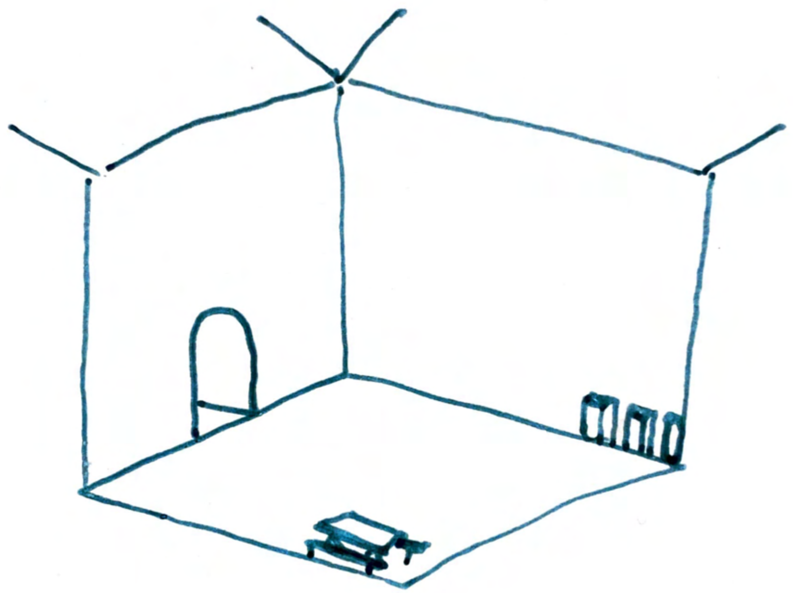


Figure 3.63 D. Map of Frogner with places for suggested interventions.

Homogenous, grey backyard



Heterogenous, green backyard

Figures 3.67 A-B with sketched suggestions.

Source functions

The more heterogenous the backyards are for different user groups and considering vegetation the greater the aesthetic value will be for the social system. In an ubran matrix the abundance of green is almost always lower than in a rural matrix so one should aim at maximizing the green potential for places that allow it. Backyards can provide a semi-private outdoor room safe for kids play and without too many distrubances. Making these rooms green increases their source function to the ecological and environmental system that will benefit the social system directly and indirectly. Cooling, air filtering, shade, biodiversity and nesting sites are some of the source functions green backyards can provide. In addition vegetation can become identity markers for places and become valuable to the residents.

A reflection after suggested improvements
variability

Figure 3.68. Photo from Voss, Norway of a novel ecosystem in the foreground with a natural ecosystem in the background. These ecosystems will have different source and sink functions to the present ecosystem health, and differetn elements will have different functions, both depending on the context and system.

Context dependence

Tylianakis et al. (2008) emphasized that the biodiversity impact on ecosystem functioning was given the contextual environment and setting. Different research outcomes are often explained by the attribution of context dependence (Catford et al., 2022). Context dependence refers to situations where the conditions and context impacts the relationships studied and when the strength or direction of a relationship differs under contextual differences (Catford et al., 2022). Palmer & Febria (2012) and Rapport et al. (1999) stressed context dependency within ecosystem dynamics and ecosystem health as stress responses are individual, with a contextual nature. It depends what the context is (e.g. forest or agricultural matrix), it depends what the ecosystem is (e.g. urban or natural) , it depends what species one invests (e.g. humans or pollinators), what system one works for (e.g. social or ecological) and what outcome one desires (e.g. increased connectivity or decreased disturbance). Elements or landscapes that are considered to have source functions in a novel ecosystem might be considered to have sink functions in a natural ecosystem.

System dependence

This system dependence is important to consider in planning as different elements and landscape metrics can have different effects to the natural and social system. As Forman (2008) emphasized one should aim at combining benefits to the natural and social system. The ultimate goal should be to find solutions that don't compromise on any of them, in other words, that benefit all three systems: the ecological, social and environmental. In some
typologies the social system might be given priority due to the context, and in other the ecological system might. These dependencies are important to recognise.

The photo to the lef, figure 3.68, depicts contrasting ecosystems with contrasting sources and sinks to the ecosystem health.

Even though the tree-groups in IKEA functioned as stepping stones and therefore sources to that site, their source function to the ecosystem health might be weaker than the stepping stones' function in Bjørvika. The graded source and sink functions tried to illustrate the strength of the elements function. The source might also function differently to the social than to the ecological system. When seing the wide range of source- and sink functioning elements in the different sites it is evident that there is potential in improving the ecosystem health in the specific context by different and multiple means. This was the idea for demonstrating multiple "better" alternatives.

There is a constant weighing that should be done to the present sub-systems within the ecosystem that make the total ecosystem health. Solutions will always give trade-offs to some systems and gains to other as with the example of outdoor lighting that is beneficial for the social system of providing safety but that can have negative effects for the natural system. The ultimate goal however, should be to find solutions that don't compromise on any of the systems and that can be beneficial to the ecological, social and environmental system simultaneously. For some scenarios the social system might be prioritizes while other might prioritize the ecological.

In addition, there are dynamics between elements, organisms and functions in the site-scale
that are hard to detect in maps. In Frogner front gardens were categorized as sources despite the different source-quality different design can have. Equally in Korsvoll with the different garden patches that can function as sources and sinks depending on the gardens. This will be further discussed in the discussion.

Relatives

Adding the scale dependency addressed within landscape ecological theory (Wiens & Milne, 1989; Dramstad et al., 1996; Forman, 2008; Newman et al., 2019) to the discoveries from the suggestions three types of relativity can be addressed.

Scale relativity

There is a constant relativity between scale in landscape ecology for different landscape metrics and their ecological function as explained with the ant and the bird (Wiens & Milne, 1989; Rapport et al., 1999). addd Photo/drawing.

Same scale but different context

There is a relativity between functions in different contexts, i.e. what functions as a source in the rural industrial ecosystem might not have the same function in another ecosystem like the rural residential (e.g. the stepping stones in the parking lot in IKEA might not function as sources in Korsvoll that both has a higher abundance of green, and compositional and configurational heterogeneity of the green structures present). The function is relative to the context – the existing ecosystem qualities, metrics, structures and dynamics (Wiens & Milne, 1989; Palmer & Febria, 2012).

Same scale and context but different systems

There is also a relativity between the systems of the ecosystem in the same scale and context. What functions as a source for the social system, like a green corridor with recreational properties for people might function as a sink to wildlife due to the disturbances it creates, or an evergreen hedgerow as a noise-buffering fence might function as a source to the social system but a sink to biodiversity as the vegetation types does not provide pollen to pollinating insects. To deal with this relativity it is imperial to consider the trade-offs of different solutions, if modifications are possible to ensure a win-win to both systems or if one of the systems should be prioritized.

IV Discussion

Presenting the discussion, final thoughts and suggestions for future research.

4.1 Discussion

The aim of this thesis was to explore what potential an ecosystem health approach has for landscape architects to achieve sustainable land-use development? To answer this, the three sub-questions were answered and landscape ecology was tested as a method to achieve healthy ecosystems.

1. **What is ecosystem health?**
2. **Why is ecosystem health relevant for a (sustainable land-use) development?**
3. **How can landscape architects create healthy ecosystems?**

What is ecosystem health?

By combining a set of theories like system theory, system thinking, Earth System Science, ecological systems theory a new understanding of ecosystem health and ecosystems appeared as something that weaved together environmental, social and ecological sustainability. This new understanding set the premises for the rest of the thesis as it presented a new way of seeing and relating to the environment and planet around us coming together as one system. By understanding the ecosystem as a set of sub-systems in which everything in society works together, maybe a holistic view on society could be developed that in turn could make sustainability easier to achieve. As landscape architects are dealing

Sub-systems and levels

By applying the ideas of system thinking, ecological systems theory for influences on the individual health as a set of factors from multiple levels to ecosystems, one could break down the understanding of ecosystem to similar sub-system levels. Using Formans (2008) 'hierarchy theory' for relatively isolated levels in a landscape hierarchy of three scales led to an understanding of sub-systems with constant up- and downstream effects and interactions that together make up the health of the total ecosystem. That said, there is more to an ecosystem, but these sub-systems were the ones I found most relevant to the work of landscape architects. As defined by Gillson and Willis (2004) ecosystems are unique in time and space and occur where there is an interaction between organisms and their environments. A tree in a round-about is just as much an ecosystem as the garden surrounding your house or the balcony outside your apartment. A forest is just as much an ecosystem as a city, or a neighbourhood with more grey than green elements. Ecosystems contain both natural and artificial elements, but what emerged was that the desired characteristics within ecosystems were surprisingly similar for the social and natural system.

How to achieve healthy ecosystems?

The seemingly similar desired and undesired characteristics of an ecosystem was explored with landscape ecological theory and principles that are mainly used to study the relation between landscape structures and organisms using them, and the influence landscape patterns can have on species survival, population growth, wildlife conservation etc. What became evident was that many of the same functions were desired and undesired in equal terms of both the ecological and social system. What the ecological systems need to thrive (i.e. more supporting functions - more sources than sinks) did not conflict with the social system, on the contrary they were in tune with each other. In addition, the bigger the green distribution was (that supports the ecological and social system) the more support would be given to the environmental system. Landscape ecological theory and principles as a tool for improving the livelihoods, or ecosystems of both humans and wildlife proved to hold much potential. People thrive in heterogenous landscapes, with green views, with a higher abundance of green than grey – much like biodiversity.

My personal opinion is that too few projects actually consider the whole of these three sub-systems within the ecosystem, and way too often the natural system has to give way to the social system. Existing vegetation is rarely included in new designs, extensive changes are planned to sites with little consideration to what exists or to the solutions that would benefit the social and natural system simultaneously. What I wanted to test with these four case studies was both to determine the functioning of typical elements in outdoor rooms in relation to ecosystem health but also to see if it would be possible to identify a correlation between the benefits between different systems. My hope was that this system could prove that it is possible, and even beneficial to plan for the whole ecosystem rather than one of its sub-systems.

Sinks and sources

Sinks and sources are two landscape ecological concepts that are typically used to identify what hinders or limits population growth (i.e. sinks) or promotes and enables population growth (i.e. sources). I wanted to test how elements in the outdoor room function as sources and sinks to the ecosystem health and tried to develop a system for grading elements based on their function to the social and natural system of ecological and environmental sub-systems. I selected typically occurring elements in a built landscape and presented their source or sink function to the three sub-systems. The function was determined based on literature (Appendix 1) on the effects different elements have for the sub-systems and their functioning (e.g. light pollution on the ecological system).

To deal with the variances within elements' function as strong or weak sources or sinks I further developed a gradient with criteria for achieving the different scores. This scoring was based on literature, empirical data and a personal evaluation of elements function as a landscape architect. To test if this graded scoring could work in practice, I tested applying the system to four case study sites. For each site, I tried to map the functions of sources and sinks within the three scales of ecosystems, the macro, meso and micro scale according to Forman's landscape hierarchy. The reasoning for choosing these four sites were a) they are land-uses widely distributed across Norway, b) these land-uses are found around in the world as a result of growing populations, urbanisation and urban sprawl, and finally c) these industrial and residential sites are typical projects for landscape architects.

Spatial overlaps and prioritization

Inspired by Ian McHarg's layering of maps and spatial overlays, a prioritization could be made for where to make improvements for the different sub-systems, or for the overall ecosystem. In other words, the resulting analyses could imply where the highest potential for a positive outcome was(common sinks for all systems), where it was the most urgent (strong sinks) and where even simple improvements could make things better (from weak to strong sources).

The benefit of identifying sources and sinks for each of the three systems was that it resulted in a clear picture of the state of the sub-system given the present elements. It also enabled a clearer understanding of the site, the main challenges and what worked well, as well as the options for prioritizations of interventions based on given project objectives (e.g. increased biodiversity or sustained use by multiple user groups). The potential within this system to provide a set of prioritizations was a positive surprise and proves the potential within landscape ecological theory as a tool towards an objective like ecosystem health. To aid an evaluation of what system to prioritize, it however became clear that additional thematic maps like of native species, threatened species, air quality, social services, cultural history or special land-uses could be beneficial.

Landscape ecology as a tool

One positive finding was that landscape ecological theory proved to be applicable and effective as a tool for landscape architects and planners aiming for achieving healthy ecosystems in the strive towards sustainable land-use development for the future. Desired and undesired functions, like barriers or corridors were surprisingly often the same for different systems. The same was true for sources and sinks, many of the sink- or source-scoring elements were the same for the different systems (however not all as addressed within "system dependence").

In addition, improvements for one system often proved to have positive effects on the other systems as well, e.g. more abundance of green to improve the public health would also benefit the ecological and environmental system. Almost all improvements to the natural system, for example more heterogenous vegetation, would be assessed as a change that would positively affect the social system for example improved aesthetic value. For the social system however, certain elements e.g. outdoor lighting to improve the feeling of safety could have negative effects on the natural system. This made it clear that when prioritizing the social system, caution must be given to the effects it can have to the natural system. By using the score system developed combined with mapping of sinks and sources, it became apparent where elements scored differently. Such results could then suggest where further assessments would be needed to ensure desired effects.

Missing out details

The approach and gradient developed worked in terms of mapping overall landscape structures and identifying what in the site hindered or promoted ecosystem health for all sub-systems. However, it became evident that mapping can lead to a lack of detail, for instance dependent on what is known as the smallest mappable unit or based on the categorisation applied. In these case studies, certain elements and details were undetectable in maps and were therefore not included in the assessment of source and sink dynamics. Typical examples of details that are undetectable in mapping are maintenance regimes or species choice for plantings or quality of green structure.

When mapping a green area as a source important details like the condition of the element, the quality, the longevity, age and other significant details about the quality and function are left out. These missing details can be significant for the function in multiple sub-systems.

A front garden like in Frogner can either be a heterogenous green patch with compositional and configurational heterogeneity, full of source qualities to the ecosystem, or it can contain a simple, tired, homogenous lawn with a much lower source quality. When mapping green structures, it is hard to detect these differences and therefore their score might not be complete or correct. Figures 4.1 A-C shows three front gardens along the same street with different qualtiies.

The aspect of longevity or sustainability for green elements is also important, as the growth conditions are vital to the function and quality of the element. For instance, a row of street-trees can be planted directly on the pavement without any soil, vegetation in the ground cover and with little root-volume. Their contribution then, will be limited compared to street-trees that are planted in vegetated belts with much root-volume and limited disturbances. Similarly, age of vegetation also plays a role for its functioning. An old tree, in general contributes to more ecosystem services than a newly planted tree.

Figure 4.1 A - showing a front garden of herbaceous ground cover vegetation and some bigger shrubs behind a fence.

Figure 4.1 B - showing a front garden of permeable ground cover vegetation (lawn) and some shrubs.

Figure 4.1 C - showing a front garden of herbaceous ground cover vegetation together with mulitple shrubs. This front garden was the most heterogenous (with both compositional and configurational heterogeneity).

Adding a level
A danger of mapping the gradients as is done here, is that the source function might seem indifferent. By adding another, site-scale level where the case study sites were analysed on a more detailed level, more elements would appear, and additional improvements could be suggested. Examples are growth conditions for green structures like choices of soil or non-native/native species, shade and light conditions, planting design that require minimum management efforts, social interactions, user groups and user needs for a place. These elements are hard to trace in a map and would typically require field work, which was not possible for this thesis.

In addition, the number of elements to assess with such a mapping gradient is nearly unlimited, one could for instance add in materials that could enable more or less desired effects, provide habitat to species, study innovations to avoid undesired effects like bird collisions with glass facades, the use of innovative fences that don't hinder flow of energy and so on. Somewhere I had to draw a line for the thesis scope to be manageable.

Scoring sheet, gradient and criteria
The elements and criteria chosen in this first development phase and testing are limited and there is a bundle of additional aspects that could be added like statistics for traffic, air pollution, proximity to urban green, safe or walkable access and other present conditions that could impact the prioritization for improvements. The criteria could be further developed to be adapted to special conditions, like where the abundance of summer and spring droughts are increasing as currently seen in Spain this spring (Elster & Aasen, 2023). Conditions that require specialised species or even considering environmental impacts of different solutions like energy or water demand could also be added in a similar system. In Barcelona, there is an ongoing "naturalisation" programme where they use weeds as understory vegetation due to their limited water- and maintenance requirements (The International Association of Horticultural Producers, n.d.). There is a number of elements to assess, for this thesis a selection was made and the criteria used for this thesis were simplified to test the utilization potential.

Subjectivity
Even though I went from a table of elements' function as sources and sinks to a gradient with criteria to balance out these variances a lot still depends on the interpreter or user of the system and his/her personal evaluations. Also, the comparative evaluation of the different systems will be subjective, unless the aims are clear and explicit. Otherwise, an ecologist would probably argue differently than a sociologist. As literature can support either prioritization, in the end it becomes a question of sub-system prioritizing. In addition, some of the social values of ecosystem services are objectives of preference like aesthetic value; some prefer homogenous garden designs while other prefer messy gardens. This relativity is hard to avoid with gradients when there is no method for measuring quality.

Measuring quality
Another challenge of mapping source-sink quality of elements, is that there is no existing method for measuring the quality of an outdoor room in relation to objectives. There are topic maps that can identify different environmental factors like light pollution, air pollution, green abundance etc. but there are no known methods for measuring how good or bad an element function in an outdoor room, or function relative to its original intention, neither for the social nor natural system. Life-cycle assessments are on the rise as tools to measure the in- and output demands of e.g. materials, shipping or the carbon sequestration of vegetation. However, a joint assessment for the ecological, environmental and social system is not existing as far as I know, and therefore these types of scoring systems will always have a degree of subjectivity to them. To counter this, using adequate and updated literature on the effects of elements is a required pre-condition to ensure empirical evidence for the criteria within the gradients.

Suggested interventions
The suggestions for how to improve the source-sink dynamics of the sites are also presented in a graded order from as-is to better or even best, i.e. strong source. Grading the better suggestions is also a relative matter. What is better and best will always be a result of relativity, to what system one prioritizes and to what function is intended. In addition, there will always be contrasts between different ecosystems, for example an urban ecosystem with a strong source function will probably struggle to ever achieve the same source function as a natural ecosystem like a forest. That is a relativity one has to keep in mind when using this mapping system. However, there are a range of examples where ecosystems that today are considered natural have been sustainably managed or modified by humans to function as they do today (Gillson & Willis, 2004). Therefore, I believe in the value of the social systems working together with and for the natural system and I hope that my developed system might be a tool to achieve this.

Why ecosystem health for a sustainable land-use development?

Healthy versus unhealthy ecosystems
The approach of this thesis is the idea that healthy ecosystems is a key to a sustainable development of our societies. The world is faced with multiple challenges of climate change, nature crises and increasing public health challenges, i.e. unhealthy ecosystems. In this situation, the global society is working to find good and applicable solutions, limit the negative consequences and find ways to transform our systems to make them more sustainable. Landscape architects are no exception and people, nature and the environment are issues that need to be dealt with within all projects.

What are the benefits of healthy ecosystems? Nature regulates global and local climates, and the state of nature is key to maintaining ecosystem functioning and biodiversity. Ecosystem services providing large benefits to human societies are the results of complex interactions between healthy ecosystems and the environment. Unhealthy ecosystems hinder or are deprived from this functioning and the trajectory we are presently on can limit the chances of ecosystem service provision from numerous ecosystems.

Ecosystem services
It is important to emphasize that ecosystem services are just as vital for the natural system itself, and that a continued provision only can be expected if they are sustainable for the systems providing them. If the natural system provides ecosystem services at the expense of the system itself, it cannot be considered sustainable, as Rapport (1995) stressed long before the concept was widely established. This is also a reason why that is mentioned as a criterion within the source-sink gradient.

I chose to use ecosystem services for the criteria of the gradient due to their recognised status as valuable for societies world-wide. There are of course many other benefits of healthy ecosystems that I could have mentioned, but ecosystem services function to highlight the benefits in a way that people are familiar with. The foundation of this thinking is that by planning with healthy ecosystems as the main objective, it can benefit and sustain the human society and the natural systems on Earth.

The risk that comes with using ecosystem services as the "product" of healthy ecosystems is that it can reinforce the anthropocentric view on ecosystems and nature as a subject to support human societies. With the system thinking of ecosystems, I have tried to address that the social system is just one of many sub-systems that all work together and interact. The output from the social system to the natural system has to be just as rewarding to the natural system as the output from the natural system is for the social system.

4.2 Final thoughts

Redistributing used land

According to Coresight Research (2018) 25 % of the malls in America will probably shut down within the next three to five years (Thomas, 2020). Norway has the densest concentration of shopping malls relative to the number of inhabitants in the world, with 572 malls on 5.4 million inhabitants (Statistisk sentralbyrå, 2022b; Stugu, 2015). Looking at the land occupied by these malls, 382 out of them occupy more than 2500 square meters (Stugu, 2015). In comparison, “Slottsparken” in Oslo (the park surrounding the castle) covers an area of 2250 square meters (Oslo byleksikon, n.d.). The trend of land-use change can be expected also in Norway and should urge some sort of redistribution of used land. In my perspective, that makes for another reason to study this type of land-use and see the potential these sites hold to serve a new purpose or achieve an improved function to multiple sub-systems of the ecosystem.

Temporary landscape interventions

There is an increasing abundance of temporary land-use changes around the world like parking day or seasonal redistributions of streets to serve a social source function (Jolma Architects, 2021). The latter happened during the summer of 2022 in Oslo in Grønland where a street was turned into a “city life street” of temporary plantings, trees, benches, outdoor seating for restaurants and upheaval of traffic for the time being (Bykuben, n.d.).

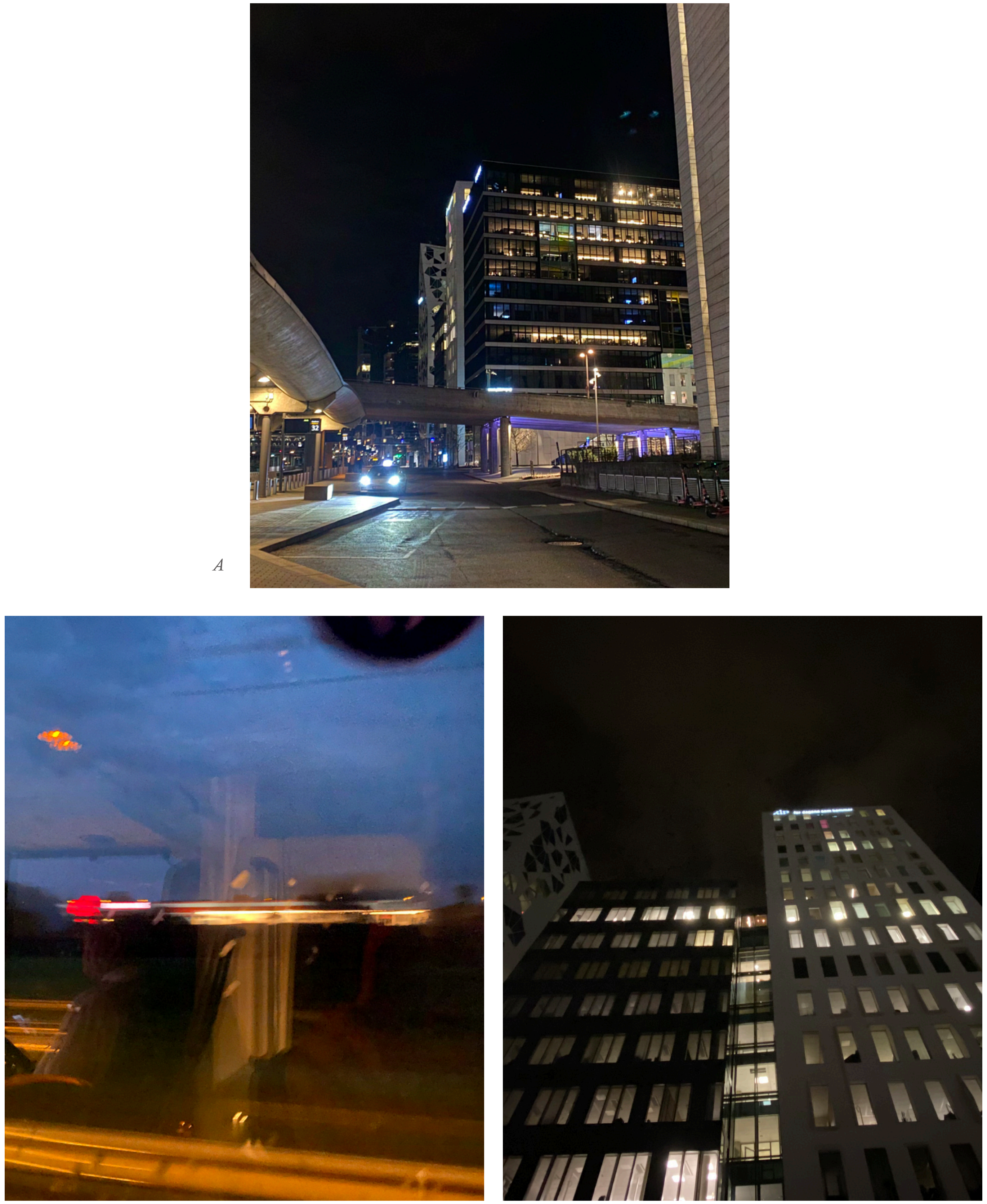
Another trend is the emphasis on car-free city centres like in Oslo (Oslo kommune, n.d.). The future of land as we know it is far from certain, and possibly new use and function of city elements and structures can be expected. Hopefully the suggestions presented can serve as inspiration not only on how to improve the sites with their current function but also to how differently things can be done if one prioritizes other systems or all of them together as for ecosystem health when developing a location. Who says that walls should be made of hard surfaces and not be living plants? Or that the main function of parking lots should be to serve parking to cars and not humans with human-friendly landscapes that can give people a break, enable a moment to sit on a bench under a tree and listen to the birds singing or some water running? My hope is that by showing some “ultimate” scenarios we can open up our minds also to alternative functions or design.

Operating space

The operating space for when the majority of energy of activity is present in a site varies, see figures 4.2 A-C. Typically, industrial sites have an operating space concentrated during a limited timeslot in the daytime of week-days while residential sites are the opposite, with an operating space concentrated during afternoons, evenings, weekends and holidays. This means that industrial sites often are empty during the night, in weekends and holidays. Signs of this can be empty parking lots, empty but lit office buildings and less life and interactions occurring on the street level. Similarly, a residential neighbourhood will often be empty and silent when people are at work or in school.

These different operating spaces for the given land-uses creates possibilities. If one can utilize this potential of certain areas that are empty in given timeslots to benefit the ecosystem, this “lack” of function can instead become a source.

The parking lot, building and site in IKEA for instance is not in use during the evening and night, or on Sundays when the store is closed. Nevertheless, the outdoor lights are most probably on during the whole night. By changing the lighting regime so that it is switched off during the night hours or installing sensors so that the lights only switch on in the presence of a moving human or car, the sink function of outdoor lighting producing light pollution would be strongly decreased. This would benefit the ecological system of removing disturbances that have profound effects on wildlife, insects, birds and vegetation (Appendix 1). It is almost overwhelming considering the cascading effects these types of operating space-adjustments could have if done for all similar sites in an industrial area. In addition to the spatial aspects, I wanted to highlight these types of possibilities that arise when considering the time-slot of use for landscape projects as one should aim for a function, and ultimately a source function for a site during and without human use.



A

B

C

Figures 4.2 A-C showing different types of industrial areas in both an urban and rural matrix. The land-uses are lacking night-time activity, however they are extensively lit either from the inside as in the high-rises (A, C) or from outdoor lighting in the rural matrix (B). All three examples have light pollution effects and are wasted land at night.

4.3 Research for the future

Relative comparisons and quality measurements

Due to time and practical limitations of this thesis work, there are additional areas that could have been studied in more depth. I will suggest some future areas to explore within the topic of ecosystem health.

One suggestion is looking at the possibility to develop a method for 'relative comparison' of natural and novel ecosystems. Using natural ecosystems and measuring or mapping their source functions could serve as reference for novel ecosystems. Natural ecosystems are a great resource with blue-print smart, natural solutions. Identifying reference values, structures or functions of "best practice" in the natural world could aid the development of novel ecosystems. Nature-based solutions is one alternative of this, where natural systems and functions are used in novel ecosystems with great success. Merging nature-based solutions with the approach in the thesis could also be done. Other suggestions are to develop a grading system of better and best options, and for measuring the quality of elements' function in both quantity and quality. In addition, establishment and management schemes of planted vegetation could be researched within the same tunes of sources and sinks as they are significant for the functioning and sustainability of plantings. The use of native and non-native species, the benefits of avoiding open soil and even discussing weeding (i.e. what defines a weed, isn't a weed better than open soil considering the ecosystem services it can provide?) are topics that could be studied within ecosystem health.

Check points

Additionally, to emphasize the relativity of source/sink- functions within systems, objectives and prioritizations, simple check points could be developed, like:

- Who are you planning for? Detect the systems present, their current state (i.e. health as in dyna mics of source and sink functions), interaction and provision of ecosystem services.
- Are there any special conditions or considerations in the site that should be emphasized or pri oritized (e.g. wet ground conditions, threatened species, risk of drought, user-groups etc.)?
- If so, why should these be considered?
- What are the pros and cons for all systems of the suggested intervention?
- Do the suggested source functions outweigh the current or the sink functions? If not, how are you planning to make up for it, the total ecosystem health?

Modelling landscape designs

In addition, models or methods to measure the results of planned interventions after a number of years (5, 10, 20 years) could be developed to detect blind spots, elements or considerations that were forgotten, the actual functioning of the ecosystem (i.e. is it working as intended, better, worse?), the potential for further improvements (identified by mapping the gradients and seeing the development i.e. if the colours changed or not after a number of years). In general, there are currently few methods to track the development of landscape projects be it plantings, installations, functions or use. This holds great potential as a learning source to everyone involved. This is also closely linked to sustainability, as we need to start mapping what works and not across projects and between individual landscape architects, to avoid making the same mistakes and waste resources, nature and continue hasty and thoughtless degradation of ecosystems. This links back to holism and the foundation of ecosystem health as an approach that enables a holistic, joint assessment to maximize health for all.

Green land-uses

The approach developed for this thesis should also be tested for ecosystems like parks, forests, plantations, urban greenery and similar. I chose not to include green land-uses in my case study sites and rather focus on heavily developed sites, but it would be interesting to see the potential in such a context. Combined with a more detailed scale to include the scope of quality rather than just abundance of green would then possibly be easier to achieve. Adding in existing methods of area-smart greenery with boosting effects to a multitude of sub-systems like SUGI-forests or the Miyawaki-method can further elevate the potential of such an approach as they build on many of the same principles.

V Conclusion

Conclusion

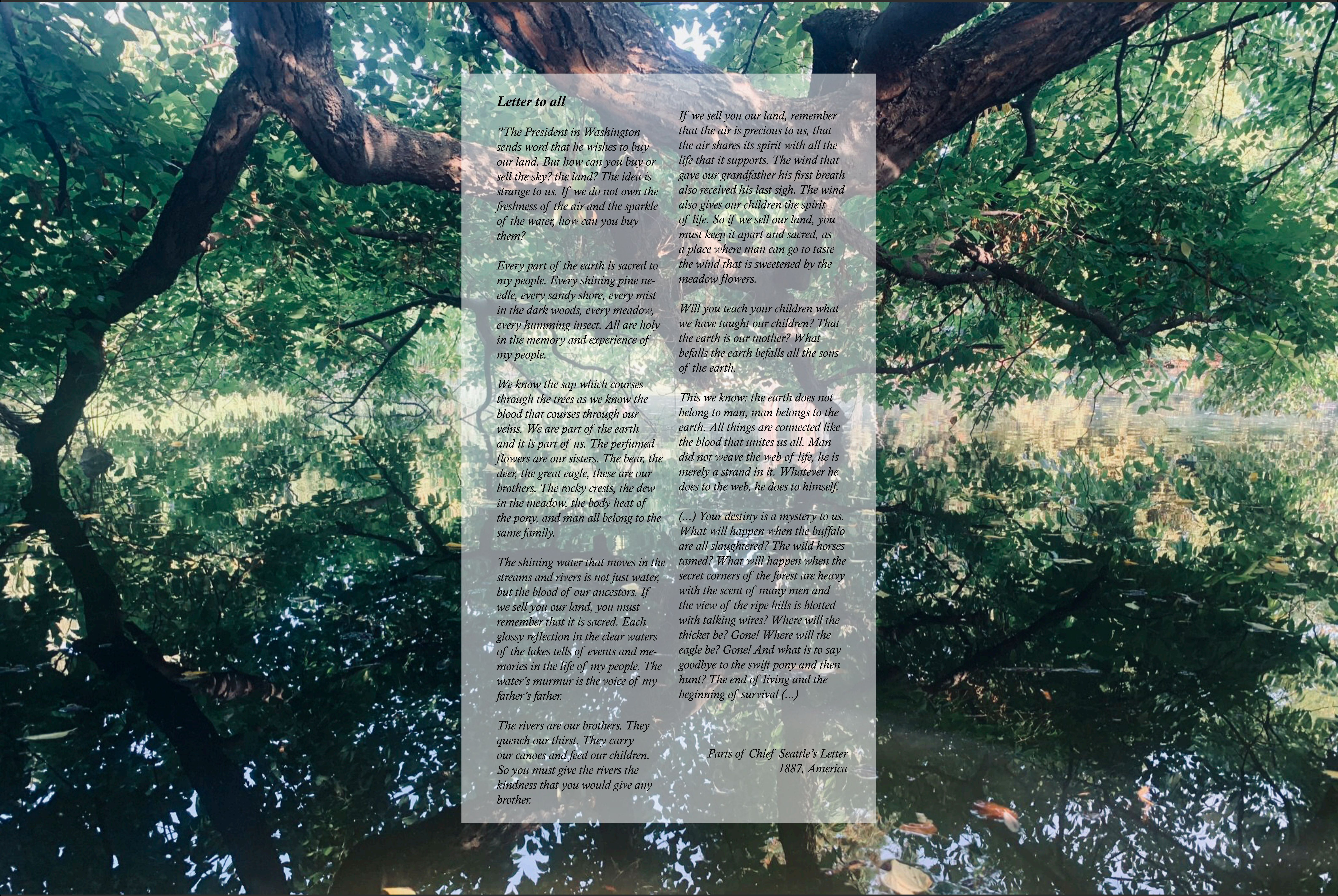
The purpose of this thesis has been to present a new understanding of the ecosystems that we are surrounded by and act in, in and provide a toolkit of how this understanding can be elevated by landscape architects when merging landscape ecological theory to achieve healthy ecosystems. The main aim was to explore the potential of an ecosystem health approach for sustainable land-use development and test what potential landscape ecology had as tool to achieve healthy ecosystems. These objectives were achieved.

All of the detailed "how to"s for making the optimal vegetation patch, roof garden, green wall or permeable ground cover is not mentioned in the thesis as there is an abundance of expertise on the field on how to best suit design proposals with the local context, using the right species and fitting the design to the social, ecological and environmental needs. The priority of this thesis has been to highlight the array of considerations a landscape architect must address when designing, and to remind the profession of the fact that we need to address them all, holistically as a joint ecosystem in the pursuit of making some positive land-use change. Simply designing a green roof for the sake of stormwater management without considering the rest of the system is continuing on the trajectory of business as usual, that has led us to the state of the world today. We need to constantly try to make the best of what we have, but for the ecological, social and environmental system together. In my opinions that should be our "pillars of sustainability" and the way forward as a profession. Finally, I want to emphasize the fact that this thesis does not separate between the ecological and environmental system as the world leading scientists clearly have stated the need to stop doing. This builds on the understanding of the natural and social system of the ecosystem, and by sub-dividing the natural into ecological and environmental the intention was to make joint, sustainable solutions easier to access. The ecological and environmental system are and work together as a fine-tuned dynamic in the natural system.

As Inger Andersen said as the UN Under-Secretary-General and UNEP Executive Director during the launch of the IPCC report in 2022 (22:23, IPCC, 2022b):

"Backing nature is the best way to adapt to, and slow climate changes while providing jobs and boosting economies (…) in the end, nature can be our biggest saviour. But only if we save it first"

I would like to end this thesis with the letter of Chief Seattle from the end of the 19th century.



Letter to all

"The President in Washington sends word that he wishes to buy our land. But how can you buy or sell the sky? the land? The idea is strange to us. If we do not own the freshness of the air and the sparkle of the water, how can you buy them?

Every part of the earth is sacred to my people. Every shining pine needle, every sandy shore, every mist in the dark woods, every meadow, every humming insect. All are holy in the memory and experience of my people.

We know the sap which courses through the trees as we know the blood that courses through our veins. We are part of the earth and it is part of us. The perfumed flowers are our sisters. The bear, the deer, the great eagle, these are our brothers. The rocky crests, the dew in the meadow, the body heat of the pony, and man all belong to the same family.

The shining water that moves in the streams and rivers is not just water, but the blood of our ancestors. If we sell you our land, you must remember that it is sacred. Each glossy reflection in the clear waters of the lakes tells of events and memories in the life of my people. The water's murmur is the voice of my father's father.

The rivers are our brothers. They quench our thirst. They carry our canoes and feed our children. So you must give the rivers the kindness that you would give any brother.

If we sell you our land, remember that the air is precious to us, that the air shares its spirit with all the life that it supports. The wind that gave our grandfather his first breath also received his last sigh. The wind also gives our children the spirit of life. So if we sell our land, you must keep it apart and sacred, as a place where man can go to taste the wind that is sweetened by the meadow flowers.

Will you teach your children what we have taught our children? That the earth is our mother? What befalls the earth befalls all the sons of the earth.

This we know: the earth does not belong to man, man belongs to the earth. All things are connected like the blood that unites us all. Man did not weave the web of life, he is merely a strand in it. Whatever he does to the web, he does to himself.

(...) Your destiny is a mystery to us. What will happen when the buffalo are all slaughtered? The wild horses tamed? What will happen when the secret corners of the forest are heavy with the scent of many men and the view of the ripe hills is blotted with talking wires? Where will the thicket be? Gone! Where will the eagle be? Gone! And what is to say goodbye to the swift pony and then hunt? The end of living and the beginning of survival (...)

Parts of Chief Seattle's Letter
1887, America

Figures and tables

Figures

Tables

References

Alimov, A. F. (2000). *Elementy teorii funk-tsionirovaniya vodnykh ekosistem.* Saint Petersburg: Nauka.

Anderson, V. & Johnson, L. (1997). *Systems Thinking Basics: From Concepts to Causal Loops*: Pegasus Communications.

Aoki, I. (2012). 9 - The Earth. In Aoki, I. (ed.) *Entropy Principle for the Development of Complex Biotic Systems*, pp. 89-95. Oxford: Elsevier.

Åsnes, E., Møretrø, N. A. L., Steinbakk, B., Seeger, L., Kittelsen, J. & Gylver, G. (2023). *Klimaforskningens siste nødskrik*: NRK. Available at: https://www.nrk.no/ytring/klimaforskningens-siste-nodskrik-1.16340950 (accessed: 20.03.23).

Babu, S. (2016). *Theory of island biogeography: Understanding patch size and connectivity*: ecointelligent. Available at: https://eco-intelligent.com/2016/10/13/the-theory-of-island-biogeography/ (accessed: 30.03.23).

Bannerman, S. (1998). *Biodiversity and Interior Habitats: The Need to Minimize Edge Effects part 6 of 7*. Management Concepts in Landscape Ecology: British Columbia: Ministry of Forests Research Program. Available at: https://www.for.gov.bc.ca/hfd/pubs/docs/en/en21.pdf (accessed: 03.04.23).

Banyan, M. E. (2022). *tragedy of the commons*. Encyclopedia Britannica.

Barton, J. & Rogerson, M. (2017). The importance of greenspace for mental health. *BJPsych Int*, 14 (4): 79-81. doi: 10.1192/s2056474000002051.

Bertalanffy, L. v. (1968). ***General System Theory: Foundations, Development, Applications***. New York, US: Geroge Braziller, Inc.

Bolund, P. & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, 29 (2): 293-301. doi: https://doi.org/10.1016/S0921-8009(99)00013-0.

Bormann, F. H. (1996). ECOLOGY: A Personal History. *Annual Review of Energy and the Environment*, 21 (1): 1-29. doi: 10.1146/annurev.energy.21.1.1.

Boston, P. J. (2008). Gaia Hypothesis. In Fath, B. (ed.) *Encyclopedia of Ecology (Second Edition)*, pp. 86-90. Oxford: Elsevier.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*: Harvard university press.

Brown, T. (2009). *Change by Design, Revised and Updated*
How Design Thinking Transforms Organizations and Inspires Innovation: Harper Business.

Bykuben. (n.d.). *Bylivsgata Grønland 2022* : Oslo kommune. Available at: https://www.oslo.kommune.no/slik-bygger-vi-oslo/bylivsgata-gronland-2022/#gref (accessed: 28.04.23).

CBD. (2022). *Official CBD Press Release*. COP15: NATIONS ADOPT FOUR GOALS, 23 TARGETS FOR 2030 IN LANDMARK UN BIODIVERSITY AGREEMENT, 9: Convention on Biological Diversity

Chen, L.-D. & Fu, B.-J. (2008). Source-Sink Landscape Theory and Its Ecological Significance. *Frontiers of Biology in China*, 3: 131-136. doi: 10.1007/s11515-008-0026-x.

Clayton, S. (2020). Climate anxiety: Psychological responses to climate change. *Journal of Anxiety Disorders*, 74: 102263. doi: https://doi.org/10.1016/j.janxdis.2020.102263.

Collins, S. J. & Fahrig, L. (2017). Responses of anurans to composition and configuration of agricultural landscapes. *Agriculture, Ecosystems & Environment*, 239: 399-409. doi: https://doi.org/10.1016/j.agee.2016.12.038.

Coresight Research. (2018). *Deep Dive: The Mall Is Not Dead* Available at: https://coresight.com/?s=the+mall+is+not+dead (accessed: 28.04.23).

Costanza, R., Norton, B. G. & Haskell, B. D. (1992). *Ecosystem Health - New Goals for Environmental Management*. Washington, Covelo, California: Island Press,.

Costanza, R. (2012). Ecosystem health and ecological engineering. *Ecological Engineering*, 45: 24-29. doi: https://doi.org/10.1016/j.ecoleng.2012.03.023.

Council of Europe Landscape Convention. (n.d.). *Preamble of the Convention*: Council of Europe. Available at: https://www.coe.int/en/web/landscape (accessed: 21.03.23).

Dahlgren, G. & Whitehead, M. (2021). The Dahlgren-Whitehead model of health determinants: 30 years on and still chasing rainbows. *Public Health*, 199: 20-24. doi: https://doi.org/10.1016/j.puhe.2021.08.009.

Dale, V. H. & Haeubner, R. A. (2001). *A Guide to Rooftop Gardening*. Chicago: Chicago Department of Environment.

De Bono, E. (1971). *The Use of Lateral Thinking*: Intl Center for Creative Thinking.

Dean, J., Dooren, K. v. & Weinstein, P. (2011). Does biodiversity improve mental health in urban settings? *medical hypothesis* 76: 877-880.

Deming, M. E. & Swaffield, S. (2011). *Landscape Architectural Research: Inquiry, Strategy, Design*: John Wiley & Sons.

Doherty, T. S., Hays, G. C. & Driscoll, D. A. (2021). Human disturbance causes widespread disruption of animal movement. *Nature Ecology & Evolution*, 5 (4): 513-519. doi: 10.1038/s41559-020-01380-1.

Douglas, I. (1981). The city as an ecosystem. *Progress in Physical Geography: Earth and Environment*, 5 (3): 315-367. doi: 10.1177/030913338100500301.

Dramstad, W. E., Olson, J. D. & Forman, R. T. T. (1996). *Landscape Ecology Principles in Landscape Architecture and Land-Use Planning*: Harvard University Graduate School of Design, Island Press, The American Society of Landscape Architecture.

Elster, K. & Aasen, K. R. (2023). Spania går tomt for vann – bøndene gir opp årets avling. *NRK*. Available at: https://www.nrk.no/urix/spania-gar-tomt-for-vann-_-bondene-gir-opp-arets-avling-1.16391165 (accessed: 30.04.23).

Emerald Necklace Conservancy. (n.d.). *Frederick Law Olmsted*
. Available at: https://www.emeraldnecklace.org/park-overview/frederick-law-olmsted/ (accessed: 09.05.23).

Ercan, G. (2013). Understanding Landscape Structure Using Landscape Metrics. In Murat, Ö. (ed.) *Advances in Landscape Architecture*, p. Ch. 25. Rijeka: IntechOpen.

Ernest, S. K. M. (2008). *Homeostasis*. Encyclopedia of Ecology.

ESCAP, U. N. (2019). *Introduction to SystemsThinking Principles and AnalyticalTools*. In UNESCAP (ed.).

Systems Thinking and Integration of the Sustainable Development Goals (SDGs) into National Planning: UNESCAP. Available at: https://www.unescap.org/sites/default/files/Session%202%20-%20Introduction%20to%20Systems%20Thinking_Tools_final.pdf (accessed: 01.03.23).

European Commission. (2022). *COP15: historic global deal for nature and people*. Brussels: EU.

European Environment Agency. (2020). *Healthy environment, healthy lives: how the environment influences health and well-being in Europe*, ISSN 1977-8449. Luxembourg: Publications Office of the European Union.

Evans, G. W. (2003). The built environment and mental health. *J Urban Health*, 80 (4): 536-55. doi: 10.1093/jurban/jtg063.

Fabius, L., Pulgar-Vidal, M., Figueres, C., Tubiana, L. & Topping, N. (2022). *Secure a Strong Sister Agreement for Biodiversity or Risk Undermining Climate Action*. Statement. Call from Paris Agreement Champions: . Available at: https://4783129.fs1.hubspotusercontent-na1.net/hubfs/4783129/NDNP/PDFs/COP27-%20Call%20from%20Paris%20Agreement%20Champions.pdf (accessed: 05.05.23).

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., Sirami, C., Siriwardena, G. M. & Martin, J.-L. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters*, 14 (2): 101-112. doi: https://doi.org/10.1111/j.1461-0248.2010.01559.x.

Fainstein, S. S. & Campbell, S. (1996). *Readings in Urban Theory*. Cambridge, MA: Blackwell.

FAO. (2023). *Ecosystem Services & Biodiversity (ESB)*: Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/ecosystem-services-biodiversity/en/ (accessed: 04.05.23).

Flemming, B. (2019). 50 Years After Design With Nature, Ian McHarg's Ideas Still Define Landscape Architecture. *Metropolis Magazine*.

Folke, C., Carpenter, S., Walker, B., Scheffer, M. & Rockström, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society*, 15. doi: 10.5751/ES-03610-150420.

Folke, C., Biggs, R., Norström, A. V., Reyers, B. & Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, 21. doi: 10.5751/ES-08748-210341.

Forman, R. T. T. & Godron, M. (1981). Patches and Structural Components for a Landscape Ecology. *BioScience*, 31 (10): 733-740. doi: 10.2307/1308780.

Forman, R. T. T. & Godron, M. (1986). *Landscape Ecology*. New York: Wiley.

Forman, R. T. T. (1995). *Land Mosaics: the Ecology of Landscapes and Regions*: Cambridge University Press.

Forman, R. T. T. (2004). *Mosaico territorial para la región metropolitana de Barcelona*. Barcelona: Editorial Gustavo Gili.

Forman, R. T. T. (2008). *Urban Regions, Ecology and Planning beyond the City*: Cambridge.

Frumkin, H., Frank, L. & Jackson, R. (2014). "Physical activity, sprawl, and health" from urban sprawl and public health: Designing, planning, and building for healthy communities (2004). In, pp. 351-358.

Fulbright, J. W. (1989). *The Price of an Empire*. New York: Pantheon Books.

Gates, D. M., Thompson, J. N. & Thompson, M. B. (2023). *biosphere*. Encyclopedia Britannica.

Gibson, K. E., Barnett, J., Haslam, N. & Kaplan, I. (2020). The mental health impacts of climate change: Findings from a Pacific Island atoll nation. *Journal of Anxiety Disorders*, 73: 102237. doi: https://doi.org/10.1016/j.janxdis.2020.102237.

Gillson, L. & Willis, K. (2004). 'As Earth's testimonies tell': Wilderness conservation in a changing world. *Ecology Letters*, 7: 990-998. doi: 10.1111/j.1461-0248.2004.00658.x.

Gilroy, J. J. & Edwards, D. P. (2017). Source-Sink Dynamics: a Neglected Problem for Landscape-Scale Biodiversity Conservation in the Tropics. *Current Landscape Ecology Reports*, 2 (1): 51-60. doi: 10.1007/s40823-017-0023-3.

Girvetz, E. & Greco, S. (2007). How to define a patch: A spatial model for hierarchically delineating organism-specific habitat patches. *Landscape Ecology*, 22: 1131-1142. doi: 10.1007/s10980-007-9104-8.

Gladwell, M. (2000). *The Tipping Point: How Little Things Can Make a Big Difference*. London: Littlebrown.

Gómez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPhearson, T., O'Farrell, P., Andersson, E., Hamstead, Z. & Kremer, P. (2013). Urban Ecosystem Services. In Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C., et al. (eds) *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment*, pp. 175-251. Dordrecht: Springer Netherlands.

Grimm, N., Grove, M., Pickett, S. T. A. & Redman, C. (2008). Integrated Approaches to Long-Term Studies of Urban Ecological Systems. In vol. 50, pp. 123-141.

Guthold, R., Stevens, G. A., Riley, L. M. & Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *The Lancet Child & Adolescent Health*, 4 (1): 23-35. doi: 10.1016/S2352-4642(19)30323-2.

Hall, P. G. (2002). *Cities of Tomorrow: An Intellectual History of Urban Planning and Design in the Twentieth Century*. Oxford: Blackwell.

Hansen, A. (2021). *Depphjärnan : varför mår vi så dåligt när vi har det så bra?*: Bonnier Fakta.

Harvey, H. A. (2010). *Building Bridges to Protect Health: Enhanced Partnerships among Animal, Human, and Ecosystem Health Sectors in New Zealand* ISBN 978-1-877502-21-7 Fulbright New Zealand

Hjort, P. (1982). *Helsebegrepet, helseidealet og helsepolitiske mål*. Helsepolitikk og helseadministrasjon. Oslo: Tanum-Norli.

Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., Epstein, P. R., Ewel, J. J., Klink, C. A., Lugo, A. E., et al. (2006).

Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, 15 (1): 1-7. doi: https://doi.org/10.1111/j.1466-822X.2006.00212.x.

Holtmeier, F.-K. (2015). Carl Troll:His footprints in physical geography. *Progress in Physical Geography: Earth and Environment*, 39 (4): 554-565. doi: 10.1177/0309133315595573.

Hyrynsalmi, S. & Mäntymäki, M. (2018, 2018//). *Is Ecosystem Health a Useful Metaphor? Towards a Research Agenda for Ecosystem Health Research*. Challenges and Opportunities in the Digital Era, Cham: Springer International Publishing.

Iansiti, M. & Levien, R. (2004). The keystone advantage. *Harvard Business School Press, Boston*.

IPBES. (2022a). *Summary for policymakers of the methodological assessment of the diverse values and valuation of nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* In Pascual, U., Balvanera, P., Christie, M., Baptiste, B., González-Jiménez, D., Anderson, C. B., Athayde, S., Barton, D. N., Chaplin-Kramer, R., Jacobs, S., et al. (eds). IPBES secretariat Bonn, Germany.

IPBES. (2022b). *Summary for Policymakers of the Methodological Assessment Report on the Diverse Values and Valuation of Nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. In Pascual, U., Balvanera, P., Christie, M., Baptiste, B., González-Jiménez, D., Anderson, C. B., Athayde, S., Barton, D. N., Chaplin-Kramer, R., Jacobs, S., et al. (eds). Bonn, Germany: IPBES secretariat.

IPCC. (2012). *Glossary of terms*. In Field, C. B., Barros, V., Stocker, T. F., Qin, D., Dokken, D. J., Ebi, K. L., Mastrandrea, M. D., Mach, K. J., Plattner, G.-K., Allen, S. K., et al. (eds). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change Cambridge, UK
New York, NY, USA: IPCC.

IPCC. (2022a). *COP 27: Glasgow Sharm el-Sheikh work programme on the global goal on adaptation referred to in decision 7/CMA.3.* : UNFCCC. Available at: https://unfccc.int/sites/default/files/resource/GGA_AUV.pdf (accessed: 04.05.23).

IPCC. (2022b). *IPCC Press Conference - Climate Change 2022: Impacts, Adaptation & Vulnerability.*: IPCC. Available at: https://www.youtube.com/watch?v=VKhoVnC3lNk&t=2364s (accessed: 12.10.22).

IPCC. (2023). *Summary for Policymakers* Synthesis Report of the IPCC Sixth Assessment Report (AR6): United Nations.

IPCC. (n.d.). *Reports*: ipcc.ch. Available at: https://www.ipcc.ch/reports/ (accessed: 07.05.23).

IUCN. (2023). *Climate Change in Twelve Pictures* Resources. IUCN: International Union for Conservation of Nature Available at: https://www.iucn.org/resources/brochure/climate-change-12-pictures (accessed: 04.05.23).

Jansson, Å. (2013). Reaching for a sustainable, resilient urban future using the lens of ecosystem services. *Ecological Economics*, 86: 285-291. doi: https://doi.org/10.1016/j.ecolecon.2012.06.013.

Jimenez, M. P., DeVille, N. V., Elliott, E. G., Schiff, J. E., Wilt, G. E., Hart, J. E. & James, P. (2021). Associations between Nature Exposure and Health: A Review of the Evidence. *Int J Environ Res Public Health*, 18 (9). doi: 10.3390/ijerph18094790.

Johnson, B. & Hill, K. (2002). *Ecology and Design: Frameworks For Learning*.

Jolma Architects. (2021). *Increasing Sustainability with Temporary Interventions in the Landscape* : land8. Available at: https://land8.com/increasing-sustainability-with-temporary-interventions-in-the-landscape/ (accessed: 28.04.23).

Kaimowitz, D. & Sheil, D. (2007). Conserving What and for Whom? Why Conservation Should Help Meet Basic Human Needs in the Tropics. *BIOTROPICA*, 3900332: 567-5741744. doi: 10.1111/j.1744-7429.2007.00332.x.
Kareiva, P. & Marvier, M. (2007). Conservation for the people.

Karr, J. R. (1999). Defining and measuring river health. *Freshwater Biology*, 41 (2): 221-234. doi: https://doi.org/10.1046/j.1365-2427.1999.00427.x.

Karr, S. J. (2021). *PROGRESSIVISM AND PURIFIED AIR: OLMSTED'S PUBLIC LANDSCAPES FOR PUBLIC HEALTH*: olmstednow.org. Available at: https://olmstednow.org/progressivism-and-purified-air-olmsteds-public-landscapes-for-public-health/ (accessed: 07.05.23).

Kaste, A. M. (2022). *Over en av fire unge nordmenn har klimaangst*. Miljø: forskning.no. Available at: https://forskning.no/klima-psykologi-samfunn/over-en-av-fire-unge-nordmenn-har-klimaangst/2094865 (accessed: 07.05.23).

Kim, K. H., Kabir, E. & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. *Environ Int*, 74: 136-43. doi: 10.1016/j.envint.2014.10.005.

Klenske, N. (2021). *Nature and climate crises: two sides of the same coin*. Environment: Horizon The EU Research & Innovation Magazine,

European Commission,. Available at: https://ec.europa.eu/research-and-innovation/en/horizon-magazine/nature-and-climate-crises-two-sides-same-coin (accessed: 05.04.23).

Klima- og miljødepartementet. (2018). *Klimaloven*: lovdata.

Kolasa, J. & Rollo, C. D. (1991). Introduction: The Heterogeneity of Heterogeneity: A Glossary. In Kolasa, J. & Pickett, S. T. A. (eds) *Ecological Heterogeneity*, pp. 1-23. New York, NY: Springer New York.

Kuznetsova, T. V. & Manvelova, A. B. (2022). Ecosystem Health: a Concept, Methodlogical Apporaches, and Assessment Criteria *Marine Biological Journal* 7(2): 41-62. doi: https://doi.org/10.21072/mbj.2022.07.2.04.

Landscape Architecture Foundation. (2016a). *Action Plan*. In Declaration, N. L. (ed.). Available at: https://www.lafoundation.org/take-action/act/action-plan#actionplan (accessed: 20.03.23).

Landscape Architecture Foundation. (2016b). *New Landscape Declaration*. Available at: https://www.lafoundation.org/take-action/new-landscape-declaration#nlddocument (accessed: 20.03.23).

Lawler, O. K., Allan, H. L., Baxter, P. W. J., Castagnino, R., Tor, M. C., Dann, L. E., Hungerford, J., Karmacharya, D., Lloyd, T. J., López-Jara, M. J., et al. (2021). The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health. *The Lancet Planetary Health*, 5 (11): e840-e850. doi: https://doi.org/10.1016/S2542-5196(21)00258-8.

Leichenko, R. & O´Brien, K. (2019). *Climate and Society - transforming the future*: Polity Press.

Leopold, A. (1949). *A Sand County Almanac* Oxford: Oxford University Press Inc.

Li, B., Zhang, W., Wang, Z., Xie, H., Yuan, X., Pei, E. & Wang, T. (2020). Effects of landscape heterogeneity and breeding habitat diversity on rice frog abundance and body condition in agricultural landscapes of Yangtze River Delta, China. *Current Zoology*, 66 (6): 615-623. doi: 10.1093/cz/zoaa025.

Linnean Solutions. (2016). Servicing those ecosystems: The value of trees
. *FMLink*. Available at: https://www.fmlink.com/articles/servicing-ecosystems-value-trees/ (accessed: 07.05.23).

Lo, Y. S. (2009). *Leopold's Land Ethic, Ecosystem Health, and the Challenge of Affluenza.* Department of Philosophy. Victoria, Australia.: La Trobe University. Available at: https://www.latrobe.edu.au/__data/assets/pdf_file/0016/240073/land-health.pdf (accessed: 06.02.23).

Lovelock, J. E. (1972). Gaia as seen through the atmosphere. *Atmospheric Environment (1967)*, 6 (8): 579-580. doi: https://doi.org/10.1016/0004-6981(72)90076-5.

Lovelock, J. E. (1988). *The Ages of Gaia: A Biography of Our Living Earth.* London: W.W. Norton.

Lovett, G. M., Jones, C. G., Turner, M. G. & Weathers, K. C. (2005). *Ecosystem function in heterogeneous landscapes*: Springer.

Lucero-Prisno III, D. E., Shomuyiwa, D. O., Kouwenhoven, M. B. N., Dorji, T., Odey, G. O., Miranda, A. V., Ogunkola, I. O., Adebisi, Y. A., Huang, J., Xu, L., et al. (2023). Top 10 public health challenges to track in 2023: Shifting focus beyond a global pandemic. *Public Health Challenges*, 2 (2): e86. doi: https://doi.org/10.1002/puh2.86.

Macarthur, R. H. & Wilson, E. O. (1967). *The Theory of Island Biogeography*. REV - Revised ed.: Princeton University Press.

Mageau, M. T., Costanza, R. & Ulanowicz, R. (1995). The development and initial testing a quantitative assessment of ecosystem health. *Ecosystem Health*, 1: 201-213.

Marsh, W. M. (2005). *Landscape Planning: Environmental Applications*. New York: John Wiley.
McHarg, I. (1969). *Design With Nature* Wiley.

McHarg, I. (1969). *Design With Nature* Wiley.

McRae, B. H., Hall, S. A., Beier, P. & Theobald, D. M. (2012). Where to restore ecological connectivity? Detecting barriers and quantifying restoration benefits. *PLoS One*, 7 (12): e52604. doi: 10.1371/journal.pone.0052604.

Miljødirektoratet. (2023). *Redusert nedbygging er bra for klima, miljø og landbruk*: Miljødirektoratet. Available at: https://www.miljodirektoratet.no/aktuelt/nyheter/2023/april-2023/redusert-nedbygging-er-bra-for-klima-miljo-og-landbruk/ (accessed: 05.05.23).

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press. Available at: https://millenniumassessment.org/en/Framework.html (accessed: 07.04.23).

Miller, C., Clay, G., McHarg, I. L., Hammond, C. R., Patton, G. E. & Simonds, J. O. (1966). *A declaration of concern*. Landscape Architecture Foundation: lafoundation.org. Available at: https://www.lafoundation.org/who-we-are/values/declaration-of-concern (accessed: 20.03.23).

Molina, G. A. R., Poggio, S. L. & Ghersa, C. M. (2014). Epigeal arthropod communities in intensively farmed landscapes: Effects of land use mosaics, neighbourhood heterogeneity, and field position. *Agriculture, Ecosystems & Environment*, 192: 135-143. doi: https://doi.org/10.1016/j.agee.2014.04.013.

Moore, J. F. (1993). Predators and prey: a new ecology of competition. *Harvard business review*, 71 (3): 75-86.
Murphy, M. D. (2016). *Landscape Architectural Theory - an Ecological Approach*. Washington Island Press.
myNASAdata. (n.d.). *About the Earth as a System: Background Information*. Available at: https://mynasadata.larc.nasa.gov/basic-page/about-earth-system-background-information (accessed: 4.05.23).

n.a. (2020). *Introduction to Systems Theory in Social Work*: Online Msw Programs. Available at: https://www.onlinemswprograms.com/social-work/theories/systems-theory-social-work/ (accessed: 01.03.23).

Nassauer, J. (1997). *Placing Nature: Culture And Landscape Ecology*. Washington, DC: Island Press.

National Geographic. (n.d.-a). *Abiotic factors*. Education: Resource: National Geographic. Available at: https://education.nationalgeographic.org/resource/resource-library-abiotic-factor/ (accessed: 10.05.23).

National Geographic. (n.d.-b). *Biotic factors*. Education: Resource. Available at: https://education.nationalgeographic.org/resource/resource-library-biotic-factors/ (accessed: 10.05.23).

National Park Service. (n.d.). *The Emerald Necklace: Boston's Green Connection*. nps.gov. Available at: https://www.nps.gov/articles/the-emerald-necklace-boston-s-green-connection.htm (accessed: 23.03.23).

NationMaster. (2008). *sq.km Countries compared*. In Area, S. L. (ed.). Available at: https://www.nationmaster.com/country-info/stats/Geography/Land-area/Sq.-km (accessed: 05.05.23).

Newman, E. A., Kennedy, M. C., Falk, D. A. & McKenzie, D. (2019). Scaling and Complexity in Landscape Ecology. *Frontiers in Ecology and Evolution*, 7. doi: 10.3389/fevo.2019.00293.

Nordenfeldt, L. (1993). Concepts of health and their consequences for health care. *Theoretical Medicine*, 14: 277-285.

Nordenfeldt, L. (1995). *On the nature of health: An action-theoretical approach*. Dordrecht: Kluwer Academic Publishers.

Noss, R. F. & Cooperider, A. Y. (1994). *Saving Nature's Legacy: Protecting and Restoring Biodiversity*. Washington, DC
: Island Press.

Nyhus, H. (2023, 17.01.23). Ny naturavtale set norske vegprosjekt i spel. *NRK*. Available at: https://www.nrk.no/vestland/ny-naturavtale-set-norske-vegprosjekt-i-spel-1.16258918.

O'Brien, K. & Sygna, L. (2013). Responding to climate change: The three spheres of transformation. *Proceedings of the Conference Transformation in a Changing Climate*: 16-23.

O'Neill, R., Johnson, A. & King, A. (1989). A Hierarchical Framework for the Analysis of Scale. *Landscape Ecology*, 3: 193-205. doi: 10.1007/BF00131538.

Ogunbode, C. A., Doran, R., Hanss, D., Ojala, M., Salmela-Aro, K., van den Broek, K. L., Bhullar, N., Aquino, S. D., Marot, T., Schermer, J. A., et al. (2022). Climate anxiety, wellbeing and pro-environmental action: correlates of negative emotional responses to climate change in 32 countries. *Journal of Environmental Psychology*, 84: 101887. doi: https://doi.org/10.1016/j.jenvp.2022.101887.

Orr, D. W. (2002). *The Nature of Design: Ecology, Culture, and Human Intention*: Oxford University Press.
Oslo byleksikon. (n.d.). *Slottsparken*. Available at: https://oslobyleksikon.no/index.php?curid=8678 (accessed: 28.04.23).

Oslo kommune. (n.d.). *Bilfritt byliv*: Oslo kommune: byutvikling. Available at: https://www.oslo.kommune.no/byutvikling/bilfritt-byliv/#gref (accessed: 28.04.23).
Palmer, M. & Febria, C. (2012). The Heartbeat of Ecosystems. *Science (New York, N.Y.)*, 336: 1393-4. doi: 10.1126/science.1223250.

Palmer, M. & Febria, C. (2012). The Heartbeat of Ecosystems. *Science (New York, N.Y.)*, 336: 1393-4. doi: 10.1126/science.1223250.

Parrish, J. D., Braun, D. P. & Unnasch, R. S. (2003). Are We Conserving What We Say We Are? Measuring Ecological Integrity within Protected Areas. *BioScience*, 53 (9): 851-860.

Peace, M. M. I. И. M. M. G. I. o. E. f., Sustainable, D., Mahatma Gandhi Institute of Education for, P., Sustainable, D., Institut Mahatma Gandhi d'éducation pour la paix et le développement, d., Instituto Mahatma Gandhi de Educación para la Paz y el Desarrollo, S., Институт Махатмы Ганди по образованию в интересах мира и устойчивого, p., معهد المهاتما غاندي للتربية من أجل السلام والتنمية, l., 圣雄甘地和平与可持续发展教育研究所, Mgiep, et al. (2022). *Humans and nature: exploring relationships*
Blue dot: exploring new ideas for a shared future: UNESCO MGIEP.

Perdue, W. C., Stone, L. A. & Gostin, L. O. (2003). The built environment and its relationship to the public's health: the legal framework. *Am J Public Health*, 93 (9): 1390-4. doi: 10.2105/ajph.93.9.1390.

Pineo, H. (2022a). Ecosystem Health. In Pineo, H. (ed.) *Healthy Urbanism: Designing and Planning Equitable, Sustainable and Inclusive Places*, pp. 107-140. Singapore: Springer Nature Singapore.

Pineo, H. (2022b). Towards healthy urbanism: inclusive, equitable and sustainable (THRIVES) – an urban design and planning framework from theory to praxis. *Cities & Health*, 6 (5): 974-992. doi: 10.1080/23748834.2020.1769527.

Porensky, L. & Young, T. (2013). Edge-Effect Interactions in Fragmented and Patchy Landscapes. *Conservation biology : the journal of the Society for Conservation Biology*, 27. doi: 10.1111/cobi.12042.

Purvis, B., Mao, Y. & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, 14 (3): 681-695. doi: 10.1007/s11625-018-0627-5.

Ramade, F. (1995, 1995//). *Qualitative and Quantitative Criteria Defining a "Healthy" Ecosystem*. Evaluating and Monitoring the Health of Large-Scale Ecosystems, Berlin, Heidelberg: Springer Berlin Heidelberg.

Rapport, D. (1989). What Constitutes Ecosystem Health? *Perspectives in biology and medicine*, 33: 120-132. doi: 10.1353/pbm.1990.0004.

Rapport, D. J., Thorpe, C. & Regier, H. A. (1979). Ecosystem Medicine. *Bulletin of the Ecological Society of America*, 60 (4): 180-182.

Rapport, D. J. (1981). *Diagnosis, prognosis and treatment of ecosystems under stress*.

Rapport, D. J., Regier, H. A. & Hutchinson, T. C. (1985). Ecosystem Behavior Under Stress. *The American Naturalist*, 125 (5): 617-640.

Rapport, D. J. (1995). Ecosystem Health: More than a Metaphor? *Environmental Values*, 4 (4): 287-309.

Rapport, D. J., Böhm, G. M., Buckingham, D. E., Cairns, J. J., Costanza, R., Karr, J. R., Kruijf, H. A. M. d., Levins, R. A., Mcmichael, A. J., Nielsen, N. O., et al. (1999). Ecosystem Health: The Concept, the ISEH, and the Important Tasks Ahead. *Ecosystem Health*, 5: 82-90. doi: 10.1046/J.1526-0992.1999.09913.X.

Rapport, D. J. (2007). Sustainability science: an ecohealth perspective. *Sustainability Science*, 2 (1): 77-84. doi: 10.1007/s11625-006-0016-3.

Rapport, D. J. (n.d.). *David J. Rapport: Principal, Ecohealth consulting*: ecohealthconsulting. Available at: http://www.ecohealthconsulting.com/Team/consultants/d_rapport.html (accessed: 02.05.23).

Richmond, B. & Peterson, S. (2001). *An introduction to systems thinking*. Lebanon, NH: High Performance Systems Incorporated.

Robinson, J. M., Aronson, J., Daniels, C. B., Goodwin, N., Liddicoat, C., Orlando, L., Phillips, D., Stanhope, J., Weinstein, P., Cross, A. T., et al. (2022). Ecosystem restoration is integral to humanity's recovery from COVID-19. *The Lancet Planetary Health*, 6 (9): e769-e773. doi: 10.1016/S2542-5196(22)00171-1.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., et al. (2009). A safe operating space for humanity. *Nature*, 461 (7263): 472-475. doi: 10.1038/461472a.

Rutledge, K., McDaniel, M., Teng, S., Hall, H., Ramroop, T., Sprout, E., Hunt, J., Boudreau, D. & Costa, H. (2022a). *Ecosystem*. In Evers, J., Editing, E. & West, K. (eds). Resource library. National Geographic: National Geographic Society. Available at: https://education.nationalgeographic.org/resource/ecosystem (accessed: 10.02.23).

Rutledge, K., McDaniel, M., Teng, S., Hall, H., Ramroop, T., Sprout, E., Hunt, J., Boudreau, D. & Costa, H. (2022b). *Habitat*
. Evers, J., Editing, E. & West, K. (eds). National Geographic Society: Education - National Geographic.

Sachs, J. & Reid, W. (2006). Investments Toward Sustainable Development. *Science (New York, N.Y.)*, 312: 1002. doi: 10.1126/science.1124822.

Sasaki, H. (1950). THOUGHTS ON EDUCATION IN LANDSCAPE ARCHITECTURE: SOME COMMENTS ON TODAY'S METHODOLOGIES AND PURPOSE. *Landscape Architecture*, 40 (4): 158-160.

Seddon, G. (1997). *Landprints: Reflections on Place and Landscape*. Cambridge: Cambridge University Press.

Seiler, A. (2003). Effects of infrastructure on nature. In, pp. 31-50. European Communities: Belgium.

Senel, E., Ballovara, M., Aslaksen, E. A. & Myrskog, L. M. (2023). – Ekte mennesker lever med dette overgrepet hver dag. *NRK*. Available at: https://www.nrk.no/sapmi/500-dager-siden-fosen-dommen_-na-aksjonerer-ella-marie-haetta-isaksen-departementet-1.16307645.

Seto, K., Güneralp, B. & Hutyra, L. (2012). Global Forecasts of Urban Expansion to 2030 and Direct Impacts on Biodiversity and Carbon Pools. *Proceedings of the National Academy of Sciences*, 109: 16083-8. doi: 10.1073/pnas.1211658109.

Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barber, E. & Fuller, R. A. (2016). Health Benefits from Nature Experiences Depend on Dose. *Scientific Reports*, 6 (1): 28551. doi: 10.1038/srep28551.

Sharma, A., Madaan, V. & Petty, F. D. (2006). Exercise for mental health. *Prim Care Companion J Clin Psychiatry*, 8 (2): 106. doi: 10.4088/pcc.v08n0208a.
Sharma, M. (2007). Personal to planetary transformation. *Kosmos Journal*.

Søgaard, G., Mathiesen, H. F., Bjørkelo, K., Eriksen, R., Hobrak, K., Mohr, C. W. & Smith., A. (2021). *Arealbruksendring til utbygd areal
Faktagrunnlag for vurdering av avgift på utslipp fra arealbruksendring – rapporterte utslipp og mulige kartgrunnlag
Revidert utgave*. Miljødirektoratet: NIBIO.

Statistisk sentralbyrå. (2022a). *Arealbruk og arealressurser, 25.juli 2022*
. Available at: https://www.ssb.no/natur-og-miljo/areal/statistikk/arealbruk-og-arealressurser (accessed: 23.04.23).

Statistisk sentralbyrå. (2022b). *Befolkningen - hvor mange bor det i Norge?*: SSB. Available at: https://www.ssb.no/befolkning/faktaside/befolkningen (accessed: 09.05.23).

Statistisk sentralbyrå. (2023a). *Arealprofiler 2022, 5 januar 2023*. Available at: https://www.ssb.no/natur-og-miljo/areal/arealprofiler-2022 (accessed: 23.04.23).

Statistisk sentralbyrå. (2023b). *De 10 største byene, tettstedene og kommunene i Norge*. Available at: https://www.ssb.no/befolkning/folketall/artikler/de-storste-byene-og-tettstedene-i-norge (accessed: 28.04.23).

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347 (6223): 1259855. doi: 10.1126/science.1259855

Steffen, W., Richardson, K., Rockström, J., Schellnhuber, H. J., Dube, O. P., Dutreuil, S., Lenton, T. M. & Lubchenco, J. (2020). The emergence and evolution of Earth System Science. *Nature Reviews Earth & Environment*, 1 (1): 54-63. doi: 10.1038/s43017-019-0005-6.

Stjernman, M., Sahlin, U., Olsson, O. & Smith, H. (2019). Estimating effects of arable land-use intensity on farmland birds using joint species modeling. *Ecological Applications*, 29. doi: 10.1002/eap.1875.

Stugu, S. (2015). *Kjøpesentre i Norge: Konsentrert makt*: De Facto: kunnskapssenter for fagorganiserte.

Sutton, M., Billen, G., Bleeker, A., Erisman, J. W., Grennfelt, P., Grinsven, H., Grizzetti, B., Howard, C. & Leip, A. (2011). European nitrogen assessment - Technical summary. *European Nitrogen Assessment*: XXXV-LI.

Taylor, P. D., Fahrig, L., Henein, K. & Merriam, G. (1993). Connectivity is a vital element of landscape structure. *Oikos*: 571-573.

The International Association of Horticultural Producers. (n.d.). *New approaches to existing green spaces and ambitious street reclamation transform Barcelona*. Case Study: AIPH. Available at: https://aiph.org/wp-content/uploads/2020/11/AIPH_Case-Studies_Barcelona_FINAL.pdf (accessed: 09.05.23).

The World Bank. (2023). *Urban Development*. Understanding Poverty. Available at: https://www.worldbank.org/en/topic/urbandevelopment/overview (accessed: 05.05.23).

The World Commission on Environment and Development. (1987). *Report of the World Commission on Environment and Development: Our Common Future*.

Thomas, L. (2020). 25% of U.S. malls are expected to shut within 5 years. Giving them a new life won't be easy. *CNBC*. Available at: https://www.cnbc.com/2020/08/27/25percent-of-us-malls-are-set-to-shut-within-5-years-what-comes-next.html (accessed: 28.04.23).

Troll, C. (1968). Landschaftsokologie. In *Pflanzensoziologie und Landschaftsokologie – Symposium Stolzenau*, pp. 1-21. The Hague: Junk.

Turnhout, E., Waterton, C., Neves, K. & Buizer, M. (2013). Rethinking biodiversity: From goods and services to "living with". *Conservation Letters*, 6. doi: https://doi.org/10.1111/j.1755-263X.2012.00307.x.

U.S. Department of Agriculture. (2015). *Stream Corridor Restoration: Principles, Processes, and Practices*: CreateSpace Independent Publishing Platform.

Ulrich, R. (1984). View Through a Window May Influence Recovery from Surgery. *Science (New York, N.Y.)*, 224: 420-1. doi: 10.1126/science.6143402.

Ulvin, P. B., Nematpoor, S., Elster, K., Honningsøy, K. H. & Reisjå, M. (2023). FNs klimapanel sender en «siste advarsel»: – Nå teller alle valg. *NRK*. Available at: https://www.nrk.no/klima/fns-klimapanel-sender-en-_siste-advarsel__-_-na-teller-alle-valg-1.16327262.

UN News. (2022a). *COP27: Protecting biodiversity is protecting the Paris Agreement*. Climate and Environment: United Nations. Available at: https://news.un.org/en/story/2022/11/1130677 (accessed: 05.05.23).

UN News. (2022b). *'Without nature, we have nothing': UN chief sounds alarm at key UN biodiversity event*. Global Perspective Human stories: United Nations. Available at: https://news.un.org/en/story/2022/12/1131422 (accessed: 04.05.23).

UNDP. (2023). *What are the Sustainable Development Goals?*: United Nations Development Programme Available at: https://www.undp.org/sustainable-development-goals?gclid=Cj0KCQjw0tKiBhC6ARIsAAOXutk9pg0eFmN4X-3ptoU1GW15N4AmwltACy7JQy3IDZEsYj4A3HilencaAhNnEALw_wcB.

UNEP. (n.d.-a). *Facts about the nature crisis* : unep. Available at: https://www.unep.org/facts-about-nature-crisis (accessed: 04.05.23).

UNEP. (n.d.-b). *UN Biodiversity Conference (COP 15)*: UN environment programme. Available at: https://www.unep.org/un-biodiversity-conference-cop-15 (accessed: 04.05.23).

United Nations. (1946). *The Constitution of the World Health Organization* New York

United Nations. (n.d.-a). *The 17 Goals*: UN. Available at: https://sdgs.un.org/goals (accessed: 14.01.23).

United Nations. (n.d.-b). *Population*. Global Issues. Available at: https://www.un.org/en/global-issues/population (accessed: 05.05.23).

University of Minnesota: School of Public Health. (n.d.). *About the Socio-Ecological Model*: Center for Leadership Education in Maternal & Child Public Health. Available at: https://mch.umn.edu/sem/ (accessed: 3.05.23).

Wacherhausen, S. (1994). *Et åbent sundhedsbegreb - mellom fundamentalisme og relativisme*. Sundhedsbegreber. Filosofi og praksis. . Århus: Philosophia.

Weller, R. (2014). Stewardship Now? Reflections on Landscape Architecture's Raison d'être in the 21st Century. *Landscape Journal*, 33 (2): 85-108.

Westley, F., Olsson, P., Folke, C., Homer-Dixon, T., Vredenburg, H., Loorbach, D., Thompson, J., Nilsson, M., Lambin, E., Sendzimir, J., et al. (2011). Tipping Toward Sustainability: Emerging Pathways of Transformation. *Ambio*, 40: 762-80. doi: 10.1007/s13280-011-0186-9.

White, M. P., Elliott, L. R., Grellier, J., Economou, T., Bell, S., Bratman, G. N., Cirach, M., Gascon, M., Lima, M. L., Lõhmus, M., et al. (2021). Associations between green/blue spaces and mental health across 18 countries. *Scientific Reports*, 11 (1): 8903. doi: 10.1038/s41598-021-87675-0.

WHO. (2015). *Public Health Implications of Excessive Use of the Internet, Computers, Smartphones and Similar Electronic Devices: Meeting report*. Main Meeting Hall, Foundation for Promotion of Cancer Research National Cancer Research Centre, Tokyo, Japan: World Health Organization.

WHO. (2018). *Global action plan on physical activity 2018–2030: more active people for a healthier world.* Geneva: World Health Organization.

WHO. (2022). *Climate change* : World Health Organization. Available at: https://www.who.int/health-topics/climate-change#tab=tab_1 (accessed: 04.05.23).

Wiens, J. A. (1976). Population Responses to Patchy Environments. *Annual Review of Ecology and Systematics*, 7 (1): 81-120. doi: 10.1146/annurev.es.07.110176.000501.

Wiens, J. A. & Milne, B. T. (1989). Scaling of 'landscapes' in landscape ecology, or, landscape ecology from a beetle's perspective. *Landscape Ecology*, 3 (2): 87-96. doi: 10.1007/BF00131172.

Wildlife & Countryside Link. (2015). *Joint Links Further Evidence Submission - The "ecosystem services" approach and the Nature Directives*. Joint links. wcl.org.uk. Available at: https://www.wcl.org.uk/docs/Joint_Links_The_Eco_Ser_App_and_Nature_Directives.pdf (accessed: 07.05.23).

Wilson, E. O. (1984). *Biophilia*. Cambridge, MA: Harvard University Press.

Wilson, S. (2000). Ecological consequences of habitat heterogeneity. *Heterogeneity, diversity and scale in plant communities*: 53-69.

Wittmer, H. & Haripriya, G. (2012). *The economics of ecosystems and biodiversity in local and regional policy and management.* : Routledge.

World Wildlife Fund. (n.d.). *What is the sixth mass extinction and what can we do about it?* Washington, DC. Available at: https://www.worldwildlife.org/stories/what-is-the-sixth-mass-extinction-and-what-can-we-do-about-it (accessed: 07.04.23).

Worldometer. (n.d.). *Largest Countries in the World (by area)*. Geography: worldometers.ino (accessed: 05.05.23).

Wu, J. & Hobbs, R. (2007). Landscape ecology: The-state-of-the-science. In, pp. 271-287.

Wu, J. (2013). Landscape Ecology. In *Ecological Systems*, pp. 179-200.

Wurtzebach, Z. & Schultz, C. (2016). Measuring Ecological Integrity: History, Practical Applications, and Research Opportunities. *BioScience*, 66 (6): 446-457. doi: 10.1093/biosci/biw037.

WWF. (2022). *Living Planet Report 2022 – Building a naturepositive society*. In Almond, R. E. A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (eds). Gland, Switzerland: WWF.

Yang, B. & Li, S. (2016). Design with Nature: Ian McHarg's ecological wisdom as actionable and practical knowledge. *Landscape and Urban Planning*, 155: 21-32. doi: https://doi.org/10.1016/j.landurbplan.2016.04.010.

Appendices

Appendix 1
Reference list for appendix 1

Appendix 1

Infrastructure - mobility
Social system
Enables movement and connectivity.

Ecological system
Mobility infrastructure like roads or rail roads have profound effects on the ecological system. Examples are traffic intensity, roadside vegetation, integration of roads in the landscape, road(side) attractiveness, mitigation measures, habitat juxtaposition and barrier alternatives (figure 3.8, Müller & Berthoud, 1997). Müller & Berthoud (1997) developed a theoretical model that illustrated the relationship between the barrier effect and the traffic intensity on fauna trying to pass a road. The number of roadkills would only increase linearly until the barrier effect would reach 100 % in preventing crossings either through fences or traffic noise/light with the similar effect (Müller & Berthoud, 1997).

Insects like pollinators are alsov negatively impacted by infrastructure as high mortality rates are found due to collisions with vehicles that can have cascading ecological effects (Baxter-Gilbert et al., 2015).

Infrastructure – fences
Social
Fences are put off to define boundaries between different patches, properties, activates or dangers. They can have a limiting movement effect as barrier, however that is intentional or desired most times.

Ecological
Fences are suggested to be the most common form of human infrastructure in the world, estimated to be 10 times greater the length than all roads on the globe (Jakes et al., 2018). Fences have significant ecological impacts on multiple scales from physiology (e.g. injury or fitness), behaviour (e.g. movement, foraging, migration, predation), population (e.g. disutrbiton, direct and indirect mortality, population isolation, demography), community (e.g. composition, multitrophic effects, disease susceptitbility), ecosystem (e.g. ecosystem processes, habitat state, erosion) to human effects (McInturff et al., 2020). Fences have the power to reorganize whole ecosystems globally and create more losers than winders (McInturff et al., 2020). Photo of the ecological impact of the Mexican wall.

Infrastructure - grey surfaces
Social
One of the effects of grey facades is the impact they on the urban heat island effect of increasing surface temperatures by "trapping" the heat when absorbing solar radiation (Qi et al., 2019). Color, thickness, melting temperature and construction materials are some of the variables that determine the extent that grey surfaces impede solar reflection (Qi et al., 2019). In addition, grey surfaces can be less stimulating aesthetically to the human mind than more natural looking surfaces according to the Biophilia hypothesis (Kellert & Wilson, 1993).

Ecological
Reflective and clear panes are the most fatal surfaces for birds due to collisions (Klem et al., 2009; Parkins et al., 2015). 1 billion bird deaths (of both migratory and local birds) annually are due to the collision with glass in the U.S, 60 million deaths are due to vehicular collisions and 400 000 to wind turbines (Klem et al., 2009).

Environmental
Urban heat-island effect increases energy consumption for cooling as well as other effects (Azkorra et al., 2015; Weso□owska & Laska, 2019).

Infrastructure - green surfaces/walls
Social
Green walls can reduce local noise intensity of up to 10 dB (Wong et al., 2010) and laboratory experiments achieved higher noise buffering potential in green walls (Azkorra et al., 2015). Other benefits are energy savings due to the cooling and insulating effect vegetation can have, reducing the urban heat island effect by lowering surface temperatures and providing storm-water control and even improve indoor air-quality (Azkorra et al., 2015; Weso□owska & Laska, 2019).

Ecological
Green walls can support biodiversity as well as other properties provided by urban green (Azkorra et al., 2015).

Environmental
Green walls reduce urban heat island effect which lowers energy consumption and surface temperatures, provide storm-water control, air purification, pollutant dispersion and other properties of urban greenery (Azkorra et al., 2015; Weso□owska & Laska, 2019).

Infrastructure - grey roofs
Environmental
Grey roofs function like other grey structures in the ground by increasing the urban heat island effect, increase surface run-off etc. By transforming grey roofs to contain solar panels their environmental contribution increases.

Infrastructure - green, vegetated roofs
Social
Green roofs provide new possibilities for urban greenery as a both land-efficient and public or private recreational space (Kotzen, 2018). Green roofs offer social and aesthetical values like urban greenery (i.e. cultural provision), possibilities for community cohesion through activities like urban farming with health and well-being benefits (Kotzen, 2018). Today most green roofs are private property but examples exist of public, green roof"parks" like Økern Portal in Oslo with a running strip, beehives, an urban food-forest

and biodiversity-supporting vegetation and elements (Hansen & Espedal, 2021).

Ecological
Can enrichen biodiversity, support pollinators, provide habitat to ground nesting birds that is free from disturbances and threats that are typically found on the ground (e.g. humans, pets, predators) (Li & Yeung, 2014). However there are limitations to the conservational prospect of green roofs as they are not equivalent to ground-level habitats, and according to Williams et al. (2014) this needs to be investigated further. Photo bird nest Braathen

Environmental
Contribute to hydrologic and energy saving benefits of reducing the urban heat island effect, enriching the urban environment by purifying the air and runoff water, delaying storm peaks to drainage systems and diminish runoff quantity (Li & Yeung, 2014; Williams et al., 2014). Additional benefits are similar to the ones provided by urban green.
If covering a grey roof with solar panels one achieves an environmental contribution of green energy.

Sports facilities w. artificial turf (add photo from bygdøy)
Social
Artificial turf enables sport activity all year round without seasonal and weather limitations like those of natural grass and a higher usage capacity compared to natural turf (Burton, 2021).

Ecological
Compared to natural turf there are benefits with artificial turf of saving water, the need for maintenance ceases like mowing, using pesticides or herbicides to remove weeds (Burton, 2021; Walker & Branham, 2020). However, by leaches of rubber crumb into nature there is microplastic pollution of waterways, oceans, natural ecosystems and ultimately biodiversity that are significant (Burton, 2021).

Environmental
Artificial turf is promoted as a water saving and low maintenance replacement for natural grass (Cheng et al., 2014). However the infill material typically used comes from scrap tires and this rubber crumb contains organic contaminants and heavy metals that can leak out to nature with surface rainwater or volatilize into the air (Cheng et al., 2014). Sports fields are sources of microplastic emissions with a 7 % share of total microplastic emissions in Switzerland (Frischknecht et al., 2021).

Urban green – these effects are present in all vegetation structures

Social

Environmental psychology has become increasingly relevant to understand the public health impacts of the ecosystems most people in the world inhibit - cities. The stressors in the city are linked to an array of public health challenges like increased chances of experiencing anxiety and mood disorders (Peen et al., 2010). Urban stressors provoke neural responses linked to emotional regulation, depression, stress and anxiety and linked environmental risk factors in the urban environment to social stress processing (Lederbogen et al., 2011). Urban noise, light, traffic, density of people and activity are some of the present attributes of the city, with light-, noise- and air pollution often following them with negative contributions (see further down).

Urban nature can deliver a range of mental and physical health benefits and is increasingly considered a cost-effective tool for planning and achieving healthy cities (Shanahan et al., 2014). Experiences of urban nature is proven to reduce stress in a daily life context and health promoting effects like faster hospital recovery due to a natural view is one of the impacts (Hunter et al., 2019; Ulrich, 1984). Nature provides direct physiological health benefits of air, pollution and water purification, decreased urban heat island effect, protection of floods and extreme weather events (Remme et al., 2021). Links are also found between the chances people are of undertaking physical activity and the natural elements present in their environment (Shanahan et al., 2014). Physical activity undertaken in natural environments even reduces the risk of poor mental health more significantly than when undertaken in other environments (Mitchell, 2013).

Some of the most highly valued services of ecosystems are the cultural ones of outdoor recreation, natural beauty and community identity (Elderbrock et al., 2020). The recreational aspects of natural environments offering recreation, physical activity, play and the connection it enables to nature, seeing wildlife and biodiversity are highly valued by the public (Bolund & Hunhammar, 1999).

Ecological

Urban green spaces are invaluable for biodiversity conservation in cities worldwide (Aronson et al., 2017). Green corridors, green surfaces like walls or roofs, green patches of parks, public and private gardens, riparian corridors and remnant vegetation patches are biodiversity supporting elements (Aronson et al., 2017). Urban areas provide habitat to support biodiversity (Muñoz-Pedreros et al., 2018)Vegetation also improves microbiotic conditions in the soil that provides a number of ecosystem services to the ecological, social and environmental system.

Environmental

The spill-over effect from the hinterlands (i.e. surrounding areas) of cities is detrimental for cities according to a study of the 29 largest cities in the Baltic Sea region (Folke et al., 1997). It was estimated that these cities needed areas that provided ecosystem support at least 500-1000 times larger than the area of the cities themselves, for both input and taking care of the output of the cities (Folke et al., 1997). This illustrates the need of ecosystem services for cities, with a similarly positive effect from natural areas situated in them. The ecosystem services provided by green areas that impact the microclimatic conditions are multiple, like reducing the urban heat island effect, manage stormwater, air and water purification, carbon sequestration and storage and so forth. (need source as I mention it all further down?)

Public green

Social

The value of public green is great in an urban matrix' with societies comprising of different people with different backgrounds and opportunities to connect with nature. Having publicly accessible green spaces that are free and available to all, even at night is a public health investment that benefits all ages and socio-economic groups (European Environment Agency, 2022). Living, working or being educated near blue/green spaces improve cognitive and immune functioning, enhance physical activity, improve mental health and social cohesion, improve metarnal and foetal outcomes, relaxation and restoration, reduce cardiovascular morbidity and mortality (European Environment Agency, 2020; European Environment Agency, 2022). The degree of accessibility and greening across neighborhoods often vary, but WHO recommends a minimum distance of 300m to green spaces to all to ensure the multiple health- and well-being benefits to all (European Environment Agency, 2022). In Oslo, immigrants and low-imcome households have relatively less access to green spaces for outdoor recreation than non-immigrants (Suárez et al., 2020). Involving local communities in design and management processes of green space foster sustained use over time and a sense of ownership and care (European Environment Agency, 2022).

Ecological

Recreational and human activity have major impacts on the vegetated features in an urban area due to movement, use, vandalism, light and noise that comes with human use of green elements (Erfanian et al., 2021). Visitor load and type of activity determines the effects it can have on the ecological system, both vegetation, soil health and biodiversity (Erfanian et al., 2021). Most wild animals shy humans and human activity and therefore urban environments can be stressful for species. Some species can even adapt to human interactions, like certain types of birds or roedeer that are periodically seen in urban environments like Oslo.

Individual trees

Social

Provides cultural ecosystem services of recreation, aesthetical beauty, psychologhical benefits, community identity and belonging, well-being and public health benefits (Jansson et al., 2013). Trees can achieve a strong identity function for a place, communal belonging and positively impact a neighborhood by providing seasonal variations in addition to above mentioned ecosystem services of different types (Cimburova & Berghauser Pont, 2021).

Ecological

Can function as habitat or resource to a number of species. Trees with flowers or fruits have a bigger ecological function to support biodiversity like pollinating insects. Leaf litter and other plant residuals can be used as compost to enrichen the soil and cycle nutrients.

Environmental
There are differences in the provision of ecosystem services from different tree species. Coniferous trees with a larger total surface leaf area have a bigger capacity to filter the air and provide ecosystem services during the worst months for air quality in the winter and have a longer seasonal value (Bolund & Hunhammar, 1999). Deciduous trees loose their leaves in the winter months, and therefore provided limited ecosystem services (e.g. air filtering and aesthetical value) in the winter season. However, coniferous trees are more sensitive to air pollution than deciduous trees so a mixed species planting is optimal for maximized filtering capacity from vegetation and maximized aesthetical value (Bolund & Hunhammar, 1999).

Tree rows or alleys
Social
Often act as a structural component in streets, along roads and where there is limited space, and some times budget for urban green (Weber et al., 2014). Vegetation that is suitable along movement corridors to add in ecological and aesthetical values. Trees are important to city dwellers in this consent, as well as other types of roadside vegetation that are less planted or maintained (Weber et al., 2014). People valued ecological and economical function over orderliness (Weber et al., 2014).

Ecological
Together with patch area and quality, green corridors, like tree rows or alleys have been proven to be most significant to support biodiversity in urban environments (Beninde et al., 2015). Trees with flowers or fruits have a bigger ecological function to support biodiversity like pollinating insects. In addition, as Weber et al. (2014) argued, cultivated and wild roadside vegetation offer cheaper and space-saving opportunities for biodiversity conservation and enhancement in cities.

Environmental
Street trees have been reported to be able to filter up to 70 % of air pollution (Bolund & Hunhammar, 1999) and adding in the aspect of different tree species' air filtering capacity gives many options for maximizing the ecosystem services available (further up on coniferous and deciduous).

Heterogenous vegetation patches (structure, layers, vegetation types, function)
Social
An overall increased provision of ecosystem services of cultural, regulating, provisioning and supporting character has been linked to habitat or vegetation heterogeneity. With a diverse planting there is naturally an increased aesthetical heterogeneity and value, more biomass to provide services like carbon sequestration and storage, air filtering, water infiltration and evapotranspiration, bigger capacity to buffer noise and light and so forth. Studies on diverse, heterogenous forests even showed an increase in ecosystem services like higher berry production due to an overall increased biomass productivity and understory species richness (Gamfeldt et al., 2013). However, the perceived feeling of safety might be threatened with heterogenous vegetation patches. Possibilities for overview and control, landscape design, vegetation density, character and maintenance are some of the aspects that are highlighted to be of importance for perceived personal safety (Jansson et al., 2013). Jansson et al. (2013) suggest vegetation of an open character to have more positive effects, with an undergrowth of low density. According to Suàrez et al. (2020) the preferred green space for recreation for residents in Oslo is large wooded areas with dense tree vegetation and presence of water, however preferences differ depending on place of residence and age. Other identified preferences are colorful, native flowers, trees that provide shade, grass and food-bearing plants that can support native species as habitat (Talal et al., 2021). The recurring preference for relatively dense urban vegetation speaks for a heterogeneous preference in the public (Bjerke et al., 2006). In addition, Talal et al. (2021) found that visitors desired to learn more about plants so installing signs or labels can help educate and engage visitors further (Talal et al., 2021).

Ecological
Different types of vegetation offer different extents of ecosystem services so a mixed planting would optimize the extent of ecosystem services provided (Elderbrock et al., 2020).
The relationship between resource heterogeneity and biodiversity is complex and has been much studied with varying results. Diversity patterns have been explained by habitat heterogeneity as one of the primary drivers (Thomsen et al., 2022). Thomsen et al. (2022) described three axes of habitat heterogeneity to be a) amount of habitat b) its morphological complexity (i.e. the arrangement of spatial and structural components like plants, animals and microorganisms, their shape and size and the relationships between (Villee, 2018)) and c) the ecological resources available, like food.

They concluded that the positive and additive effects from habitat heterogeneity proves the biodiversity promoting impact it can have "via cascades of facilitative interactions" (Thomsen et al., 2022). Not only does habitat heterogeneity impact biodiversity, but biodiversity also impacts the functioning of ecosystems (Tylianakis et al., 2008). Tylianakis et al. (2008) suggested that biodiversity might have the greatest impact on the functioning of diverse naturally, heterogeneous ecosystems" showing a positive effect from biodiversity (Tylianakis et al., 2008). One study claimed different, that with increasing habitat heterogeneity the effective area available for given species would decrease – making a tradeoff between environmental heterogeneity and amount of suitable habitat area and thus biodiversity (Allouche et al., 2012). Studies on species diversity in forests have shown benefits of higher biomass- and game productivity and increased understory plant species richness (Gamfeldt et al., 2013; Vilà et al., 2007).

Environmental
Some of the ecosystem services that urban ecosystems can provide were analyzed by Elderbrock et al. (2020) to detect the provisioning difference of vegetation types. They monitored Runoff retention of e.g. stormwater, air purification, carbon storage, cooling fraction and recreation and found strong differences of different vegetation types. Lawn/grass provided the biggest share of services when it came to runoff retention, recreation and cooling fractions followed by trees (Derkzen et al., 2015; Elderbrock et al., 2020). Trees on the other hand provided the biggest share of services when it came to air purification, carbon storage and cooling fraction together with woodlands and shrubs (Elderbrock et al., 2020). Jonsson et al. (2019) studied the relation between mixed forest stands and provision of ecosystem services

and found that plant monocultures provided less ecosystem services than mixed forest stands with a composition and degree of mixing types and ages. Additional benefits from diverse forests are increased soil carbon storage (Gamfeldt et al., 2013).

Impermeable ground cover
Social system
Enables universal design and movement all year round during all weather and seasons. Enables vehicle, biking and pedestrian movement. Often asphalt, concrete, tiles or bricks. Necessary with literature?

Ecological system
Impermeable surfaces have significant effects on the exchange of water, materials and gasses between the atmosphere and soil (Hu et al., 2018). Soil bacteria communities were analyzed for different surfaces in Beijing where it was found that the impermeable surface presented a lower bacterial diversity than vegetated surfaces, with changes in bacterial community composition (Hu et al., 2018). Interactions between soil properties and heavy metals were found to be the cause of this change (Hu et al., 2018).

Environmental system
Impermeable surfaces lead to increased surface water run-off that lead to increased vulnerability to street flooding and degrades water quality through the pick-up of street pollutants (Bolund & Hunhammar, 1999). In densely populated areas impermeable surfaces together with higher extractions of water cause decreasing groundwater levels (Bolund & Hunhammar, 1999). This increases the vulnerability to climate change with a prediction of more frequent extreme weather events.

Permeable ground cover
Social
Permeable ground coverages enable a hard surface that at the same time provide ecosystem services. These can be suspended pavements or pavement types like permeable asphalt types, reinforced concrete or bricks and grillage that infiltrate surface water (Çelik, 2013).

Ecological
Can impact nutrient load and cycling in the soil (Minixhofer & Stangl, 2021).

Environmental
Can provide stormwater management, water pollution filtration and to varying extent impact the nutrient load and the soil carbon storage ability (Minixhofer & Stangl, 2021).

Permeable vegetated ground cover
Social
Besides stormwater management some of the contributions are decreasing noise, the urban heat island effect and water availability (Minixhofer & Stangl, 2021). In addition vegetation has health and well-being effects as well as contributing with aesthetical value (Minixhofer & Stangl, 2021). Vegetation also improve soil community biota by increasing soil biodiversity and this have multiple benefits to human health by suppressing pathogens, shaping a beneficial human microbiome, promoting immune fitness and remediating soil (Sun et al., 2023).

Ecological
Providing biodiversity and ecological benefits, increasing the nutrient load, increasing water availability and managing metal pollution are some of the ecological benefits (Minixhofer & Stangl, 2021). In addition this surface has a higher composition of bacterial community in the soil (e.g. lawn, shrub coverage or roadside trees) that are important for a number of ecosystem services provided by soil such as soil structure, aggregation, recycling of nutrients and water recycling (Hoorman, 2016; Hu et al., 2018). Soil biodiversity is positive for plant productivity, organic matter decomposition, plant-soil mutualism, antibiotic resistance regulation and support microbial activity (Bastida et al., 2021; Fan et al., 2023).

Environmental
In vegetation-free cities around 60 % of the rain water is led off through drains while only 5-15% is led to drainage systems in vegetated areas due to evaporation or infiltration (Bernatzky, 1983). The urban heat island effect is strongly reduced by vegetation and evapotranspiration as well as air quality being improved in addition to other ecosystem services like carbon storage (Minixhofer & Stangl, 2021).

Light pollution
Social system
The world atlas of artificial sky luminance was published in 2016 to show the extent of light pollution in the world (Falchi et al., 2016). More than 80 % of the world and more than 99 % of the population in the U.S and Europe live under light polluted skies (Falchi et al., 2016). Light pollution affects the ability to see stars in the night sky, the Milky Way and perturbates the darkness that comes with the night and night-vision (Chepesiuk, 2009). Light pollution can occur as sky glow, light trespass of unwanted light "spillover", horizontal glare or be a result of overillumination like a lit office building at night (Chepesiuk, 2009). Add photo of night sky oslo form phone. Links have been drawn between light pollution and health in multiple studies in relation to sleep and sleep disturbances like effects on melatonin and the circadian clock due to light (Chepesiuk, 2009). These links have made lighting an expressed public health issue (Pauley, 2004).

Positive effects of outdoor lighting
The feeling of safety to pedestrians and people in urban areas after dark increases with public space lighting (Haans & de Kort, 2012; Kaplan & Chalfin, 2022; Portnov et al., 2020). Therefore outdoor lighting also acts as a source to the social system.

Ecological system
Many claim that the biological world mainly is organized after light (Gaston et al., 2013). The spreading artificial lighting of human settlement and transport networks has provided perturbations to natural light regimes and therefore has proven to impact the ecological systems (Gaston et al., 2013). Artificial light encroaches in former natural environments and disrupts natural cycles of light and darkness that impact photosynthesis, circadian clocks, photoperiodism, spatial orientation, light environments and other ecological and ecosystem processes (Gaston et al., 2013). Light pollution increases the environmental pressures on insects and Grubisic et al. (2018) argue that this needs to be considered as a causal factor of insect decline worldwide. Light can change animal navigation, change predator-prey alteration, change competitive interactions and affect physiology (Longcore & Rich, 2004). The orientation or disorientation animals can experience by artificial light sources they are either attraction or repulsed to by glare have negative effects on foraging, reproductivity, communication and other behaviours in the ecological community (Longcore & Rich, 2004). (picture grasshopper hytta).

Another study found a negative relation between photosynthetic activity of plants growing near street lights, with adverse effects on several parameters – indicating some sort of stress in the plants (Meravi & Kumar Prajapati, 2020). A 13 year dataset of the UK was used to analyze budburst data matched with satellite imagery of night-time light and average spring temperatures (ffrench-Constant et al., 2016). Budburst in trees came 7.5 days earlier in brighter areas, and this was independently from the urban heat island effect that occur in denser urban areas that might increase spring temperatures (ffrench-Constant et al., 2016). Another study adds in the acceleration in spring leaf development by up to 20 days of urban trees exposed to light pollution and that fall colour change was delayed by nearly six days on average (Czaja & Ko□ton, 2022; Meng et al., 2022).

Noise pollution
Social system
Noise has become one of the main environmental challenges of the WHO European Region with an increasing trend of public complaints (World Health Organization, 2010). Noise pollution sources are road traffic, railway, aircraft, wind turbines and leisure activities (World Health Organization, 2022). WHO reports that traffic noise alone damages the health of almost every third person in the European Region of the WHO and that every fifth European is regularly exposed to significantly health damaging sound levels at night (World Health Organization, 2010). Some of the health effects with both long- and short term are cardiovascular effects, sleep disturbance, poorer work and school performance, hearing impairment and so forth (World Health Organization, 2010).

Ecological system
It has been found that noise pollution also has significant effects on the ecological system with effects from DNA repair, gene expression and cell structure to physiological, behavioural and community level (Kight & Swaddle, 2011). Acoustic stress can impact avian, aquatic and terrestrial species, individuals, communities and have both direct (e.g. acoustically oriented birds) and indirect impacts like on predator-prey interactions or on reverberates like grasshoppers (Francis et al., 2012; Senzaki et al., 2020).

Vegetation to mediate noise pollution
Noise reduction is an acute matter for the public health of the population and an estimation of the cost of noise was in 1998 0.2-2% of GDP in the EU (Bolund & Hunhammar, 1999). A vegetated lawn decreases the noise level to the same extent as doubling the distance to the noise source (3dB), and dense or wide plantations can lower them even more (3-6dB). Water can on the other hand carry the noise long distances (Bolund & Hunhammar, 1999). Moderate plantings have been shown to reduce traffic noise by 50 % with an optimal depth of 5m on the vegetation barriers (Ow & Ghosh, 2017). This study showed that vegetative barriers with moderate to dense plantings were able to reduce traffic noise by 9-11dB (Ow & Ghosh, 2017). Synthetical (man-made) noise barriers were inferior to tree belts with consideration to the noise buffering effects and the psychological value they provide (Ow & Ghosh, 2017). Also green walls can buffer noise pollution, in Singapore it was found that green facades could reduce the local sound intensity up to 10 dB (Wong et al., 2010). The annoyance responses or perception of chronic noise exposure in humans are accentuated to be reduced by vegetation as a psychological buffer, however these study results are inconsistent (Dzhambov & Dimitrova, 2014).

Appendix 1 reference list

Allouche, O., Kalyuzhny, M., Moreno-Rueda, G., Pizarro, M. & Kadmon, R. (2012). Area–heterogeneity tradeoff and the diversity of ecological communities. *Proceedings of the National Academy of Sciences*, 109 (43): 17495-17500. doi: doi:10.1073/pnas.1208652109.

Aronson, M. F., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., MacIvor, J. S., Nilon, C. H. & Vargo, T. (2017). Biodiversity in the city: key challenges for urban green space management. *Frontiers in Ecology and the Environment*, 15 (4): 189-196. doi: https://doi.org/10.1002/fee.1480.

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Bures, S., Álvaro, J. E., Erkoreka, A. & Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. *Applied Acoustics*, 89: 46-56. doi: https://doi.org/10.1016/j.apacoust.2014.09.010.

Bastida, F., Eldridge, D. J., García, C., Kenny Png, G., Bardgett, R. D. & Delgado-Baquerizo, M. (2021). Soil microbial diversity–biomass relationships are driven by soil carbon content across global biomes. *The ISME Journal*, 15 (7): 2081-2091. doi: 10.1038/s41396-021-00906-0.

Baxter-Gilbert, J. H., Riley, J. L., Neufeld, C. J. H., Litzgus, J. D. & Lesbarrères, D. (2015). Road mortality potentially responsible for billions of pollinating insect deaths annually. *Journal of Insect Conservation*, 19 (5): 1029-1035. doi: 10.1007/s10841-015-9808-z.

Beninde, J., Veith, M. & Hochkirch, A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters*, 18 (6): 581-592. doi: https://doi.org/10.1111/ele.12427.

Bernatzky, A. (1983). *The effects of trees on the urban climate. Trees in the 21st Century*. Berkhamster: Academic Publishers.

Bjerke, T., Østdahl, T., Thrane, C. & Strumse, E. (2006). Vegetation density of urban parks and perceived appropriateness for recreation. *Urban Forestry & Urban Greening*, 5 (1): 35-44. doi: https://doi.org/10.1016/j.ufug.2006.01.006.

Bolund, P. & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, 29 (2): 293-301. doi: https://doi.org/10.1016/S0921-8009(99)00013-0.

Burton, K. (2021). *Natural Grass vs Synthetic Turf Decision Making Guide*: The Government of Western Australia. Available at: https://www.dlgsc.wa.gov.au/sport-and-recreation/facility-management/natural-grass-vs-synthetic-turf-decision-making-guide (accessed: 19.04.23).

Çelik, F. (2013). Sustainability with landscape design: the example of Sille (Konya-Turkey). *International Journal of Academic Research*, 5: 134-142. doi: 10.7813/2075-4124.2013/5-4/A.19.

Cheng, H., Hu, Y. & Reinhard, M. (2014). Environmental and Health Impacts of Artificial Turf: A Review. *Environmental Science & Technology*, 48 (4): 2114-2129. doi: 10.1021/es4044193.

Chepesiuk, R. (2009). Missing the dark: health effects of light pollution. *Environ Health Perspect*, 117 (1): A20-7. doi: 10.1289/ehp.117-a20.

Cimburova, Z. & Berghauser Pont, M. (2021). Location matters. A systematic review of spatial contextual factors mediating ecosystem services of urban trees. *Ecosystem Services*, 50: 101296. doi: https://doi.org/10.1016/j.ecoser.2021.101296.

Czaja, M. & Kołton, A. (2022). How light pollution can affect spring development of urban trees and shrubs. *Urban Forestry & Urban Greening*, 77: 127753. doi: https://doi.org/10.1016/j.ufug.2022.127753.

Derkzen, M. L., van Teeffelen, A. J. A. & Verburg, P. H. (2015). REVIEW: Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. *Journal of Applied Ecology*, 52 (4): 1020-1032. doi: https://doi.org/10.1111/1365-2664.12469.

Dzhambov, A. & Dimitrova, D. (2014). Urban green spaces' effectiveness as a psychological buffer for the negative health impact of noise pollution: A systematic review. *Noise and Health*, 16 (70): 157-165. doi: 10.4103/1463-1741.134916.

Elderbrock, E., Enright, C., Lynch, K. A. & Rempel, A. R. (2020). A Guide to Public Green Space Planning for Urban Ecosystem Services. *Land*, 9 (10). doi: https://doi.org/10.3390/land9100391.

Erfanian, M. B., Alatalo, J. M. & Ejtehadi, H. (2021). Severe vegetation degradation associated with different disturbance types in a poorly managed urban recreation destination in Iran. *Scientific Reports*, 11 (1): 19695. doi: 10.1038/s41598-021-99261-5.

European Environment Agency. (2020). *Healthy environment, healthy lives: how the environment influences health and well-being in Europe*, ISSN 1977-8449. Luxembourg: Publications Office of the European Union.

European Environment Agency. (2022). ***Who benefits from nature in cities? Social inequalities in access to urban green and blue spaces across Europe***: European Environment Agency.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C. C. M., Elvidge, C. D., Baugh, K., Portnov, B. A., Rybnikova, N. A. & Furgoni, R. (2016). The new world atlas of artificial night sky brightness. *Science Advances*, 2 (6): e1600377. doi: doi:10.1126/sciadv.1600377.

Fan, K., Chu, H., Eldridge, D. J., Gaitan, J. J., Liu, Y.-R., Sokoya, B., Wang, J.-T., Hu, H.-W., He, J.-Z., Sun, W., et al. (2023). Soil biodiversity supports the delivery of multiple ecosystem functions in urban greenspaces. *Nature Ecology & Evolution*, 7 (1): 113-126. doi: 10.1038/s41559-022-01935-4.

ffrench-Constant, R. H., Somers-Yeates, R., Bennie, J., Economou, T., Hodgson, D., Spalding, A. & McGregor, P. K. (2016). Light pollution is associated with earlier tree budburst across the United Kingdom. *Proceedings of the Royal Society B: Biological Sciences*, 283 (1833): 20160813. doi: doi:10.1098/rspb.2016.0813

Folke, C., Jansson, Å., Larsson, J. & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio*, 26 (3): 167-172.

Francis, C. D., Kleist, N. J., Ortega, C. P. & Cruz, A. (2012). Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. *Proc Biol Sci*, 279 (1739): 2727-35. doi: 10.1098/rspb.2012.0230.

Frischknecht, R., Dinkel, F., Braunschweig, A., Ahmadi, M., Kägi, T. & Krebs, L. (2021). *Ökofaktoren Schweiz 2021 gemäss der Methode der ökologischen Knappheit*. Bern: Bundesamt für Umwelt.

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M. C., Fröberg, M., Stendahl, J., Philipson, C. D., et al. (2013). Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications*, 4 (1): 1340. doi: 10.1038/ncomms2328.

Gaston, K. J., Bennie, J., Davies, T. W. & Hopkins, J. (2013). The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological Reviews*, 88 (4): 912-927. doi: https://doi.org/10.1111/brv.12036.

Grubisic, M., van Grunsven, R. H. A., Kyba, C. C. M., Manfrin, A. & Hölker, F. (2018). Insect declines and agroecosystems: does light pollution matter? *Annals of Applied Biology*, 173 (2): 180-189. doi: https://doi.org/10.1111/aab.12440.

Hansen, V. B. & Espedal, J. T. (2021). Bli med opp på Nord-Europas største spiselige takpark. *Aftenposten*. Available at: https://www.aftenposten.no/oslo/i/L5owyV/bli-med-opp-paa-nord-europas-stoerste-spiselige-takpark (accessed: 19.04.23).

Hoorman, J. J. (2016). *Role of Soil Bacteria* : Ohioline. Available at: https://ohioline.osu.edu/factsheet/anr-36 (accessed: 19.04.23).

Hu, Y., Dou, X., Li, J. & Li, F. (2018). Impervious Surfaces Alter Soil Bacterial Communities in Urban Areas: A Case Study in Beijing, China. *Frontiers in Microbiology*, 9. doi: 10.3389/fmicb.2018.00226.

Hunter, M. R., Gillespie, B. W. & Chen, S. Y.-P. (2019). Urban Nature Experiences Reduce Stress in the Context of Daily Life Based on Salivary Biomarkers. *Frontiers in Psychology*, 10. doi: 10.3389/fpsyg.2019.00722.

Haans, A. & de Kort, Y. A. W. (2012). Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape. *Journal of Environmental Psychology*, 32 (4): 342-352. doi: https://doi.org/10.1016/j.jenvp.2012.05.006.

Jakes, A. F., Jones, P. F., Paige, L. C., Seidler, R. G. & Huijser, M. P. (2018). A fence runs through it: A call for greater attention to the influence of fences on wildlife and ecosystems. *Biological Conservation*, 227: 310-318. doi: https://doi.org/10.1016/j.biocon.2018.09.026.

Jansson, M., Fors, H., Lindgren, T. & Wiström, B. (2013). Perceived personal safety in relation to urban woodland vegetation – A review. *Urban Forestry & Urban Greening*, 12 (2): 127-133. doi: https://doi.org/10.1016/j.ufug.2013.01.005.

Jonsson, M., Bengtsson, J., Gamfeldt, L., Moen, J. & Snäll, T. (2019). Levels of forest ecosystem services depend on specific mixtures of commercial tree species. *Nature Plants*, 5 (2): 141-147. doi: 10.1038/s41477-018-0346-z.

Kaplan, J. & Chalfin, A. (2022). Ambient lighting, use of outdoor spaces and perceptions of public safety: evidence from a survey experiment. *Security Journal*, 35 (3): 694-724. doi: 10.1057/s41284-021-00296-0.

Kellert, S. R. & Wilson, E. O. (1993). *The Biophilia Hypothesis*, vol. 4: Island Press.

Kight, C. R. & Swaddle, J. P. (2011). How and why environmental noise impacts animals: an integrative, mechanistic review. *Ecol Lett*, 14 (10): 1052-61. doi: 10.1111/j.1461-0248.2011.01664.x.

Klem, D., Farmer, C. J., Delacretaz, N., Gelb, Y. & Saenger, P. G. (2009). Architectural and Landscape Risk Factors Associated with Bird–glass Collisions in an Urban Environment. *The Wilson Journal of Ornithology*, 121 (1): 126-134, 9.

Kotzen, B. (2018). Chapter 4.2 - Green Roofs Social and Aesthetic Aspects. In Pérez, G. & Perini, K. (eds) *Nature Based Strategies for Urban and Building Sustainability*, pp. 273-281: Butterworth-Heinemann.

Lederbogen, F., Kirsch, P., Haddad, L., Streit, F., Tost, H., Schuch, P., Wüst, S., Pruessner, J. C., Rietschel, M., Deuschle, M., et al. (2011). City living and urban upbringing affect neural social stress processing in humans. *Nature*, 474 (7352): 498-501. doi: 10.1038/nature10190.

Li, W. C. & Yeung, K. K. A. (2014). A comprehensive study of green roof performance from environmental perspective. *International Journal of Sustainable Built Environment*, 3 (1): 127-134. doi: https://doi.org/10.1016/j.ijsbe.2014.05.001.

Longcore, T. & Rich, C. (2004). Ecological light pollution. *Frontiers in Ecology and the Environment*, 2 (4): 191-198. doi: https://doi.org/10.1890/1540-9295(2004)002[0191:ELP]2.0.CO;2.

McInturff, A., Xu, W., Wilkinson, C. E., Dejid, N. & Brashares, J. S. (2020). Fence Ecology: Frameworks for Understanding the Ecological Effects of Fences. *BioScience*, 70 (11): 971-985. doi: 10.1093/biosci/biaa103.

Meng, L., Zhou, Y., Román, M. O., Stokes, E. C., Wang, Z., Asrar, G. R., Mao, J., Richardson, A. D., Gu, L. & Wang, Y. (2022). Artificial light at night: an underappreciated effect on phenology of deciduous woody plants. *PNAS Nexus*, 1 (2). doi: 10.1093/pnasnexus/pgac046.

Meravi, N. & Kumar Prajapati, S. (2020). Effect street light pollution on the photosynthetic efficiency of different plants. *Biological Rhythm Research*, 51 (1): 67-75. doi: 10.1080/09291016.2018.1518206.

Minixhofer, P. & Stangl, R. (2021). Green Infrastructures and the Consideration of Their Soil-Related Ecosystem Services in Urban Areas—A Systematic Literature Review. *Sustainability*, 13 (6). doi: https://doi.org/10.3390/su13063322.

Mitchell, R. (2013). Is physical activity in natural environments better for mental health than physical activity in other environments? *Social Science & Medicine*, 91: 130-134. doi: https://doi.org/10.1016/j.socscimed.2012.04.012.

Muñoz-Pedreros, A., González-Urrutia, M., Encina-Montoya, F. & Norambuena, H. V. (2018). Effects of vegetation strata and human disturbance on bird diversity in green areas in a city in southern Chile. *Avian Research*, 9 (1): 38. doi: 10.1186/s40657-018-0130-9.

Müller, S. & Berthoud, G. (1997). *Fauna and Traffic Safety*. Lausanne, CH: LAVOC.

Ow, L. F. & Ghosh, S. (2017). Urban cities and road traffic noise: Reduction through vegetation. *Applied Acoustics*, 120: 15-20. doi: https://doi.org/10.1016/j.apacoust.2017.01.007.

Parkins, K. L., Elbin, S. B. & Barnes, E. (2015). Light, Glass, and Bird—Building Collisions in an Urban Park. *Northeastern Naturalist*, 22 (1): 84-94, 11.

Pauley, S. M. (2004). Lighting for the human circadian clock: recent research indicates that lighting has become a public health issue. *Medical Hypotheses*, 63 (4): 588-596. doi: https://doi.org/10.1016/j.mehy.2004.03.020.

Peen, J., Schoevers, R. A., Beekman, A. T. & Dekker, J. (2010). The current status of urban-rural differences in psychiatric disorders. *Acta Psychiatr Scand*, 121 (2): 84-93. doi: 10.1111/j.1600-0447.2009.01438.x.

Portnov, B. A., Saad, R., Trop, T., Kliger, D. & Svechkina, A. (2020). Linking nighttime outdoor lighting attributes to pedestrians' feeling of safety: An interactive survey approach. *PLOS ONE*, 15 (11): e0242172. doi: 10.1371/journal.pone.0242172.

Qi, J.-D., He, B.-J., Wang, M., Zhu, J. & Fu, W.-C. (2019). Do grey infrastructures always elevate urban temperature? No, utilizing grey infrastructures to mitigate urban heat island effects. *Sustainable Cities and Society*, 46: 101392. doi: https://doi.org/10.1016/j.scs.2018.12.020.

Remme, R. P., Frumkin, H., Guerry, A. D., King, A. C., Mandle, L., Sarabu, C., Bratman, G. N., Giles-Corti, B., Hamel, P., Han, B., et al. (2021). An ecosystem service perspective on urban nature, physical activity, and health. *Proceedings of the National Academy of Sciences*, 118 (22): e2018472118. doi: doi:10.1073/pnas.2018472118.

Senzaki, M., Kadoya, T. & Francis, C. D. (2020). Direct and indirect effects of noise pollution alter biological communities in and near noise-exposed environments. *Proceedings of the Royal Society B: Biological Sciences*, 287 (1923): 20200176. doi: doi:10.1098/rspb.2020.0176.

Shanahan, D. F., Lin, B. B., Bush, R., Gaston, K. J., Dean, J. H., Barber, E. & Fuller, R. A. (2014). Toward Improved Public Health Outcomes From Urban Nature. *American Public Health Association*.

Suárez, M., Barton, D. N., Cimburova, Z., Rusch, G. M., Gómez-Baggethun, E. & Onaindia, M. (2020). Environmental justice and outdoor recreation opportunities: A spatially explicit assessment in Oslo metropolitan area, Norway. *Environmental Science & Policy*, 108: 133-143. doi: https://doi.org/10.1016/j.envsci.2020.03.014.

Sun, X., Liddicoat, C., Tiunov, A., Wang, B., Zhang, Y., Lu, C., Li, Z., Scheu, S., Breed, M. F., Geisen, S., et al. (2023). Harnessing soil biodiversity to promote human health in cities. *npj Urban Sustainability*, 3 (1): 5. doi: 10.1038/s42949-023-00086-0.

Talal, M. L., Santelmann, M. V. & Tilt, J. H. (2021). Urban park visitor preferences for vegetation – An on-site qualitative research study. *Plants, People, Planet*, 3 (4). doi: https://doi.org/10.1002/ppp3.10188.

Thomsen, M. S., Altieri, A. H., Angelini, C., Bishop, M. J., Bulleri, F., Farhan, R., Frühling, V. M. M., Gribben, P. E., Harrison, S. B., He, Q., et al. (2022). Heterogeneity within and among co-occurring foundation species increases biodiversity. *Nat Commun*, 13 (1): 581. doi: 10.1038/s41467-022-28194-y.

Tylianakis, J. M., Rand, T. A., Kahmen, A., Klein, A.-M., Buchmann, N., Perner, J. & Tscharntke, T. (2008). Resource Heterogeneity Moderates the Biodiversity-Function Relationship in Real World Ecosystems. *PLOS Biology*, 6 (5): e122. doi: 10.1371/journal.pbio.0060122.

Ulrich, R. (1984). View Through a Window May Influence Recovery from Surgery. *Science (New York, N.Y.)*, 224: 420-1. doi: 10.1126/science.6143402.

Vilà, M., Vayreda, J., Comas, L., Ibáñez, J. J., Mata, T. & Obón, B. (2007). Species richness and wood production: a positive association in Mediterranean forests. *Ecology Letters*, 10 (3): 241-250. doi: https://doi.org/10.1111/j.1461-0248.2007.01016.x.

Villee, C. A. (2018). *morphology*. Britannica.

Walker, W. J. & Branham, B. (2020). Environmental impacts of turfgrass fertilization. *Golf Course Management & Construction*: 105-219.

Weber, F., Kowarik, I. & Säumel, I. (2014). A walk on the wild side: Perceptions of roadside vegetation beyond trees. *Urban Forestry & Urban Greening*, 13 (2): 205-212. doi: https://doi.org/10.1016/j.ufug.2013.10.010.

Wesołowska, M. & Laska, M. (2019). The use of green walls and the impact on air quality and life standard. *E3S Web Conf.*, 116: 00096. doi: https://doi.org/10.1051/e3sconf/201911600096.

Williams, N. S. G., Lundholm, J. & Scott MacIvor, J. (2014). FORUM: Do green roofs help urban biodiversity conservation? *Journal of Applied Ecology*, 51 (6): 1643-1649. doi: https://doi.org/10.1111/1365-2664.12333.

Wong, N. H., Tan, A., Puay Yok, T., Chiang, K. & Wong, N. (2010). Acoustics evaluation of vertical greenery systems for building walls. *Building and Environment - BLDG ENVIRON*, 45: 411-420. doi: 10.1016/j.buildenv.2009.06.017.

World Health Organization. (2010). *Noise*. Fact Sheets: WHO.int. Available at: https://www.who.int/europe/news-room/fact-sheets/item/noise (accessed: 18.04.23).

World Health Organization. (2022). *Environmental noise*. Compendium of WHO and other UN guidance on health and environment - 2022 update Geneva: World Health Organization.

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway