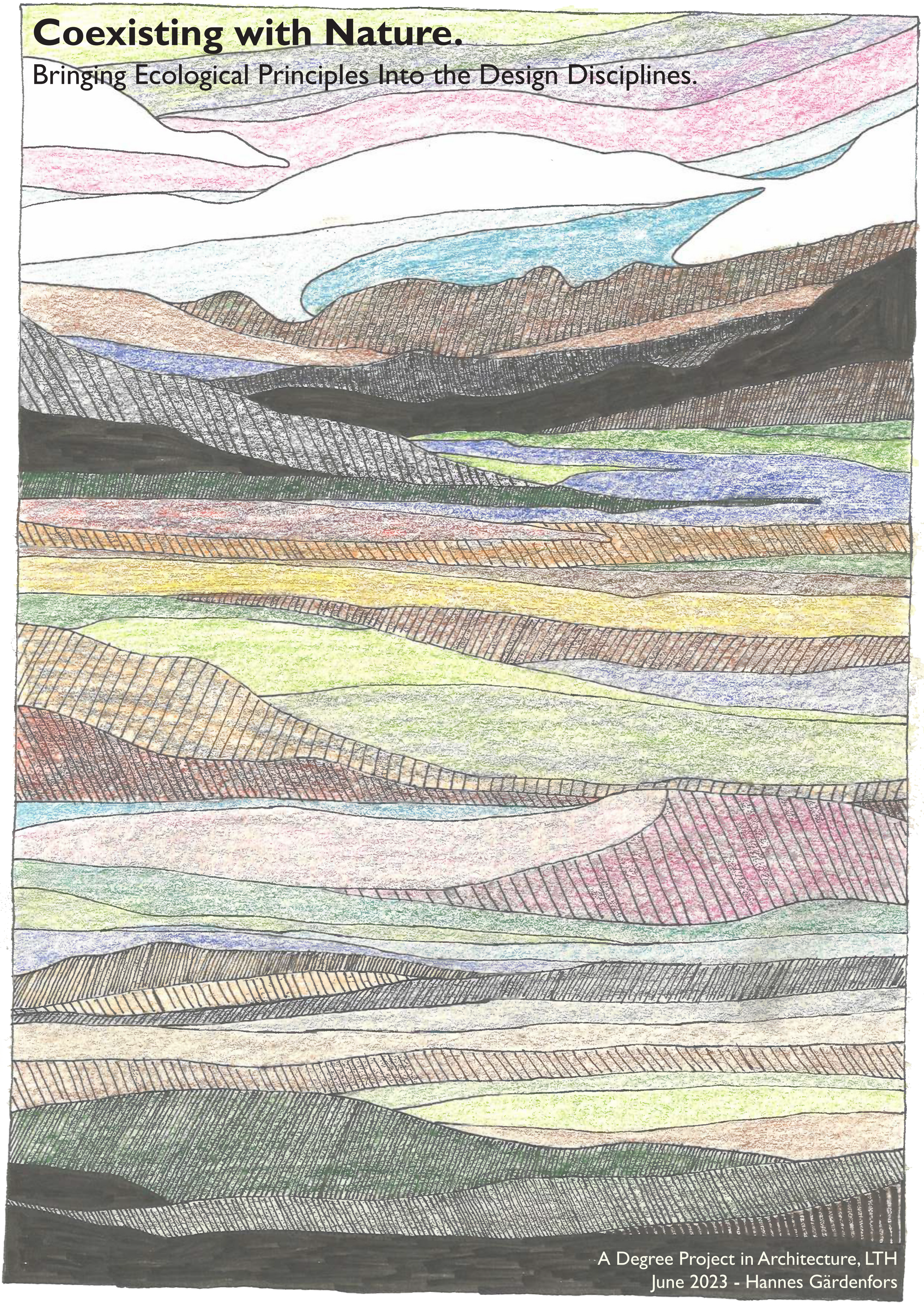
Coexisting with Nature.

Bringing Ecological Principles Into the Design Disciplines.



A Degree Project in Architecture, LTH
June 2023 - Hannes Gärdenfors

Abstract

Urban environments are often seen as the opposite of natural environments, with the belief that the built cannot accommodate the natural. However, this is a false perception. Ecological systems within urban environments are of great importance and can provide microclimates and habitats that do not exist in surrounding areas. Yet, this quality is rarely utilized because of the perception that built environments cannot be compared to natural environments. Recognizing the possibilities of incorporating nature, its use, and preservation, will allow environments to be designed to include both the built and the natural.

Built urban areas are continuously growing, being renewed, and repurposed to fit the current needs of society. As of this, there are great opportunities for exploring new solutions on how to integrate nature within cities and other urban environments. Urban planners and architects need to rethink how they approach designing and consider ecological systems at a primary stage of development.

This thesis aims to investigate how design can be used to increase biodiversity and how nature can coexist within urban environments. In using the field of ecology as the main driver for design and development it is evident that the built and natural environment are not separate from each other but are rather closely connected and linked.

The research has resulted in an ecological design methodology, where ecological principles create the foundation for discussing ecological design concepts. The methodology is intended to be used by architects and urban designers in the initial stages of development. It presents various concepts that will help guide the design to be of ecological benefit and increase biodiversity. The methodology is a comprehensive summary of the field of ecology, distilled into simple principles and concepts that apply to design.

AAHM01 - A Degree Project in Architecture.
Author: Hannes Gärdenfors
Supervisor: Andrew Karvonen
Examiner: David Andréen
School of Architecture - LTH, Lund University
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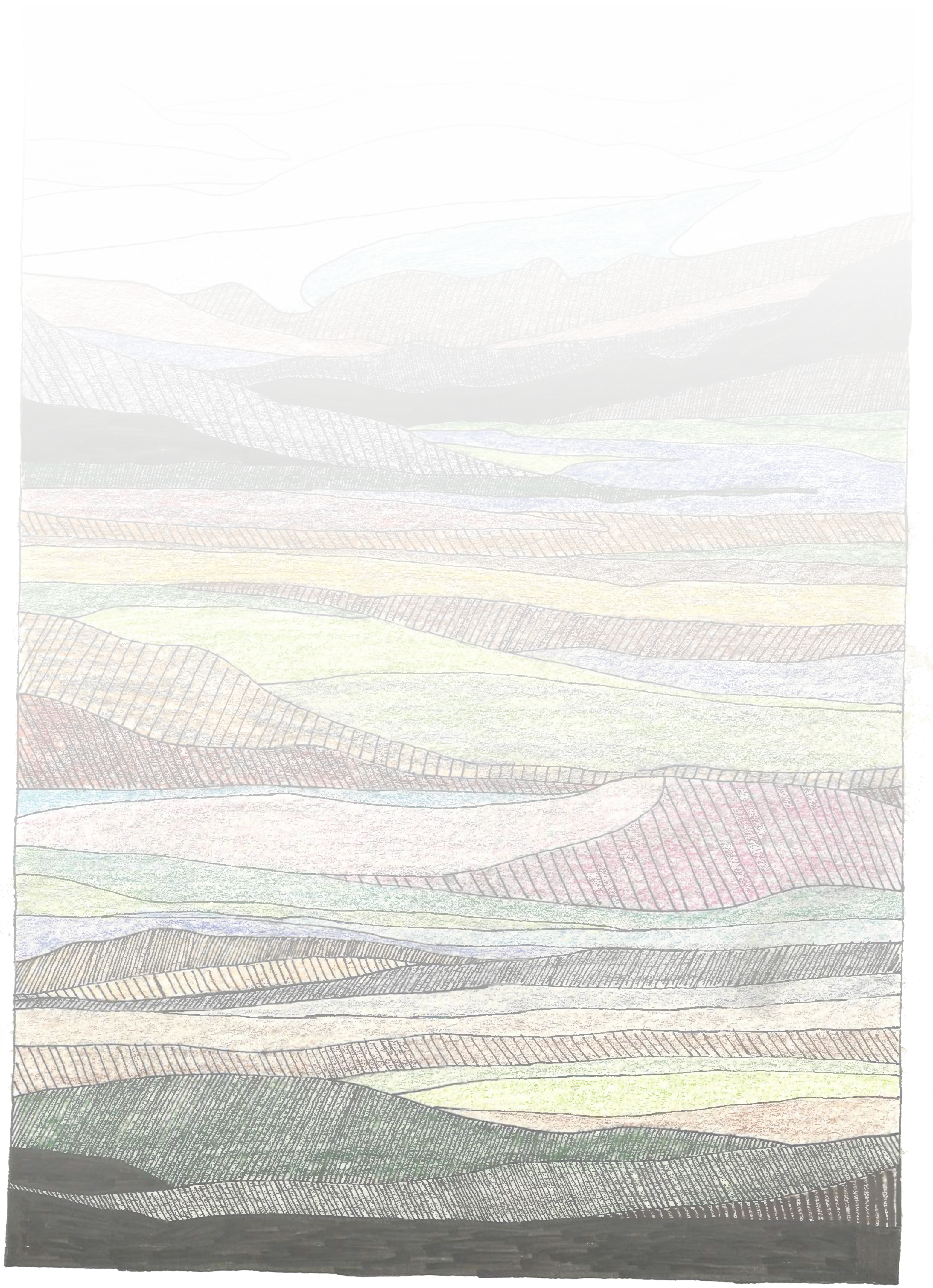


Part One.

Introduction, Background, and Theories.

Introduction.

Humans are dependent on nature and its ecological processes, and equally are the rest of the planet. We would not exist without nature, nor benefit from any of the ecological services taken for granted. Nature provides material, nutrients, and oxygen, it cleans water and air, as well as it protects and regulates the climate. Nonetheless, humans are today exploiting natural resources in an unsustainable way and heading toward the destruction of many ecological systems and processes. Consequently, we are putting our existence at risk. It is an urgent issue to preserve and protect still existing natural areas, as well as a need to increase the influence and role of nature today. Nature needs to be incorporated into cities and urban environments, and by doing so it will continue to provide ecosystem services and it will become more resilient itself.

There is a paradigm of mainly focusing on protecting and preserving nature at natural sites, disconnected from urban settlements. Conservation approaches, such as establishing protected natural reserves and natural parks, are of great importance but are not the only solution. There is a further need for a more comprehensive focus, allowing nature to prosper even outside of the protected areas. The risk of only focusing on parts of protected natural areas is that they become isolated and, consequently, run the risk of degradation. Establishing an overall green structure, naturally integrated into the urban fabric, creates a more resilient and resistant environment that can support both valuable ecosystems but also provide continuous ecosystem services.

From an ecological perspective, the built urban environment could be viewed as a degraded natural system. Before human impact, natural processes determined the characteristics, diversity, and conditions of an environment. Its properties and attributes were developed and defined by processes over time. With human impact these environments were altered and, in many cases, degraded to lower ecological quality by changes in land-use, construction, or exploitation. What we often fail to recognize is that this degradation is not irreversible, or rather it is at least possible to reduce using mitigation techniques. A natural ecosystem may be degraded by a disturbance, such as a natural disaster, but recover over time through recolonization and the re-establishment of certain fundamental conditions. By similar means may a constructed ecosystem also recover some, or even all, natural qualities of the previous environment. If we, as urban planners and architects, design urban environments to allow for the recovery of ecological systems, we may achieve urban environments which are not degraded remnants of previous natural systems, but rather prospering natural environments integrated within the urban fabric.

Figure 1.
Humans left the city of Pripyat after the Chernobyl disaster but nature presisted.
(C Colourin, no date)

This thesis is guided by the research questions; **How can design increase biodiversity?** and **could ecological principles serve as design concepts, used to integrate and benefit nature within urban environments?**. It presents an approach and a methodology on how design can be adapted to integrate nature and increase biodiversity in urban environments. This is done by using the framework of ecological principles and concepts to guide design and urban planning.

The work is divided into three parts. The first and third part includes the elaboration of research questions, the theoretical background, and the concluding discussion. This aims to give a comprehensive understanding of the ecological issues of future development and design, as well as a fundamental understanding of the field of ecology and how it relates to the field of design. Starting with discussing the background and problematization of the topic in terms of global growth in economy and population, climate change and the conflict of nature vs. built, and biodiversity as a representation of the benefits of healthy natural environments. Continuing, the fields of urban ecology, restoration ecology, and landscape ecology are briefly described by condensing ecological concepts and introducing relevant design strategies. These three fields all relate to ecology and the spatial landscape in different ways, but together they can describe and demonstrate the complexity of the urban environment. It is from this theoretical foundation that the second part of the thesis is built.

The second part of the thesis includes an elaborate description of an ecological design methodology consisting of landscape layers. This methodology is built on the theories and the context presented in the first part but can also be read and applied independently. It is a tool to be used for discussions of, and application on, design, and to be utilized by designers, architects, and urban planners. It is presented in the form of landscape layers that describe ecological principles related to spatial patterns of an environment. Each layer describes different elements of the landscape and how they affect biodiversity and the resilience of environments. These are then discussed as strategies and how they impact design, with the simple and overarching principle of ecocentricity, letting ecology guide design. The layers are not independent strategies, to be used on their own, and should rather be seen as semi-transparent layers that together generate a full picture of the landscape. The second part is summarized in a subchapter synthesizing the layers, with a short description of the core principles and focuses on the connections between the layers.

The full extent of the thesis is then discussed in a final chapter, reflecting on the process and the results of developing the methodology. It is also discussed how the methodology can answer the questions raised in the first part, and where and how it is applicable. Future development and research are mentioned both in the context of the thesis and within the field of ecological design.

Figure 2.
Nature can prosper anywhere. Fig tree, *Ficus caric*, on wall in Mostar, Bosnia & Herzegovina.
(Gärdenfors 2022)

Background.

Growth.

There are no other species on the planet that creates and consumes artefacts and products at the same rate as humans. The anthropogenic society follows a consumption pattern of extract, make, use, and discard. Post-industrial civilizations are built on a system and economy of growth and consumption. Humanity exploits, constructs, and disperses in a linear system without taking the consequences of consumption into account (Yeang 2020, p.144). Ever since the threshold of controlling fire was passed humans have, at an exponential rate, learned how to manufacture and create new materials and tools, with the consequence of emitting chemicals and substances at a non-natural rate (Yeang 2020, p.129).

Additionally, the global population continues to grow, surpassing eight billion people by November 2022 (United Nations 2022), and is expected to peak at 10.4 billion around the year 2100 (United Nations 2022). Simultaneously, there is a trend of urbanization, people are moving from rural to urban areas and the big cities grow even bigger. At the start of the 22nd century, 80% of humans are expected to live in urban areas (Yeang 2020, p.164). More and more of the global land area is of human impact through urban environments and agriculture, with the consequence of a decreasing area of natural environments, generally limited to protected or isolated areas.

With the growth of population and urban environments, the global built area is inevitably going to increase. Today the existing built floor area is expected to be 230 billion square meters and with the current approximation of growth and development this number is projected to double by the year 2060 (Hageneder 2020). At the same time, there is the continuous task of renewing, re-using, and retrofitting existing buildings. Yet, this provides an opportunity to rethink and evaluate how we build and design. Considering the current projections of climate change, a focus on creating sustainable environments is crucial. It would help to decrease global warming and mitigate climate change. It is a great responsibility to reduce the negative impact of construction, buildings, and in development, and planning. In the long-term perspective, it is an urgent task that humans to reduce their carbon footprint to decelerate climate change. As designers of the urban environment, architects and urban planners have significant influence in doing so.

Furthermore, this pattern of exploitation and growth is continuously causing harm to the environment and society. This shows the importance of questioning consumption patterns and investing in more sustainable and renewable solutions, so as not to put humanity at risk in the long-term perspective. A more circular approach would massively reduce exploitation and focus on reusing materials and resources that are already in circulation . There is still a need for innovation and research to increase efficiency and prolong the life of products, but a circular approach would reduce the demand for exploitation and thus improve the state of the environment and society. In essence, it is a natural analogy to the cyclical nutrient processes of which ecosystems work. This principle is a core value of coexisting with nature. (Yeang 2020, p.145)

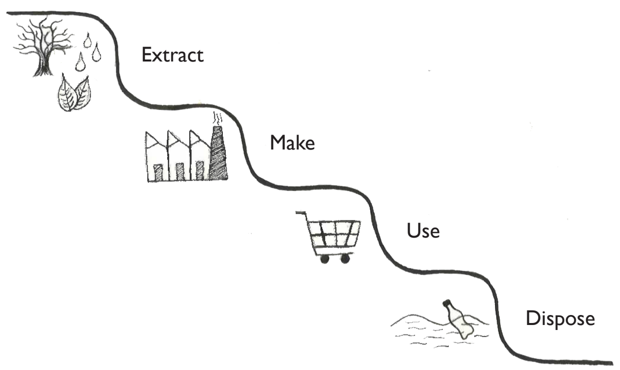


Figure 4.
Linear economy.

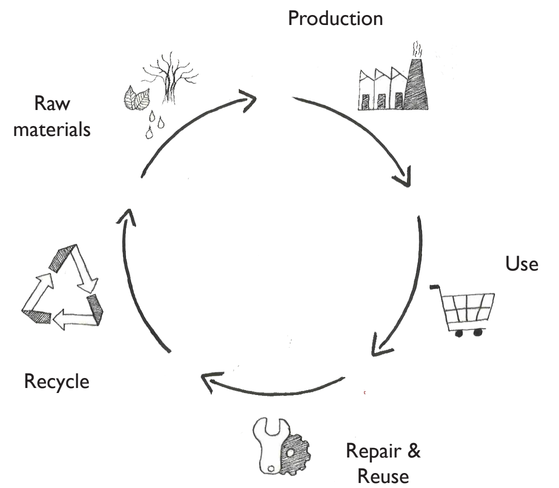


Figure 5.
Circular economy.

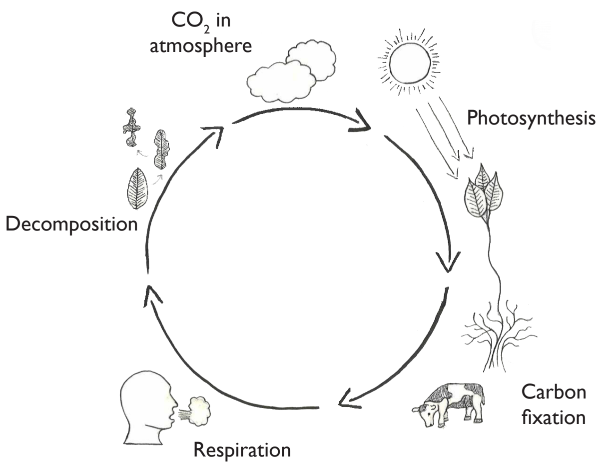


Figure 6.
Carbon cycle.

Conceptualising Nature and the Built Environment.

In contemporary society, nature and built are seen as two opposite elements. Nature is removed when a building is built, and nature can only prosper where no buildings exist. Because of this, nature's role in the urban environment has diminished and is mainly represented by parks with mowed lawns and exotic trees. A controlled and inorganic nature with the main purpose of being of aesthetical quality. There is a lost understanding of what biodiversity and healthy natural systems are, and many prefer the orderly and symmetrical over the organic and asymmetrical (Quigley 2011, p.89). However, this is primarily regarding nature within the urban environment, which is often the only natural environment people are in regular contact with. Ironically, people have a good perception of the importance of biodiversity and natural processes regarding the distant, more pristine, and greater natural areas. Yet, few people have access to experience these areas regularly. With time these truly natural areas have become more and more distanced from most people's everyday life and thus the awareness of its benefits has diminished.

> *Too often, the natural world is conceived as Nature with a capital "N," "out there" in remote mountain ranges, in rainforests, in the depths of the ocean. This has allowed us to conveniently believe that our activities can be carried out without consideration of their wider consequences. Weaving nature back into everyday life breaks down destructive dichotomies between the built world and wild nature. It reminds us of the ecological processes and biological diversity present even in the city. This kind of immediate, close-at-hand nature—a kind of small "n" nature—is one that needs to pervade culture. When we come to participate in organic processes as a necessary and intimate part of our lives, the awareness and motivation to protect the larger realms of big "N" Nature will be widespread and enormously powerful. On the other hand, if we fail to weave little "n" nature back into the everyday environment, big "N" Nature will become an expendable abstraction confined to television documentaries.* (Cowen & Van der Ryn 1996, p.188)

Figure 7.
Nature with capital 'N'. Yosemite national park. (Howard 2020)

Sim Van der Ryn and Stuart Cowen describe this formerly close, yet now lost, connection, but also mention the ability to change it. Even the most pristine and distant nature will benefit from improvements of nature most close at hand. They stress that we must change focus: Instead of looking at the distant, focus should be at caring about what is close by and what surrounds us. However, this mainly describes the dichotomy of the human perception of nature and how nature is perceived in an urban setting. Jari Niemelä describes a different approach but relates to the same dichotomy, '*…[P]eople were treated as the problem and the solution was to remove people from natural sites in order to protect or preserve them. Therefore, cities represent the worst enemies of nature'* (Niemelä 2012, p.1). This approach views the human role in, and their impact on, nature, by which the areas of essential ecological importance are the natural and pristine environments without human impact. However, this is not the case. Nature exists everywhere, both in the untouched and within cities and urban environments.

Figure 8.
Nature with small 'n'. Diverse garden of flowers in south England. (Gärdenfors 2022)

Nonetheless, urban nature is often neglected because it is perceived to be of low quality, less diverse, and with few natural functions. But also, here people overlook the importance of nature and the role it plays in cities. Jari Niemelä continues, *'The variety of human impact diversifies the urban environment by modifying the existing ecosystems and by creating unique urban ones. Consequently, biodiversity in cities may be high'* (Niemelä 2012, p.1). Niemelä describes with this the opportunities for nature in urban environments. By integrating nature into the urban environment, a diversity is established for both humans and nature, without choosing one or the other. It is a statement that levels the status of the built environment with the natural, acknowledging that they have equal opportunities and need equivalent care. The urban environment provides unique opportunities which differ from those in the natural world, it is therefore key to realize and utilize these. With an understanding and appropriate usage of the urban natural environment, the pressure of other natural environments might be eased and subsequently make the overall environment and systems more resilient.

Figure 9.
Grey squirrel, *Sciurus carolinensis*, on a fence. Squirrels has adapte to urban conditions and many species can be found within or cities. (Hodan, no date)

Figure 10.
The Eurasian carp, *Cyprinus carpio*, thrives in urban ponds where it helps with the cleaning of the water. (Spragg 2020)

Biodiversity.

The extensive use of the term 'Biodiversity' in such a broad variety of fields, has led to a semantic loss of the original literal meaning of the term. Nonetheless, biodiversity is an overarching term that could be used to describe the quality, function, and diversity of natural environments and ecosystems. It can simply be described as the diversity of species within a natural system. However, within this explanation, some unclarity has led to debate (Gaston & Spicer 2004, p.3). First, the definition of a species must be elaborated. The most used is the biological species concept, however, there are seven main concepts of how to define a species which all need to be considered. In the table below is a short description of the seven different species concepts. (Gaston & Spicer 2004, p.8).

Furthermore, factors such as richness and evenness among species, the influence of key species, as well as connections between species need to be taken into consideration. This creates a complex multidimensional system that is hard to define. For example, within a small area, 20 species are found, but three of them make up 90 percent of the individuals. An area with the same number of species but with an even distribution will generally be seen to have higher biodiversity. However, considering the prospect that the three abundant species are key species of the ecosystem, it might be of significance that the system has an uneven distribution. The factor of richness and evenness might then not be representative of biodiversity as the role of each species needs to be considered. Subsequently, the most used and accepted definition is made by the Conservation of Biological Diversity (United Nations 1992),

> *'Biodiversity diversity' means the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.* (United Nations 1992)

Species Concept	Definition
Biological Species	Argues that a species is defined by the possibility of individuals in a population, under natural conditions, to reproduce, producing fertile offspring which are reproductively isolated from other species populations. The biological species concept is the generally most used definition.
Cohesion Species	Is defined by patterns of cohesion keeping individuals in a population together and isolated from other species and does not regard the ability to mate or reproduce.
Morphological Species	Defines a species by its outer visual characters, without taking evolution into consideration. This concept was mainly used during the time before the theory of evolution was established but is still used as a quick and simple way to define species.
Ecological Species	Defines a species by looking at its role in an ecological system. In other words, every species of an ecosystem has a function and its own niche, which they are differentiated by. It is seldom used due to its more complex definition with many variables.
Evolutionary Species	Is the scientifically the most accurate and used concept as it derives from the evolutionary history and genetic development of species. Consequently, it is the least practical as it requires a thorough classification and specification of the genetic composition.
Phylogenic Species	Is based on a systematic clustering of ancestry and decent, defining the smallest groups of this patterns as distinct species.
Recognition Species	Is based on the simple principle that individuals of the same species recognize each other in the principle of mating and reproducing.

Table 1.
Seven different species concepts.

Shahid Naeem builds on this definition to signify this multidimensional complexity,

> *Biodiversity is clearly understood to be a term meant to capture biological diversity in all its dimensions including genetic, population, functional, taxonomic, phylogenetic, and interaction or network diversity as well as how they vary within and among populations, assemblages, communities, and ecosystems, over space and time.* (Naeem 2016, p.62)

The complexity of biodiversity demonstrates its significant role in ecological systems. It relates to distinct functions, services, and processes that impact human and urban environments.

The foundation for biodiversity is established by a variety of different factors, separated into two groups, abiotic and biotic factors. These could be seen as biodiversity drivers depending on their character. Abiotic factors could simply be explained as the physical or non-living elements of an environment. It includes factors of physical structure, climate, level of disturbance, spatial heterogeneity, etc., constant factors. Biotic factors, on the other hand, might change over time and are interconnected. The fundamental biotic factor is the species composition that develops over time as an effect of colonization and competition. Subsequently, this affects the biological resilience of the ecosystem, determining resistance to invasive species, diseases, and disturbance. Every area and ecosystem has its specific definitive factors that determine the biodiversity of the site.

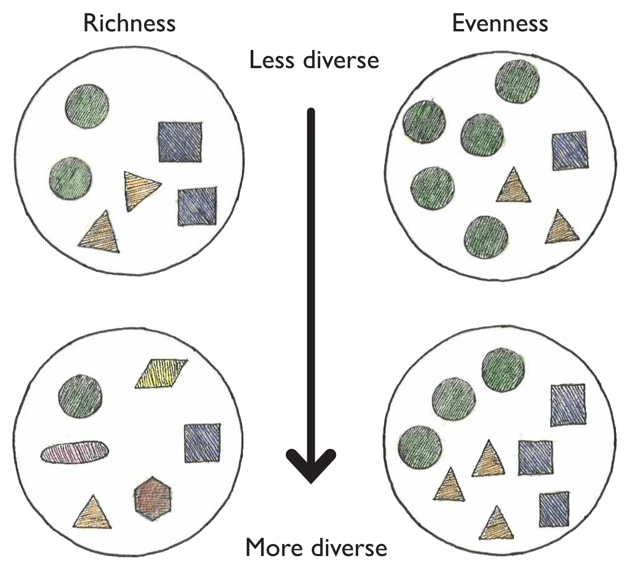


Figure 11.
Species richness & evenness affect the biodiversity.

Biodiversity relates to the resilience of a system, both within itself but also with the surrounding environment. Resilience mainly refers to the stability and resistance of a system. In a biodiverse ecosystem, there is a complex species composition, species that interact and support each other. If there would be a disturbance, e.g., a species is removed, there will be other species that take its place, allowing for the system to recover without significantly compromising other ecological functions. On the contrary, if a species were to be removed from a less diverse ecosystem, the risk of a collapse would be larger, as all species are more vulnerable. Biodiversity creates a buffer against change and establishes a balance in the system.

The importance of biodiversity can be contextualized through a variety of different values. These values might be of direct or indirect use, providing people with valuable resources or services, but can even be of non-use, yet still provide value through their existence. Direct-use values regard resources, goods, and products that are used in everyday life. Similarly, indirect-use values provide for services used frequently, although these cannot be controlled or collected in the same way as direct-use values (Gaston & Spicer 2004, p.99). These values are fundamental to human existence and cannot be substituted for artificial systems, at least not efficiently and profitably (Gaston & Spicer 2004, p.105). Ecosystems and biodiversity provide these for free, they simply need to be presented with the opportunity. In addition to the direct and indirect values provided by biodiversity comes the potential value it might have in the future. This non-use value is based on the prospect that biodiversity might hold knowledge and an unexploited potential not known or yet explored. Thus, it is important to protect biodiversity to allow future generations to experience its values of direct, indirect, and non-use (Gaston & Spicer 2004, p103).

Provisioning Services	**Regulating Services**	**Cultural Services**
Products obtained from ecosystems	*Benefits obtained from regulation of ecosystem processes*	*Nonmaterial benefits obtained from ecosystems*
• Food • Fiber • Biomass • Fuel • Freshwater • Medicine • Raw materials	• Air quality • Climate • Water run-off • Erosion • Natural Hazards • Pollination • Pest & disease control	• Ethical values • Existence values • Recreation • Ecotourism • Aestheric values • Education • Health
Supporting Services		
Services necessary for the production of all other ecosystem services		
• Nutrient cycling • Water cycling	• Soil formation • Photosynthesis	• Habitat • Biodiversity

Table 2.
Four categories of ecosystem services defined by the Millennium Ecosystem Assessment

These values are often simplified to the concept of ecosystem services provided by biodiversity. Ecosystem services are described as *'services provided without human intervention and which are essential to sustain all lifeforms on earth, including humans.'* (Yeang, p87). However, they are often adapted to an anthropocentric context and include services of benefit to humans. As per the Millennium Ecosystem Assessment, the definition is condensed to *'Ecosystem services are the benefits people obtain from ecosystems'*. They further go on to divide ecosystem services into four categories, provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment 2005, p53). The first three categories produce services that directly benefit people while the category of supporting provides services needed to maintain the other three. Table 2 contains a short description and some examples of each category.

Biodiversity is the keystone providing ecosystem services. Without biodiversity, ecosystems will degrade, and so will all its functions and services. Humans are dependent on ecosystem services, subsequently, this means we are dependent on biodiversity. There is an urgent need to commence valuing the importance of biodiversity and make it a focal part of planning and development. Biodiversity is a complex matter and something that exist everywhere. Yet, we do not need to solve its complexity, the need is only to provide for the basic conditions and nature will do the rest.

Figure 12.
The provision of food is a very important ecosystem service. Borough Market London, UK. (Gärdenfors 2016)

Figure 13.
Pollination is an focal regulating service provided by different species in an ecosystem. (Slgckgc 2012)

Figure 14.
The cultural value of natural beauty and recreation is an importan ecosystem service. Coast of Northern Ireland. (Gärdenfors 2022)

Figure 15.
The decomposition of organic matter is a keypart of nutrient cycling and a fundamental part in all ecosystems. (Ito 2007)

Delimitations.

The relationship between natural and built environments is a topic of increasing importance , both in the field of design and architecture and within the field of biology and ecology. Hence, there have been numerous publications on this topic and equally, many different approaches and theories. I decided to start my research with a broad spectrum of sources within the field. Especially regarding the fields of biology and ecology, as these are not my main discipline. By reviewing general principles and a broad variety of different topics of ecology, different connections to biodiversity and design were found. I did this to acquire an overview and an understanding of what was relevant and applicable to urban development and design. From the broader overview, I condense my findings to those relevant to denser urban developments , as to examine a clearer differentiation between the urban and natural. In denser urban areas most of the surfaces have been designed. Even nature is often designed, an example being parks or gardens, or at least a decision has been made on which urban green areas should be preserved and how they are maintained . Thus, my scope would have been ecological principles applicable to dense urban development, from the scale of a single building to the urban scale. As a result of this, I was also able to narrow down the field of ecology to three relevant categories: urban ecology, restoration ecology, and landscape ecology. Nonetheless, neither of these fields is comprehensively examined due to the scope of the thesis and limitations in time. Instead, they are used as complementary theories and tools to contribute to the discussion about ecological principles as a framework for design.

In addition, I am aware that some of these topics and developed principles will be included in the scope and field of similar design professions, such as landscape architecture and urban planning. I acknowledge this and argue that it is a necessity that I have consciously chosen to carry out. I aim to approach the built environment on many different scales, finding the principles and factors that are relevant, independent of the case being a building, a park, or a bigger urban development. Architecture applies on many different scales and situations, it is a holistic field and it is a necessity to include and work together with different fields of design, as well as other fields of research.

An important fact to note is that this thesis is, and is aimed to be, a design thesis. The research presented and the discussion derived from the research are to be viewed from within the field of design, more specifically the fields of architecture and urban design. As my main field of study is architecture it is therefore within its frame this work should be recognized. I have aimed to investigate how ecology could be perceived and contextualized in the field of design, and my interpretations and conclusions have therefore been a result of this investigation. The result of this thesis should be viewed as a perspective on how the field of ecology could be perceived in the eyes of a designer and how it could be used in practice. The derived conclusions would still need some fundamental scientific support but are still equally relevant in the discussion on ecocentric design.

Research Methodology.

The methodology used to consult the investigation of this thesis has primarily been literature based. As the research questions are about integration and combining two different fields of study, this was the most appropriate strategy. However, the literature used can be divided into categories. In terms of literature regarding the field of biology and ecology, they were academic references presenting research and facts to describe different parts of the field. These were overarching, descriptive and, most notably, objective publications presenting the topics without personal theories and opinions. This was focal as to provide a consistent foundation on which to establish a discussion. Regarding literature within the field of design, these were more of subjective character, presenting theories and arguments of why and how. Authors and publications used were chosen based on their relevance to ecological design and biointegration, in some way dealing with the question of combining ecology and design. These references were used to present different perspectives, present arguments, and support a discussion.

The initial task of the research was to find a framework within the field of ecology, from which further investigation could be conducted. As discussed in the previous chapter, on Delimitations, I started with a broad spectrum of exploring the field of ecology and biology. The topic of 'Biodiversity' was used as a starting point. Together with the research questions a selection of further relevant topics was collected. A selection was then made of what topics to further investigate, and so the overarching topic of 'Biodiversity' was condensed to a few more specific topics. This was a process of several steps, with loops, dead ends, and side tracks, but all equally important to get an understanding of the meaning and role of each topic. A mapping of this process can be found in Appendix (p.102-103). With this method, a comprehensive understanding of the field of ecology was achieved and allowed for a more concise and relevant discussion when further conceptualised within the field of design.

From this foundation of ecological research, a further investigation was done into existing theories of ecological design and of implementation of ecology within the design disciplines. This provided a broad spectrum of ideas and approaches and allowed for a further selection of relevant topics. It showcased what aspects of ecology that are already in use but also highlighted the gaps and opportunities for further investigation. It was with the support of these existing design theories, ideas, and approaches, as well as the foundation of ecological knowledge, that I developed the ecological design methodology presented in this thesis. The ecological theories, concepts, and principles presented are gathered from other authors, and collected by me to provide a foundation for this investigation. Further is, however, the application and implementation of these, within the design context, my interpretation and contribution. Individual design examples and inspiration have been used from reference authors and theories, yet, the discussion, creation, and development of the presented methodology are a result of my theories based on the research I have conducted.

Ecological Theory.
An Introduction.

The human species are deeply connected with nature by a long evolutionary history, and this co-dependency still prevails . Humans, as a part of nature, are dependent on it, and we can equally influence nature with our behaviour and activities. Nonetheless, in recent years human society has been distancing itself from nature, cutting the ties and regarding itself as a separate entity, which is disconnected from nature. Humans, as increasingly more urban dwellers, spend less and less time in nature. Urban areas and cities grow bigger and provide all the amenities necessary. For a long time, human society has continuously been relying on technology to be the solution to increased human life quality, instead of using the attributes and services provided by nature around us. Yet, ecological systems and technological systems do not work in the same way. If compared, living natural ecosystems are significantly more complex than even the most sophisticated abiotic artificial systems. Life in ecological systems is all interdependent and strongly connected by intricate, dynamic, and intermediate networks of relationships. Every link is interactive, so changes within the system lead to consequences throughout the system, but also can recover to an equilibrium of stability. Still, constructed technological systems have the potential of being assembled to full function. Defective parts can easily be replaced to revert to the original state, and are hence more dependable and easier to control (Yeang 2020, p.46-47).

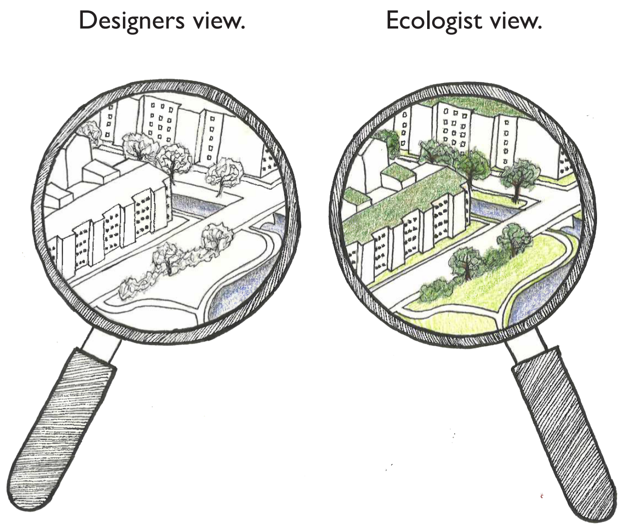


Figure 16.
Preceived view of the urban environment.

Nonetheless, one possibility does not exclude the other. Thus, the task is to learn how to integrate nature within urban areas and allow the ecological systems to do their part of the solution. In the field of design, the approach is anthropocentric, focusing on human needs and urban areas. Consequently, this has led to a loss of connection with nature and the ability to fully embrace the opportunities it presents. Ken Yeang, who is both an architect and ecologist, simply describes this difference between designers and ecologists:

> …*[T]he ecologist sees the world differently, with an environmentally critical and holistic eye. They do not just consider the human world, but the natural and human-made world (as well as our human acts and activities) together, they examine the relations between the two – how one interacts and interfaces with the other.* (Yeang 2017, p.59)

Perceiving design from the viewpoint of an ecologist would allow for a more comprehensive way of regarding systems and dynamics, not only in the realm of humans. This ecocentric approach is, in essence, a method of designing for both the human and the natural world, attempting to forgo neglecting either. Allowing ecology to have a more prominent role in design is an essential feature in the transition to coexistence and integration of nature within urban environments, and would create more resiliently built environments.

A similar pattern can be observed in the field of ecology. Urban environments are expanding and having a more and more prominent role in both land use and research. For a long time, the focus of ecology has been on studying the untouched pristine nature and its system and species. As of recently, urban environments, however, are receiving increasing attention. In the last few decennia, a big expansion has been observed in the fields of urban ecology and restoration ecology, two subfields of ecology where the urban and humans play an integral part.

Urban ecology investigates the natural processes and ecological dynamics within urban areas. It observes how nature and its' species have adapted to the built and designed world and how this affects ecological processes.

Restoration ecology adopts concepts of reconstructing and regeneration of degraded ecosystems. It deals with the processes and factors that are essential for ecosystems and continues to define the thresholds necessary to make ecosystems stable. It applies primarily to restoring ecosystems at previous natural sites, sites without major anthropogenic influence, but the processes and concepts are equally relevant for ecological restoration at urban sites.

Another subfield of ecology relevant to urban environments is landscape ecology. As its name implies, landscape ecology captures the processes and principles of ecology in the scope of a landscape, which is a defined scale-less entity in which its principles are applied. As of this, the principles of landscape ecology apply to any defined landscape, so be it a natural reserve, an agricultural area, a stone, a city, or a building.

Urban Ecology. *Nature of the urban environment.* • Urban ecosystems • Anthropogenic impact on species • Unique habitats • Ecosystem services
Restoration Ecology. *Restoration of degraded ecosystem.* • Restoring ecosystem • Threshold of the environment • Ecological processes & dynamics • Ecological resilience
Landscape Ecology. *The spatial pattern of the landscape.* • Spatial structure & pattern • Connection of elements • Heterogeneity & homogeneity • Dynamics & flows

Table 3.
Summary of the three ecologies.

Urban Ecology.

U rban environments are constructed and built by humans for humans. Every element is designed and built for a purpose, even in most of the green 'natural' areas. Most often the remaining natural environments of the city are only scattered and simplified fragments of the previously existing environment. It is seldom that urban design and development take any consideration of pre-existing nature and ecology, and consequently become more adjacent to parasitic environments rather than a part of the existing context (Yeang 2020, p.130). Nonetheless, these green urban areas within cities are still the most natural environments, constructed or not. They allow nature to establish, infiltrate, and make its presence. This urban nature can be shaped in many ways and be of varying quality and may be of human design or natural recolonization. Yet, it is these areas that make up the field of urban ecology, the study of the ecological processes and systems of the urban environment.

Within urban ecology, there are two different approaches: Ecology in cities and ecology of cities. Ecology in cities focuses on the ecological processes and patterns of urban areas, such as within a park, a neighbourhood, or a street. This approach focuses on mapping the different areas of a city, the different scales, and the ecological systems and processes within them. Ecology of cities, on the other hand, focuses on the connections and interactions between the ecological and social systems. In essence, it describes how the natural environment is affected by urban elements. In this approach, humans play a very central role, both positive and negative, as they are the main disturber, users, and drivers of urban areas (Niemelä 2011, p.2-3).

Natural environments and ecosystems within urban areas follow certain patterns of species composition in relation to the surrounding areas. Biodiversity is generally expected to be lower in an urban area compared to a non-urban area with the same ecological structure and natural characteristics . This is mainly due to the surrounding context of each area, whereas the urban area is exposed to more barriers and disturbances. However, human influence and maintenance may establish concentrated areas of high biodiversity, such as plant communities. Nonetheless, these areas are dependent on human management and, consequently, might

Figure 17.
The botanical garden, Dublin. Research on parks as ecosystems is a typical example of ecology 'in' cities. (Gärdenfors 2022)

Figure 18.
How aquatic ecosystems wayerways are impacted by urban alteration is an example on ecology 'of' cities. (Gärdenfors 2022)

only be regarded as semi-natural. There is also the circumstance where the cities have a higher biodiversity than the surrounding agricultural areas. Modern agriculture consists of fields and plantations that are simplified monocultures optimised to produce one crop or product. In this case, the city in question has an important role to provide refuge for species that inhabited the former habitat and environment. This includes nesting opportunities for pollinating insects or resting possibilities for migrating birds (Quigley 2011, p.86).

Sustaining higher urban biodiversity could help prevent and solve many of the problems that occur within contemporary urban areas. Contemporary green urban areas are often fragile ecosystems, exposed to pests and diseases due to a lack of diversity. Increasing the biodiversity of green areas will help control pests and diseases, not only for the species that inhabit them but also for us humans . The reason for this is that ecosystems with higher complexity in trophic levels, which contain a more complex network of species, will balance the systems preventing any species to become too abundant and affect negatively. Current urban ecosystems are often imbalanced due to the degradation of the natural environment, causing some species to exploit the situation due to the lack of natural control. This is evident in the case of birds, such as pigeons and seagulls, thriving due to the lack of natural predators (Yeang 2020, p.93).

Another notable aspect of urban ecology is the physical properties of the urban area, as they form the foundation of urban ecosystems. The physical properties include climate, soil, hydrology, and land use. The first three, climate, soil, and hydrology, are abiotic factors, common to all ecosystems in or outside of cities. On the other hand, the role and variation of land use are unique to urban ecosystems as the human impact is continuous. Land use also plays a major role in the attributes of the three properties as it alters the physical shape, and the ecological processes and regulates the impact of disturbances.

In the process of deciding and defining the land use of an urban area appears the possibility to create natural systems that support ecological stability and resilience, and by doing so promoting opportunities for ecosystem services. The importance is then to create a green infrastructure that supports the abiotic factors of climate, soil, and water. It should be multifunctional, integrated, and connected to both ecological and social systems. There is also a need of defining the role of the human, seeing it as a biological driver and a key species, rather than a spectator. Maintaining an ecocentric strategy in land-use planning and design will allow for higher urban biodiversity as well as better quality of urban life, due to the provision of ecosystem services.

Figure 19.
Botanical gardens is an example of how human management can increase local biodiversity. Ventnor botanical garden. (Gärdenfors 2022)

Restoration Ecology.

Many natural sites have been degraded and compromised in recent years, often with the short-term benefit of humans but with the long-term loss of ecological services. Because of this, the interest in restoring ecosystems and ecological processes has increased and, consequently, the field of restoration ecology expanded. The main concept of restoration ecology is to restore the stability of natural systems, making them resilient to change, for example, climate change. There are two different approaches on how to carry out this premise. The first is passive restoration which implies a strategy of mainly preventing further degradation and then allowing for the ecosystem to recover by itself without intervention. It focuses on creating the foundation for a natural recovery by creating the right conditions and necessary protection (Falk et al. 2016, p.13). The second approach is process-based restoration and is closely related to the theory of threshold dynamics and resilience. Its concept is to restore the underlying processes of an ecosystem, and by doing so, reach a threshold of resilience that improves the state of the ecosystem (Falk et al. 2016, p.14).

While passive restoration mainly focuses on nature's ability to recover, process-based restoration allows and even depends on human intervention. Within urban environments, passive restoration is about providing undisturbed space for nature to establish and recover, and by doing so create stability within ecosystems. Urban environments are continuously exposed to disturbances and without time the ecosystem will not become resistant to its continuous use. By simply allowing natural areas and ecosystems time to reach a more stable state it grows capable of withstanding more disturbance and use, which is a necessary ability in urban environments. The principles are the same for process-based restoration, creating stable and resilient ecosystems. However, process-based restoration additionally focuses on establishing fundamental processes and conditions for ecological function. Considering this, there is a need for human intervention in providing necessary support for underlying dynamics such as nutrient- and water-cycling, waste management, and climatic conditions. These interventions will allow ecosystems to recover more quickly and obtain a stronger resistance to disturbance.

Restoration ecology focuses on the process within ecosystems and how the alteration of these affects the state of the ecosystem itself. It relates the existing conditions and patterns to the processes and dynamics that are necessary to improve the state of the ecosystems. Likewise, it also indicates the risk of putting an ecosystem off balance and attempts to ascertain what the factors, that would undermine the stability and degrade the system, are. By evaluating and anticipating disturbances and processes, it is possible to improve the stability and quality of natural systems. Similarly can also the theories and concepts of restoration ecology be used to create optimal conditions within the urban environment. It would determine the essential processes for stability and which thresholds are necessary to cross if the state of natural urban areas is to improve.

Nonetheless, improving the state of an ecosystem to the level of reaching these thresholds of ecological dynamics and function can be extremely difficult to carry out. Ecosystem functions and services are connected and often interdependent. The removal of one often leads to the degradation of others. As a result of this, restoring the damage of one function or service often requires the restoration of several, and will thus entail a higher number of modifications than the initial alteration caused (Yeang 2020, p.91).

Due to the complexity of ecosystems, and the function and services they provide, it is difficult to restore and protect them with simple solutions. Biomimicry is a concept that draws upon resembling and taking inspiration from biological organisms and processes in the design of materials and structures (Yeang 2020, p.177). It is a useful tool for creating elements that should resemble those of nature. However, it lacks the strategy of how to mimic the dynamics of natural systems. In his book 'Saving the Planet by Design' (2020) Ken Yeang introduces the concept of 'Ecomimesis'. Comparable to the concept of biomimicry, it aims to create solutions based on nature. Instead of focusing on individual organisms or processes, ecomimesis suggests resembling the function and dynamics of entire ecosystems. Designing by the principle of ecomimesis purposes the implementation of ecosystem functions to create stable and resilient environments. Ecomimesis is relevant to the field of restoration ecology as it provides a comprehensive ecological approach to restoring ecosystems, including biodiversity and ecosystem services.

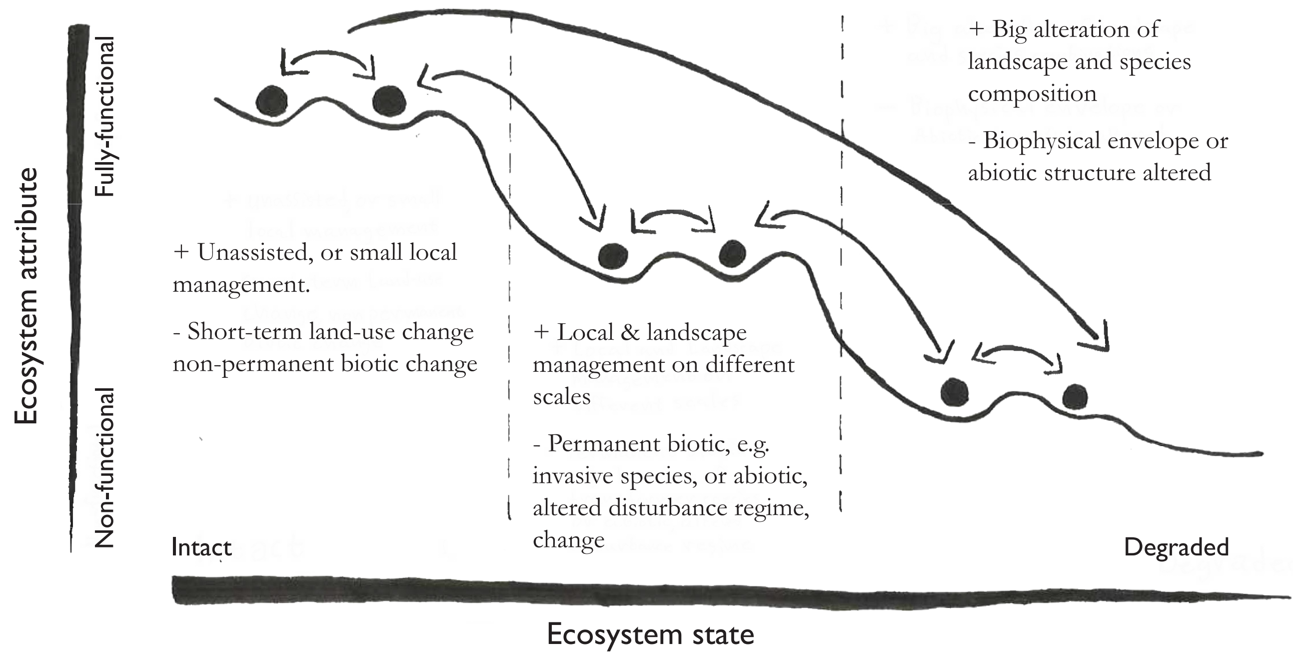


Figure 20.
Ecological resiliance & thresholds.

Landscape Ecology.

Landscape ecology connects the ecological processes of ecosystems to the spatial pattern of an area. The spatial pattern characterizes the 'landscape' and consists of a patchwork of structural elements and habitats. The scale of the landscape is changeable and an element within a landscape defines its specific landscape. The attribute and role of each element change, depending on the scale. However, the principles of landscape dynamics and relations are relevant on all scales (Forman & Godron 1986, p.3-4).

Within a defined area, several different habitats exist, hosting a variety of different species and ecological functions. This patchwork of habitats is often described as a landscape mosaic of different environments and communities. The proportion and character of these environments will affect and shape the climate and conditions of the landscape. Similarly, ecological dynamics are determined by the composition of environments and species, defining the level of movement and flow of resources within the landscape. It is this spatial pattern of the landscape, that will form the conditions for species and biodiversity within each environment, and define ecological resilience and level of ecosystem services within the landscape accordingly (Forman & Godron 1986, p.31).

It is mainly the contrast between, and diversity of, elements that determine the flow and dynamics of the landscape. It is in these transition zones where environments and habitats influence each other, which consequently take effect on the conditions of either. The boundaries between different environments are hence of major interest in defining the character of the landscape. There is the possibility of them enhancing biodiversity by promoting movement and overlap, but equally, there is the risk of creating a barrier that separates environments and disrupts the flow of species and ecological processes. The latter is common as the case of fragmentation and implies the spatial division of a habitat into two, or several, smaller areas, often with the consequence of loss in biodiversity and ecosystem services. The influence of boundaries and edges derives from the fact that they are the place where the flow of materials, energy, and species occurs and hence define the conditions and quality of connected habitats. To exemplify, a sharp edge, e.g., a border between a forest and a meadow, creates a buffer zone along the edge as the conditions of light and shade are altered and consequently differentiate from the interior habitat of either environment. On the contrary, a gradual edge, an ecotone, creates a zone with mixed characteristics from the two habitats, allowing for more natural flows between the habitats and protecting the interior habitats (Dramstad, Forman, & Olson 1996, p.14-15).

These concepts of landscape ecology define the dynamic connection between different parts of a spatial pattern. It demonstrates tools on how to optimize flows and processes, and connect areas rather than separate them. Landscape ecology and its principles are not confined to natural environments, they are equally applicable to urban areas and the spatial pattern created within cities. In urban planning, different types of mapping are used to show a pattern of amenities and services. In a similar way is it possible to map the opportunities of ecological systems, and with the theories of landscape ecology, these can be connected and designed optimally.

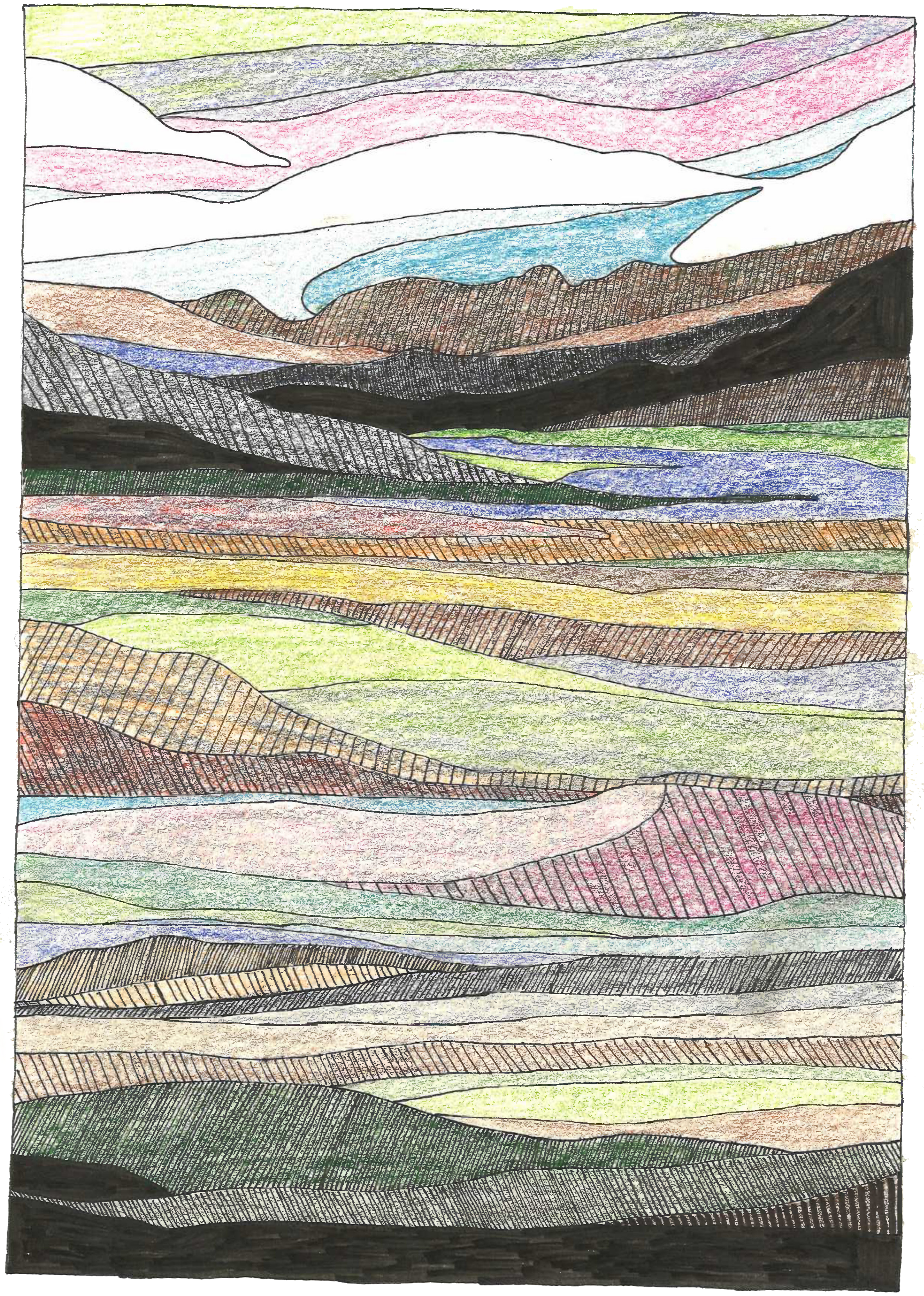
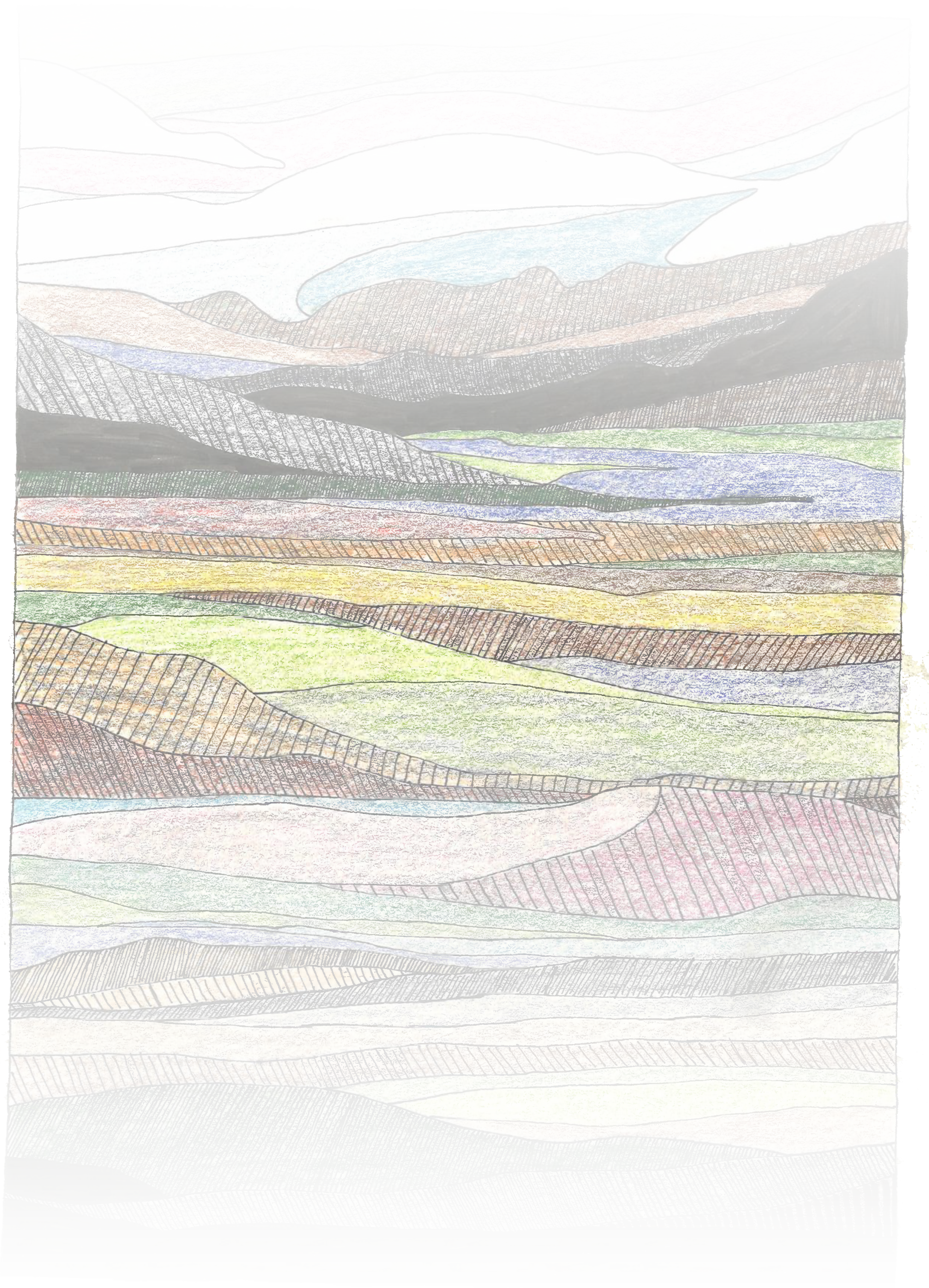


Figure 21.
Spatial abstraction of a landscape.



Part Two.

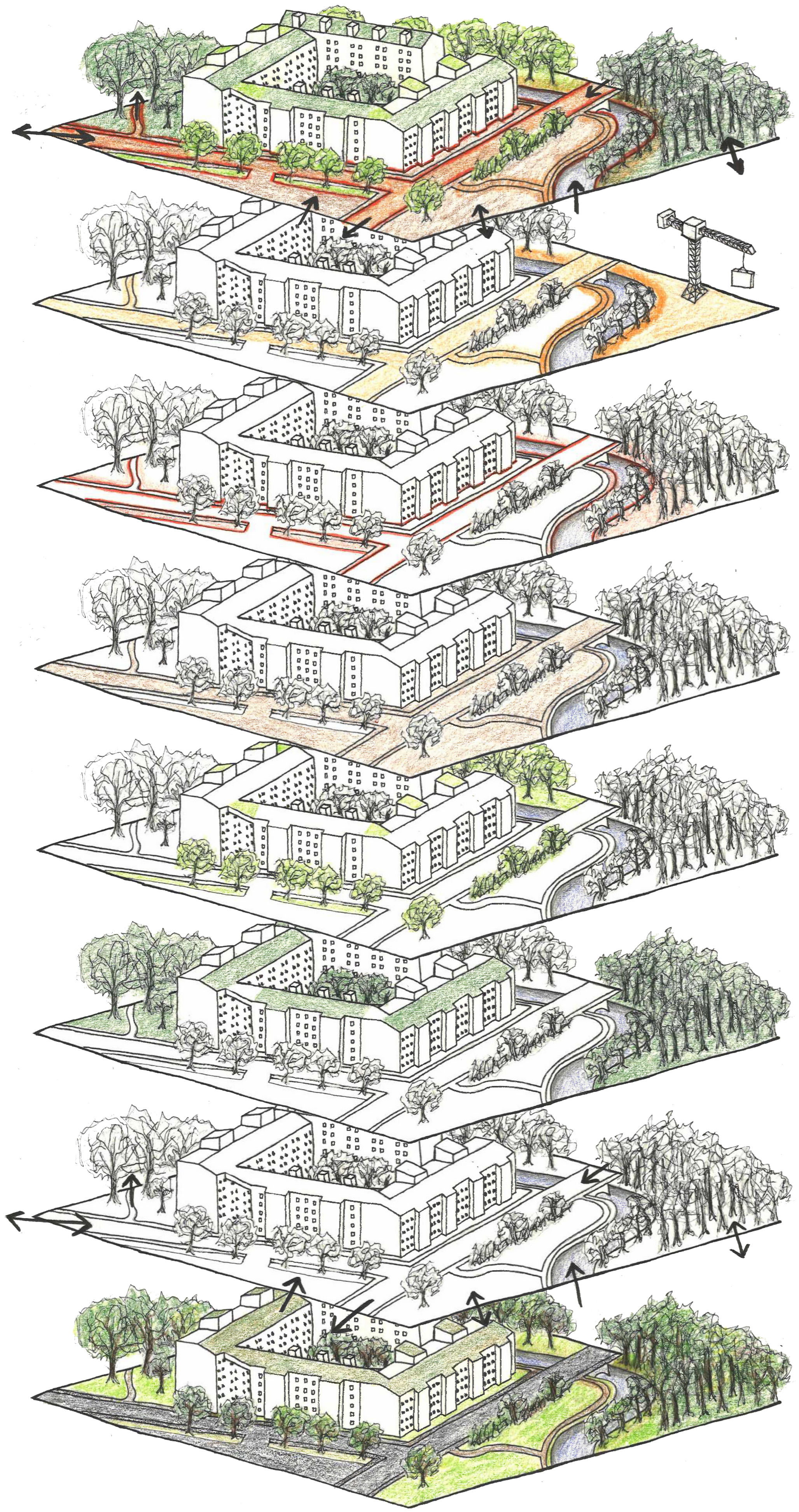
Ecological Design Methodology.

An Ecological Design Methodology.

Layers of the Landscape.

Currently, there are no overarching strong policies or pressure in favour of the implementation of ecology within the built environment. Equally there is no strong demand by human society on humanity to have its structure and technologies provide ecosystem services. This might owe to the fact that the provision of ecosystem services is not directly visually apparent to human society. Yet, by the time the loss of them become visually apparent, it may be that the degradation of natures ability of providing ecosystem services has already become too extensive and will be lost. Something that could have been prevented much earlier. (Yeang 2020, p.96)

There have been major improvements in the field of climate-smart design, technical solutions for mitigation, and the development of new smart materials. However, the role of nature within urban environments is continuously being neglected. The 'green' buildings built today are not green in the sense that they provide habitats for species and create ecosystems. It is not my aim to disregard the importance of climate-smart and sustainable green buildings, but there is a need to take one step further and implement more natural environments in urban areas. The following chapters will attempt to provide ideas for doing so , presenting an ecocentric design methodology of simple ecological principles in the context of architectural and urban design.



In his publication 'Design with Nature' (McHarg 1992), Ian McHarg describes how a landscape could be analysed in layers of different attributes and properties. Characterizing the different elements of the landscape individually is often simpler than trying to get hold of the complete picture. His concept continues with combining the separate layers to obtain a complete picture of the landscape which then could be used to investigate appropriate areas for development. This approach also facilitates the analysis of risks and consequences of different events and describes the possible alternatives to mitigate these events. However, McHarg argues that ecological principles are relevant mostly at a regional scale and time and dismisses the value of using them at a smaller scale (McHarg 1992). His strategy is because of this limited to only succeed at the broader scale of the landscape and lacks the ability to apply ecological principles at a more urban scale. Nonetheless, it is still a very effective approach to separate elements and then merge them again. It is a strategy that works as a filter that clarifies the design process and evaluates the consequences.

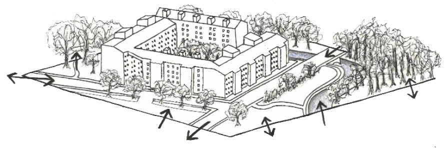
Another element that is most apparently lacking in McHarg's approach is the relation and adaptation to scale. The different layers all derive from the same regional scale and are set within a physical framework, difficult to adapt to a different context. Using the idea of the landscape as a framework for layers changes the general application of the strategy. Landscapes vary in both shape and size, from vast landscapes of forests and mountains to green patches of a city. Still, the lower limits of a landscape are not uniformly defined. Richard T.T. Foreman and Michel Godron describe that '*Landscapes vary in size down to a few kilometres in diameter.*' (1986, p.11). Yet, they continue to elaborate on this definition and describe '*Localized areas of a few meters or hundreds of meters across are finer in scale than a landscape. Nevertheless, most of the principles of landscape ecology apply to ecological mosaics at any level of scale.*' (1986, p.11). By this description, it is arguable that the definition of a landscape would include any spatial pattern that is perceptible to principles of landscape ecology and other fields of ecology. Henceforth, this definition is what will be used to define a landscape, and equally be the framework of the layers and principles described below.

Within the narrative of a landscape, certain key elements and aspects together shape the character of the landscape. These have been grouped into layers, containing principles relating to each topic, that together describe the function, structure, and dynamics of the landscape. Together, these layers conceptualize into a 'layer cake' of different landscape elements. Each layer is an interpretation of ecological principles and topics gathered from three fields of ecology, urban, restoration, and landscape ecology, discussed in the previous chapter, and work together to establish a methodology for analysing and designing a landscape. The main part of the layers originates from the field of landscape ecology, as it conceptualizes the spatial pattern and structure of the landscape. Each layer of the cake has also been adapted to comprehend the full picture of the landscape and made to be relevant to the context of design.

Nonetheless, all three fields of urban, restoration, and landscape ecology have been used in developing and discussing each layer. Because it is together that these three shape the landscape over time and by design. By gathering their principles into layers, it is possible to identify the importance of each element within the landscape structure. The central aim of developing this methodology is to discuss each layer and the underlying ecological principles in relevance to design and to illustrate how they might be implemented or used as references for design decisions. Ecology and ecosystems are present in every environment and will shape the conditions wherever they exist. Making cautious design decisions within every layer of the landscape will provide benefits in ecosystem services, biodiversity, and resilience. It will help nature to persist while also improving the state of the urban environment.

Concisely described below are the seven different ecological layers of the 'layer cake' , whereas one, mosaic, will be considered as both the start and the final layer. They are all connected and interdependent, developed to give a comprehensive picture of the landscape through an analysis of theories, methods, and strategies. It is not sufficient to only regard one layer as it will depend on the principles of another layer. Hence, it is essential to take a holistic approach and use an ecocentric strategy in combination with other strategies. On a note, this strategy of ecological landscape layers aims to give simple examples of how to integrate and regard ecology in the field of design.

Mosaic



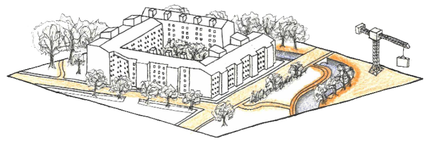
Scale

Patches

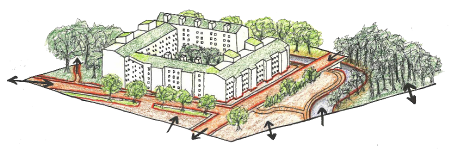
Connectivity

Matrix

Edges



Disturbance



Mosaic

Figures 22-29.
Layers of the Landscape.

Starting with an overall perspective, the principles of a landscape **mosaic** are described with a focus on spatial composition, configuration, and habitat diversity. The paper then will continue to analyse how the **scale** affects the attributes and properties of an area. Continuously the focal topic of **patches** is described the relevant spatial factors, defining the habitat, and the difference between interior and edge habitat. An influential principle for patches is **connectivity**, which is further explained with a focus on the principles of corridors and stepping-stones. The principle of connection is also relevant when describing the **matrix**, the most extensive and governing environment of a landscape, and how permeability is related to the flow and movement between ecological systems. In contrast, the topic of **edges** and boundaries is discussed. Special interest is directed to the concept of ecotone and the gradual transition between habitats, as well as the consequences of barriers. To conclude, the role of management and resilience is described through the topic of **disturbance** in relation to land use, human impact, and intervention.

In the following sections, each layer will be discussed from the premise of its ecological role within the landscape. Underlying principles will be explained, and it will be discussed how they might be considered in an urban environment. Some concrete examples are provided, when relevant, but a general level of abstraction is kept to give the concept a wide relevance, applicable on a broad scale. Yet, the relation to spatial structure and pattern of the landscape is discussed throughout as this is the main topic connecting the layers to design application. It should be made clear that the concepts and principles provided are not ready-made solutions or examples of how to design. It is rather ingredients for design discussions or primers that could be used as ecological design concepts. This is an ecocentric design methodology, developed for designers, architects, and urban designers to be used in the context of development and discussion on design. A brief introduction of the layers is given in Table 4, simply noting the connection to main theories, implementation in design, and a few examples of relevant use.

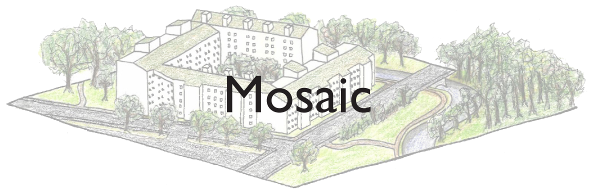
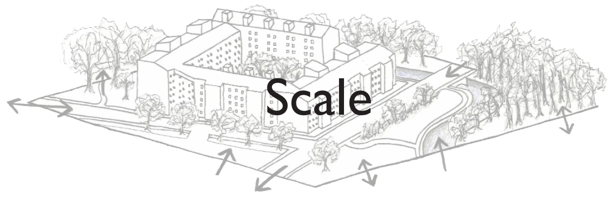
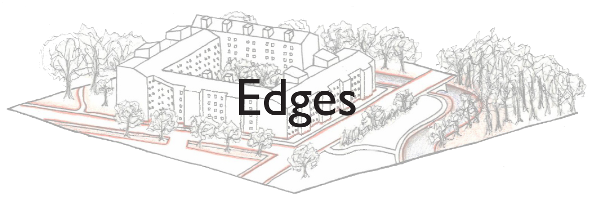
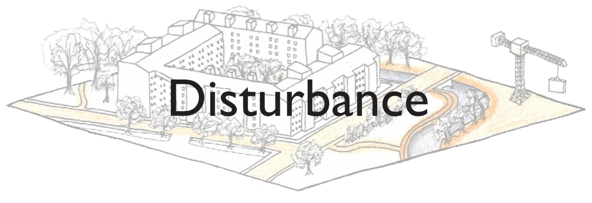
Layer	Ecological theory	Design context	Application
 Mosaic	- Spatial pattern & structure - Configuration of the landscape - Urban ecology - Landscape ecology	- Composition of urban design - Nodes & unusual features - Diversity of elements - Opportunities of areas & features	- Defining masterplan - Composition green walls & roofs - Providing unique habitats & a refuge - Places of overlap & exchange
 Scale	- Frame & context - Delimitations & consequences - Restoration ecology - Urban ecology	- Site conditions - Opportunities & risks - Position within context - Influence of surroundings	- Need of dealing with external issues - Provision of ecosystem services - Dimension of structure - Demands on heterogeneity
 Patches	- Shape & configuration of habitat - Landscape ecology - Urban ecology - Restoration ecology	- Attributes of urban green areas - Aim and target of urban natural sites - Amount and quality of green areas - Green design strategies	- Design of urban green areas (e.g., parks) - Establishing & protecting habitats - Habitat & structural diversity - Deciding quality & number of green areas
 Connectivity	- Establish connections - Preventing isolation - Landscape ecology - Restoration ecology	- Green infrastructure - Distance between green areas - Avoiding barriers - Connecting areas within a context	- Alternative movement & green networks - Eco-bridges & eco-tunnels - Green corridors & pocket parks - Street design
 Matrix	- The governing environment - Importance of the in-between - Urban ecology - Landscape ecology	- Designing the general environment - Weighing importance of in-between - Limiting contrasts in built and green - Permeability of areas	- Overall green strategy rather than specified - Increasing permeability of areas - Establishing buffer zone - Reducing hard surfaces & barriers
 Edges	- Structure in transition of elements - Ecotone & structural diversity - Landscape ecology - Urban ecology	- Structural shape of interfaces - Diversity of overlapping edges - Natural & social ecotones - Directing & promoting movement	- Soft edges create diversity & interaction - Overlapping boundaries enables mix-use - Avoiding barriers - Directing movement by structure edge
 Disturbance	- Ecological resilience - Intermediate disturbance hypothesis - Restoration ecology - Urban ecology	- Management of urban & natural areas - Provision of ecosystem services - Land-use & diversity management - Recovery & mitigation of disturbance	- Consequences of monocultures - Incorporating the recovery of nature - Design by succession & intermediate disturbance - Stormwater & flood mitigation

Table 4.
Overview of ecological layers.

Mosaic.

Composition & Configuration.

Defining Landscape.

The landscape mosaic, here denoted as the mosaic, is the tool used to describe the spatial pattern and structure of a landscape. The first step in describing the concept of mosaic is defining the term 'landscape'. Landscape is a word used in many contexts and with more than one definition. In the Oxford English Dictionary (2023) it is defined as '*everything you can see when you look across a large area of land*', while other definitions include '*the landforms of a region in the aggregate*' (Forman & Godron 1986, p.4) or '*all the visible features of an area of countryside or land, often considered in terms of their aesthetic appeal*' (Oxford Reference 2010). All these definitions describe the context of interconnected elements and attributes that establish and represent the structure and function of a certain area of land together. The size or character of the area is undefined, though often perceived as a larger and more natural environment. However, the definition of a landscape is equally relevant for smaller areas and environments of urban character and generally depends on the scope of the project as ecological systems exist in all environments.

Patterns & Dynamics.

The core attribute of the concept of mosaic is the combination of different landscape elements. A mosaic is a configuration of different land covers that create a spatial pattern. Its composition is described with different landscape elements, that together create habitats of varying quality depending on species, environment, and structure. Landscape mosaics of a specific area may, and often do, change over time This might be because of natural succession but usually is due to human impact. Changes caused by humans might lead to fragmentation, for example, land use change, and have an effect of altering the proportions between different environments or disrupting or increasing flows and movement of an area. The structure and pattern of a mosaic are therefore constantly changing over time. Through this change, it

Figure 30.
City of Malmö, a mosaic of cityscape, parks, & surrounding agriculture. (Copernicus 2020)

Figure 31.
Norra fäladen, Lund. A suburbian mosaic of housing, greenery & roads. (Google earth 2020)

Figure 32.
Bo01, Malmö. A mosaic of buildings, streets & gardens. (Google earth 2023)

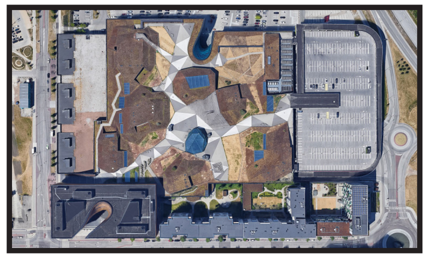


Figure 33.
Emporia shopping mall, Malmö. A mosaic of green roofs & hard surfaces. (Google Earth 2023)

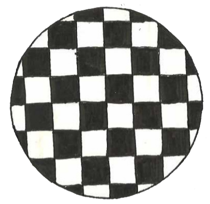


Figure 34.
Regular distribution pattern.

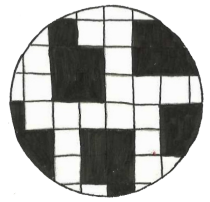


Figure 35.
Aggregated pattern.

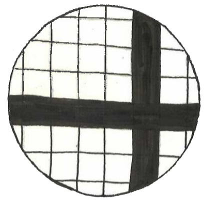


Figure 36.
Linear pattern.

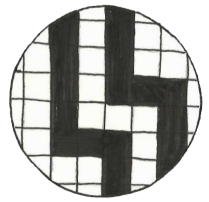


Figure 37.
Parallel pattern.

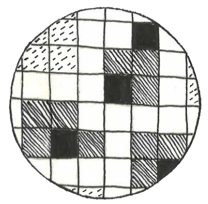


Figure 38.
Distinctive association.

is also possible to identify thresholds and governing elements of the landscape mosaic, such as which environments, processes, and habitats are principal for the resilience of the overall structure.

Examples, in a Context.

Any defined area can be described by the concept of a mosaic. A natural site could consist of a forest habitat with an environment of grass fields in between, and an urban site consists of pocket parks, a general structure of neighbourhoods and gardens, with street trees as green infrastructure connecting the different parks. Similarly, is the perceived quality of habitats dependent on the needs of a specific species. However, providing a variety of habitats connected with green corridors within a permeable environment will improve the overall quality of the landscape.

Types of Patterns.

The landscape mosaic can have many different shapes and forms. Some are uniform and homogeneous, with only a few different habitat types dispersed in a few larger areas, while others are complex and heterogeneous, with a big variety in habitat structure and size. However, nearly every landscape mosaic follows a pattern due to human or ecological factors. These factors could be processes, such as continuous erosion or clearcut patches of forestry, base conditions, such as water or nutrients, or structural elements such as topography, villages, and infrastructure. Following is a short description of the five main patterns of a landscape mosaic.

The first is **regular** or even distribution and is a pattern of relatively high symmetry and contrast. Elements of the landscape are evenly distributed throughout, mainly as a cause of planning or regular disturbances. Example of this is forestry, farm ponds, or even de distribution of amenities in suburbia, as they are only needed at a certain distance.

The second pattern is **aggregated** and builds on the concept that certain elements tend to cluster. These include for example villages in valleys, rice pads grouped on hilly terrain, or clusters of nettles under bigger trees on a field due to a higher concentration of animal dropping.

Similar is the occurrence of **linear** patterns but instead of clusters, there is a concentration of elements along a linear feature such as a road, homes and buildings, or a stream in an arid environment, cultivated fields.

The pattern of a **parallel** landscape structure primarily originates from geological processes. Within larger areas, historic glacial movements could create gouge patterns in the landscapes, that have a clear parallel structure. In smaller areas, environments with rapid erosion could create a parallel landscape structure of parallel stream corridors.

Finally, the pattern concept of **distinctive association** follows.

Here certain elements of the landscape have a spatial linkage to one another. These associations could both be positive and negative, meaning that elements of positive linkage are generally found close to each other, such as towns and roads, and elements of negative linkage are found in areas where the other does not exist, such as wetlands and arid environments (Forman & Godron 1986, p.205-206).

Similar categories could be found in urban areas where social, economic, and infrastructural elements create patterns. Knowing the pattern of a landscape will help guide general solutions and strategies for a landscape without having to define and describe every element. It could act as a template in designing, by guiding the design, but also indicating the need for certain elements within a particular pattern.

Five Urban Patterns.

In urban environments, evidence of mosaic patterns can be found. A reason for this is that humans have settled where the landscape offers a benefit for us. For example, many cities were founded along the coast or major rivers, as the water has long been used as an important source of food and water. This is namely an example of aggregated or distinctive association patterns where built environments originate in areas of specific character that fulfil certain needs. Zooming in at a smaller scale makes it possible to find evidence of other patterns. In human history of planning, design symmetry, and structure have always been central and therefore the linear and regular patterns are apparent in cities. Roads and infrastructure are straight and often long sightlines towards monuments and important buildings can be found. In terms of regularity, amenities and services are evenly spread out through the urban fabric, to be within reach for everyone. The urban examples of linear and regular patterns might not have the same origin as the regular and linear patterns in nature but still follow a similar structure. The last type of parallel pattern is the most difficult one to define within urban environments. However, it is arguably the most common. This is because of infrastructure, movement, and transportation that make up a substantial part of the urban environment. A simple road could be seen as being parallel, as it has two lanes, going in opposite directions but parallel. Within denser urban fabric, there usually also is a sidewalk and maybe even a bicycle lane following on each side. A row of trees might be added or roadside parking, together these elements create a strong parallel pattern.

Figure 39.
Cerdá plan of Barcelona.
(Google Earth 2023)

Figure 40.
Services clustered around Hyllie station. (Google Earth 2023)

Figure 41.
Grönby village aligned along a main road. (Google earth 2020)

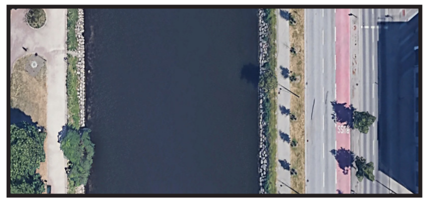


Figure 42.
Road & paths often run along wayerways. (Google Earth 2020)

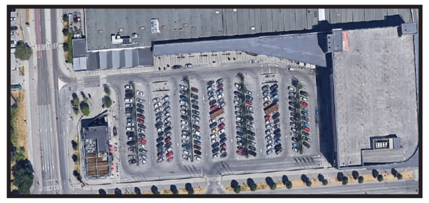


Figure 43.
Parking lots are found close to supermarkets. (Google Earth 2020)

Figures 44-46.
Examples of unusual landscape features.
Top: River (Bill 2013)
Middle: Wetland (Fike 2012)
Lower: Oasis (Nouhailler 2012)

The urban environment itself also provides special patterns due to urban life and design. One example is the verticality and three-dimensionality of urban environments: Buildings disrupt the continuous horizontal plane of the ground and project it as roofs on different levels. At the same time, it creates new vertical space to be used and inhabited. Another pattern is shown in the strong contrasts of urban environments, areas are often distinctly separated, and seldom is it difficult to distinguish the border. Green areas such as parks and lawns are often sharply cut off to make way for pavement and a building and the ground most often meets in a sharp perpendicular angle.

Unusual Landscape Features.

The earlier paragraphs describe the overall and general structure of a landscape, looking at the dominating habitats, connectivity, and spatial pattern. These are the factors that establish the conditions and dynamics of the landscape and determine which species inhabit an area, but also the extent of ecological processes and ecosystem services provided. Opposed to this general structure of the landscape, is the concept of unusual landscape features. These are elements that only occur once or a few times in the large-scale structure of the landscape. It could be a single major river running through the landscape, a city or a village, or a single hill in a largely flat landscape . Because of its uniqueness in comparison to the rest of the landscape, these elements often become hot spots for activity, flows, diversity, and materials. This could be the consequence of either structural diversity, increasing movement, microclimate, or disturbance, or because it establishes a unique habitat that attracts species not otherwise found in the area. From this concept, it is evident that the built environment has a big role in the overall landscape structure. Cities, towns, and villages are surrounded by a landscape and hence become an unusual landscape feature as their character and conditions differ largely from their surroundings. If planned and designed by the principle of being an unusual feature, a built environment can create alternative habitats for its surroundings and act as a hot spot that increases the diversity and flows in its surroundings (Forman & Godron 1986, p.218). Similarly, it is key to identify similar, unusual, features within the built environment, cities, suburbs, villages, etc., as these could provide unique ecological benefits. An unusual feature of this kind could be a structural different building, like a skyscraper or industrial area, or a special environment, such as a wetland or a brownfield.

Unusual Urban Features.

The ecological opportunities a city provides are often limited since much of the surface is paved and areas are often of high anthropogenic, human activity, influence, and disturbance. However, sometimes there are unique features of special significance for the inhabitants of the city. The most evident is a bigger park or greenspace surrounded by a built environment that will be of special importance to provide habitat and refuge to wildlife within the city. A river could have a similar role if allowed to coexist with natural areas along, could act as a natural corridor and buffer for species moving along it and to different parts of the city. Yet, many rivers have been walled and regulated to a degree in which they no longer can provide for habitats needed by species. Thus, is it important to allow the waterways to resemble their natural state, to be of ecological use. Unusual urban landscape features do not have to be natural elements and could equally be built structures of different kinds. A constructed waterway could be of ecological significance if allowed the space and designed to provide for habitats. Equally, buildings can provide unique features depending on their character. Skyscrapers can provide nesting places for birds resembling high cliffs: a refuge from dangers closer to the ground. An abandoned building might become the optimal resting place for migration birds or mammals needing a den. It is the unique opportunities provided by an unusual structure that might prove to be of great importance for other species and hence need to be cared for. There might even be a benefit in designing these kinds of features.

Convergency Points.

Continuing with areas of special significance is the principle of convergency points. In a landscape mosaic some points in which several different habitat and landscape elements intersect, and to some degree overlap, exist. These are essential to many species, as they have an increased flow of material and resources, particularly for species that are dependent on multiple habitats (Dramstad et al. 1996, p.46). Around these points, there is usually higher biodiversity due to the overlap of species from different habitats and is therefore of ecological interest. Convergency points are also notable areas for movement, as they often occur at the top of habitat peninsulas and hence are subject to the funnel effect promoting the movement to other areas. (Forman & Godron 1986, p.207) Due to this, the principle of convergency point is relevant for the overall structure, as of movement and flows, and at the finer areas, in terms of interactions.

Figures 47-49.
Examples of unusual urban landscape features.
Top: Neretva river (Gärdenfors 2022)
Mid: Schlossberg (Roletschek 2015)
Low: Brownfield (Vilgus 2007)

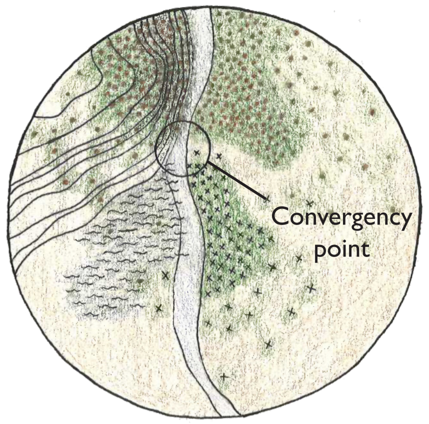


Figure 50.
Convergency point, a place of high biodiversity as a result of sturctural diversity.

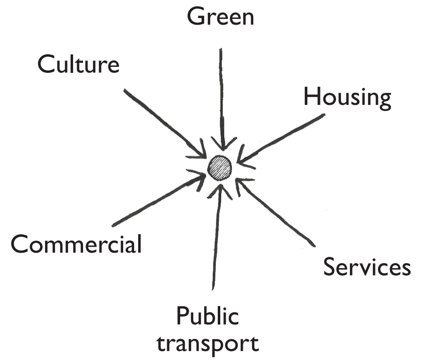


Figure 51.
Social convergency point.

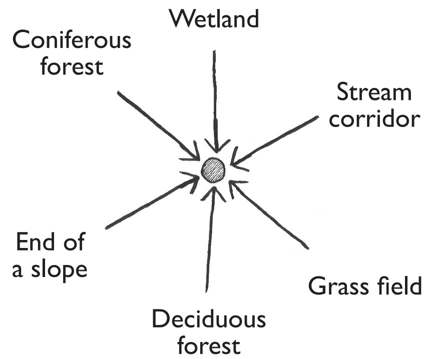


Figure 52.
Natural convergency point.

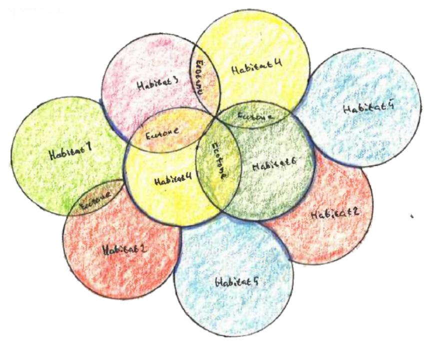


Figure 53.
Habitat diversity of a mosaic.

Urban Convergency Points.

As discussed earlier, convergency points are places where different elements of the landscape meet and often create an area of high diversity, both in terms of species and structure. In nature it is mainly about the overlap of habitats and the movement of species that makes these areas have a high ecological importance. Similarly, this concept can be applied to urban environments by looking at areas where different functions meet and areas that have a higher flow of people and usage. This kind of 'social' convergency point are places where people interact, events occur, and services are exchanged. They become hot spots for human activity. For example, this could be the area around a central transportation node, as this is where a lot of people pass through and hence will be of commercial interest. Likewise, a city centre could be seen as a social convergency point as this attracts people from all over the city and will thus have a greater diversity of people and uses. This concept is also relevant upon looking at parts of a city or an urban development. Creating spaces with high interaction is often of special interest and key for the identity of an area. As Jan Gehl states, '*It is a fact of life that the greatest interest of people is other people.*' (Gehl 2020), which argues for the importance and value of areas with high interaction. The concept of convergency points is relevant both for the design of social and natural areas and will increase the diversity, be it species, social, structural, or, preferably, all of them.

Habitat Diversity.

In a landscape mosaic, a certain variety of habitats can always be found apparent. Generally said, the more numeric and diverse the better. Habitat diversity is directly connected to the biodiversity of an area, as it allows for more niches, and consequently, species with different needs. It also offers stability and resilience to the system in question due to diversity providing more ecosystem services and making the system resistant to change. However, it is significant that enough area and space is provided for each habitat as they also make up for a landscape themselves and are also exposed to change and disturbance. Hence, it is important to create a landscape in balance, concerning its different species, habitats, and environments.

Urban Habitat Diversity.

Habitats of an urban area are often perceived and limited to parks and other green areas, but this illustrates only a part of the underlying structure of urban habitats . Every element of the environment is a habitat, even though they might not be all of ecological significance. Nonetheless, they all provide opportunities in terms of establishing healthy and beneficial habitats for a variety of different species. As mentioned above, a landscape mosaic consists of different elements and habitats, some more diverse than others. Attempting to conceptualize this principle, an urban area could be designed to establish as many different habitats as possible. The built structure itself alters the microclimate and provides different opportunities for different habitats, some areas might be shaded and wet while some might be protected, warm, and dry. As a starting point, all the roofs could be designed like green roofs resembling different habitats, some with larger trees and bushes, and some with smaller shrubs and mosses, depending on the provided microclimate. Equally, walls could be designed to provide greenery and nesting opportunities for various birds and insects. Even areas in between buildings, such as lawns, paths, and waterways, could be designed to resemble different habitats. What is important with this consideration, is that all elements of the built environment have an opportunity to become a natural habitat. Every surface cannot resemble any habitat, but it can play its role in providing ecological space. It should neither be the aim to create as many habitats as possible as that approach neglects the consideration of size, configuration, and habitat needs of local species.

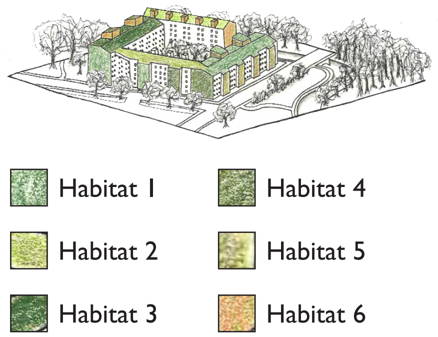


Figure 54.
A single building can support several different habitats.

Importance of Landscape as a Whole.

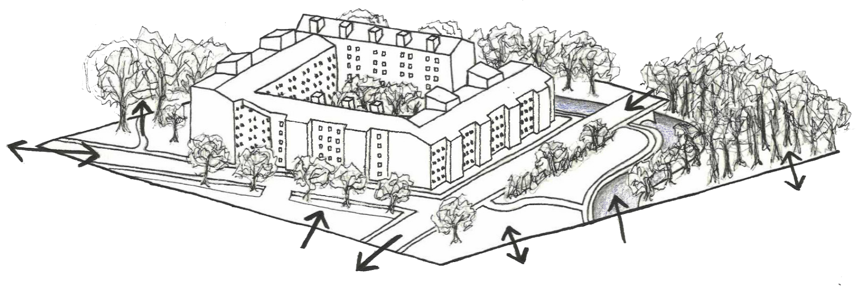
The landscape mosaic is both the starting point and the final stage of describing the composition, configuration, and spatial pattern of a landscape. Richard T.T. Foreman and Michel Godron offer an illustrative summary of the importance of considering the whole composition of the landscape mosaic,

> *In short, the landscape as a whole has properties that its parts do not possess. Therefore, we cannot describe a landscape only as the sum of cultivated fields, homes, roads, streams, and pastures. As in a synthesis, the configuration of the elements – their location and their juxtaposition – is characteristic that must also be described.* (Forman & Godron 1986, p.194)

The landscape mosaic possesses and defines all elements of the landscape. At the same time, it is the result of all other layers of the landscape. It is by gathering these different elements that the full picture of the landscape is presented.

Scale.

The Landscape Frame & Context.



The Concept of Scale.

As mentioned earlier, biodiversity is multidimensional, given that its properties and attributes cannot be simplified to only one dimension or scale (Gaston & Spicer 2004). Ecological processes of a defined system are closely related to systems and processes of many other scales, and they are interdependent. It is therefore necessary to approach the dynamics of a specific scale with the knowledge of its connections to processes and dynamics of different scales. It is also important to define how ecological patterns change, progressively going from a fine scale to a coarse scale. The contrast between scales might be sharp or be of a soft gradient. This is relevant to define as the events on one scale will affect those on another scale, direct or indirect. (Forman & Godron 1986, p.16-17)

Scale as a Frame.

In his theory of design by ecomimesis, Ken Yeang describes the need for design to be 'all-encompassing'. (2020, p.73). The design should not only reflect the factors within its border but also consider the surrounding context. This is not always recognised by designers today. Projects and designs are often limited to a site, and the context outside is sometimes neglected or disregarded as it is not aligning with the view of the designer or the design concept. The result of this is projects and designs that become alien to their context, artefacts without a site specificity , disrupting the cityscape where it is placed. This reduces the perceived quality of both the design itself and the surrounding context. However, this is not always the case but rather exemplifies the importance of regarding and using the surrounding context as a principal element.

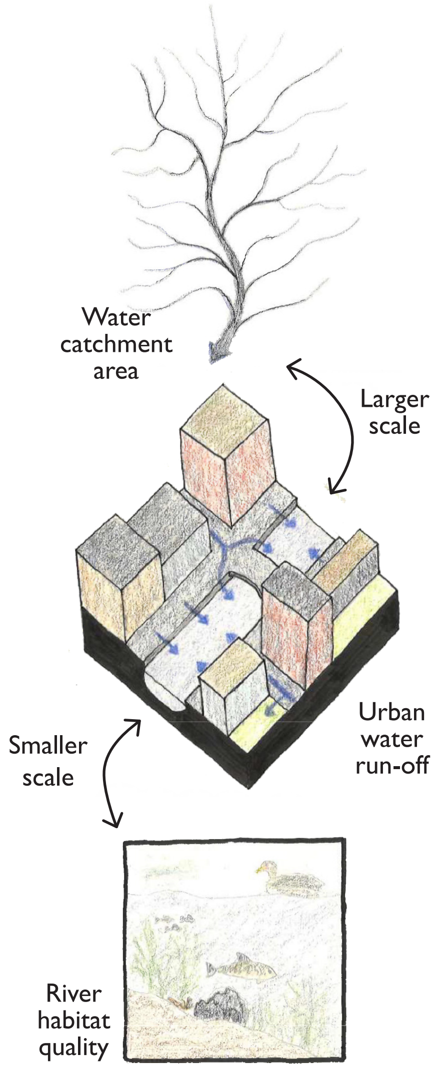


Figure 55.
Scales are interconnected.

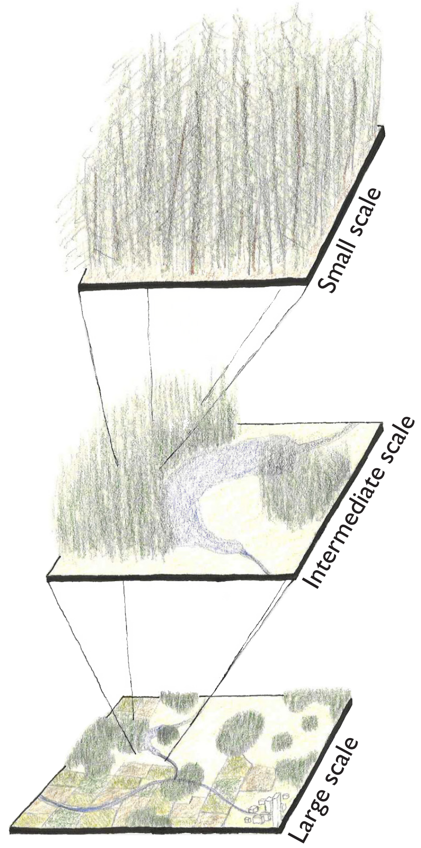


Figure 56.
The scale alters the perception of the landscape.

Nonetheless, the factors of the surrounding context do not only relate to the current state but also to events, changes, and consequences that could occur over time. Therefore, the primary task of defining a landscape is to determine the scales of relevant context. The main scale will be defined by the site, the frame of the study area, or the project. It is within these limits that the mosaic will be established and the environments, habitats, and structure be described. This scale will be the main reference for which dynamics and principles are applied and relevant, and by which attributes and properties are described. Following the principles of ecomimesis, it is then essential to determine how the mosaic is affected by its surroundings but also how it relates to ecological processes on different levels of scales. The importance of this approach is to prevent the degradation of ecosystems both within and outside of the scale of the project. The natural ecological systems are all interconnected, and it is, therefore, necessary to have a broad and all-encompassing approach to designing. (Yeang 2020, p.73)

Heterogeneity & Homogeneity.

To recapitulate the definition of a landscape, as per paragraph 'Defining landscape' in the previous chapter, the Oxford Dictionary describes it as '*everything you can see when you look across a large area of land*' (Oxford Dictionary 2023). By its' definition, the landscape is a subjective matter as it determines the landscape from a personal perspective. More outstanding is, however, the aspect of it defining the landscape as something dynamic, as it is determined by the point of view. This means that a landscape described on one scale may be very heterogeneous with a high variety of patches, corridors, and habitats. When describing the same landscape but from a more distanced, broader, perspective it might seem less heterogeneous and more homogeneous because the previously different patches and habitats now are perceived as the same and the corridors are at this scale negligible. The same thing might be observed when zooming in and describing from a closer perspective. The same element now plays a completely different role in their context and hence needs to be described differently. This means that the appearance of a landscape mosaic might differ vastly upon perceiving them from differing perspectives. Yet, these two views stand in correlation to each other and need to be acknowledged. Describing the heterogeneity of a landscape mosaic is a useful tool in describing the diversity and complexity of an area but it needs to be considered that it is closely related to a specific scale and perspective. (Forman & Godron 1986, p.198)

The Grain Size of the Landscape.

Within a landscape mosaic, different elements have varying dimensions and scales of structure. This is described as grain size. The grain size is usually determined by measuring the diameter of different elements present within the different parts of the landscape. The concept of grain size is connected to the overarching scale of the area. It is therefore relevant to define the grain size of the landscape mosaic equally as the grain size of individual parts of the mosaic. It is generally observed to be of most ecological benefit with a coarse-grained landscape containing fine-grained areas. This is because it would provide a habitat for a larger variety of species (Dramstad et al. 1996, p.45). A coarse-grained landscape mosaic could, for example, be a mountainous forest landscape with forest patches of a few kilometres in diameter, while an agricultural landscape mosaic with fields of approximately one hectare would be medium-grained, and a hay meadow with the occasional tree would be fine-grained, as each tree is a patch. (Forman & Godron 1986, p.216)

The Grain Size of Species.

In the previous paragraph, the topic of grain size regarding the landscape was discussed. Similarly, the concept of grain size should be considered in relation to species. Again, as the definition of a landscape is determined in relation to perspective it will be perceived differently by different species. To provide a suitable habitat for smaller insects, the structure of the landscape needs to be fine-grained in comparison to the perspective of a mammal or a bird. It is thereby important to look at a landscape on different scales to provide conditions for all species of an ecosystem, as all species have a vital role and cannot be neglected without running the risk of degrading the whole system (Forman & Godron 1986, p.182-183 & 216-217). A similar approach should be considered when regarding urban environments. Without consideration of detail, urban planning will not succeed, and equally will details be lost if the urban structure is not adequate. A natural environment is inhabited by different species, and an urban environment is inhabited by people with different needs and patterns. Hence, the principle of grain size is relevant in all landscapes.

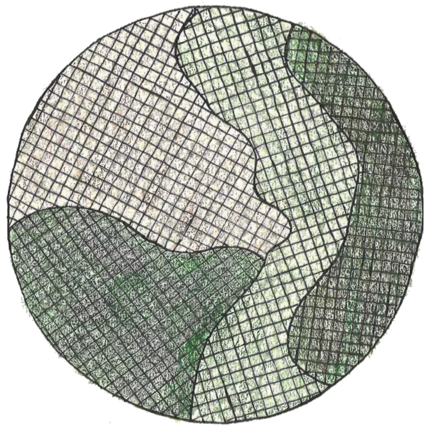
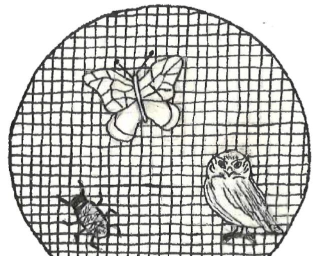
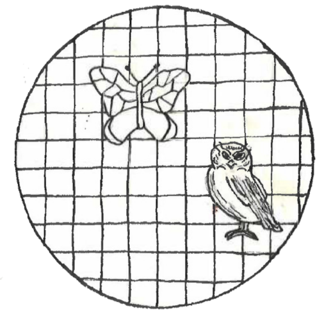


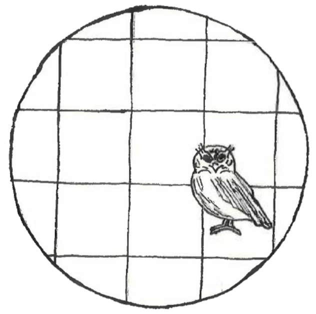
Figure 57.
Landscape grain-size.



Fine-grain structure.



Medium-grain structure.



Coarse-grain structure

Figures 58-60.
Species require different grain-size of the landscape.

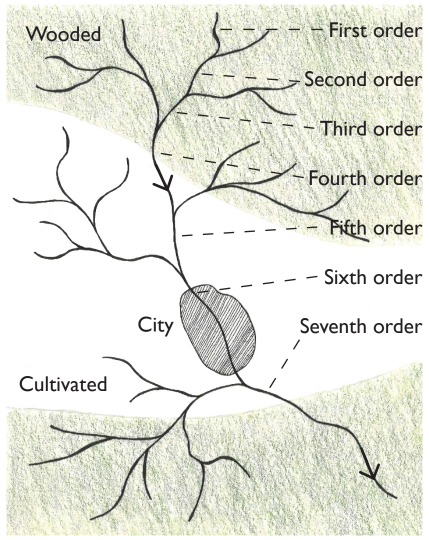
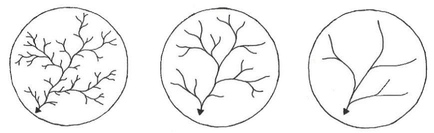
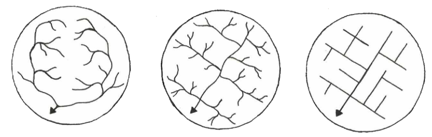


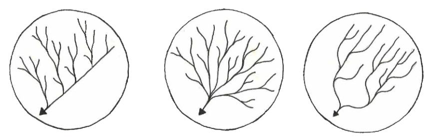
Figure 61.
The concept of stream-order.



Fine - Intermediate - Coarse



Radial - Linear - Artificial



Parallel - Centred - Ordered

Figures 62.
Variation of water catchment configuration.

The Wider Context.

As stated earlier, it is important to look at the wider context to determine the affecting ecological processes and dynamics that define the conditions of the relevant scale. The context outside of the landscape boundaries will affect the fundamental conditions for ecological systems and processes within the relevant area. Factors on a global scale, for example, climate, water cycles, and seasonal change are relevant to all areas. Also relevant are large-scale ecological processes and dynamics, such as water catchment areas, migration patterns, and local weather conditions. These factors are of high relevance to the design of an environment and will shape its structure. The most evident example is the flow and way of water. Water exists in every environment and is a necessity for all life. Water in a river originates from springs that create small streams, these are called first-order streams. Two first-order streams then merge creating a second-order stream, and as the water continues to flow downstream more streams merge and the order increases. In general, the water is clear and well-oxygenated in first-order streams while in high-order streams the water is unclear and, in many cases, suffers from eutrophication because of over-fertilized agriculture, cities, and sedimentation. Thus, where the area is located, concerning the stream order, will greatly affect the condition of the water. It will also outline the risk and consequences that might be caused by disturbance or contamination of the water. (Forman & Godron 1986, p.148-150)

The Smaller Within.

Many species living in low-order streams do not tolerate the conditions of high-order streams. A consequence of this might be that populations and ecosystems get isolated, with the risk of degradation. This exemplifies the importance of evaluating the effects of the systems within, at a finer scale than the set frame of the landscape. The value of this is to look at the effects on habitats within habitats. Even smaller areas might have a central role in the overall system, and equally in the role of ecosystems outside of the site. These habitats might provide fundamental services for the overall system and compromising specific ecosystems might cause the degradation of habitats within the site. On the other hand, it is sometimes of interest to alter the flows as a method for regeneration, preventing the risk of further degradation of specific ecosystems. An example of this is to provide natural water reservoirs within urban environments. This is a method to reduce the risk of flooding and reduce contamination, filtering the water before it enters the larger waterways. Similarly, the introduction of permeable surfaces could help to reduce surface water and contamination, and refill groundwater. (Yeang 2020, p.116, & Forman & Godron 1986, p.152)

The Urban Context.

Perceiving urban areas as a part of the wider context, including the areas outside of the city, will allow for a more comprehensive design approach and development. It prevents the degradation of ecosystems and increases resilience. The concept of scale is mainly about regarding the context and making decisions based on elements and factors in connecting areas. If the design includes mitigation methods for flooding will help and affect the areas downstream. A holistic approach of scale will guide the design to take the necessary measures to ensure the external and internal benefits. A city is not an isolated island within its context, and the same goes for sites and buildings within a city. The urban area is equally influenced by the surroundings as the surrounding is of it. Perceiving urban development as a part of the landscape composition presents opportunities in reducing the negative impact on the surrounding and can equally provide solutions for restoring degraded ecosystems.

Different Scales of a City.

A principle within the layer of scale regards framing the project and defining the relevant landscape. This will appear different depending on the scope of the project and it will determine the relevant scale of the context. With the example of a city the main factors relevant may be major waterways and significant routes for transportation. These might influence which areas are developed, preserved in terms of green infrastructure, and where there is a risk of flooding. It also shows opportunities for creating green corridors through the city and in what manner to direct water so that both the urban and natural environments benefits. Considering different parts of the city closer, is it evident that they are directly affected by design decisions made at the broader scale of the city. The character of neighbourhoods is defined by green areas and the infrastructure surrounding them. The design of the neighbourhood will therefore need to consider these conditions to not become a barrier in the larger structure.

At its frame of scale, neighbourhoods will need to consider solutions based on the conditions given. These conditions might be the need for mitigation of flooding or urban heat island, a high urban density, or a protected habitat. These conditions require more local solutions but will still be relevant to the broader context of the city. Within a neighbourhood it is critical to have a comprehensive approach, as it might not be an adequate solution that only a few buildings are adapted to mitigate a problem. For example, even if a building or a block is designed with techniques for mitigating urban heat islands, such as green roofs, plantation of trees, etc., it will not be enough if the rest of the neighbourhood is without these implementations. Thus, the design of one building will only be a part of the solution. It must be made sure that there is a continuous strategy and application throughout the scales from the biggest to the smallest.

Figure 63.
The broad scale of the city. Quebec, Kanada. (NASA 2018)

Figure 64.
Green attributes of the neighbourhood affect the overall quality. Sjølundsparken, Denmark. (Gärdenfors 2021)

Figure 65.
Small scale principles consider specific species. (Obscurasky 2017)

Figure 66.
Urban heat islands needs small scale solutions, as planting of trees. (Djedj, no date)

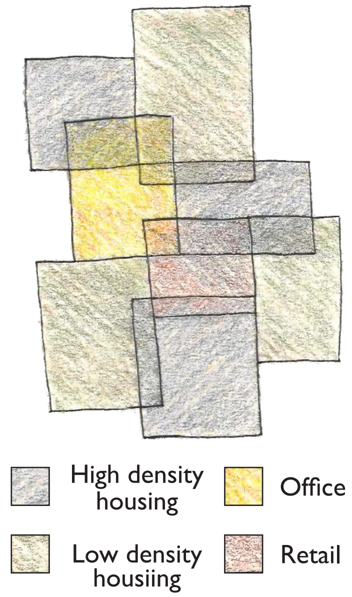


Figure 67.
Social heterogenity & mix-use by overlapping zones.

Social Heterogeneity.

As discussed in the earlier chapter, it is vital with habitat diversity to increase the resilience and biodiversity of a landscape. This can be related to the principles of heterogeneity and homogeneity whereas the habitat diversity is defined by scale and is thus multidimensional. When designing an environment of a specific scale it needs to be defined how it is perceived at the broader scale. It might be beneficial to resemble the habitat of the surroundings to increase the area of that habitat, becoming a part of the larger network and in that way increasing the ecological resilience. On the other hand, it might be of more benefit to establish a unique habitat that will provide an unusual landscape feature perceived at a broader scale. Generally, it is proven favourable to mix scales, allowing different grain sizes in the environments. A greater area of habitat is needed to support certain species and a finer grain is needed to support smaller individuals. A similar strategy could be used in urban environments, without the broader scale of areas there would be a lack of people and uses, but at the same time, there is a need for mix-use areas and structural detail to attract people and make them stay and use the area.

Patches.

Size, Shape, Configuration & Number.

Definition of Patches.

Ecologists previously regarded patches as analogous to islands and the concept of island biogeographic theory (Dramstad et al. p.19). By this theory species diversity and richness are directly correlated to the size of the area, level of isolation, and age of the island, or patch. However, because of the complexity and difference between terrestrial landscape environments and water, the use of island biogeographic theory to describe patches has been largely abandoned. Yet, it still has some relevance for areas with environments of low permeability and quality, for example, cities with isolated parks. (Dramstad et al. p.104) The current definition of patches is closely associated with the matrix of a landscape mosaic. The matrix, discussed further later, is described as the most extensive and continuous habitat, and therefore plays the dominant role in determining the function and structure of the landscape. (Forman & Godron 1986, p.159) Scattered within the matrix are areas of patches, these may be of varying size, habitat, and structure, but are differentiated by being different from the general structure and environment. The size of a patch relates to the scale of the landscape mosaic, discussed in the previous subchapters, and can vary in size, from a national park to a single tree. The quality of a patch is closely related to its structure and form, described through four different attributes within the context of the defined landscape and scale. These four attributes are size, shape, configuration, and number, described relevant below. (Forman & Godron 1986)

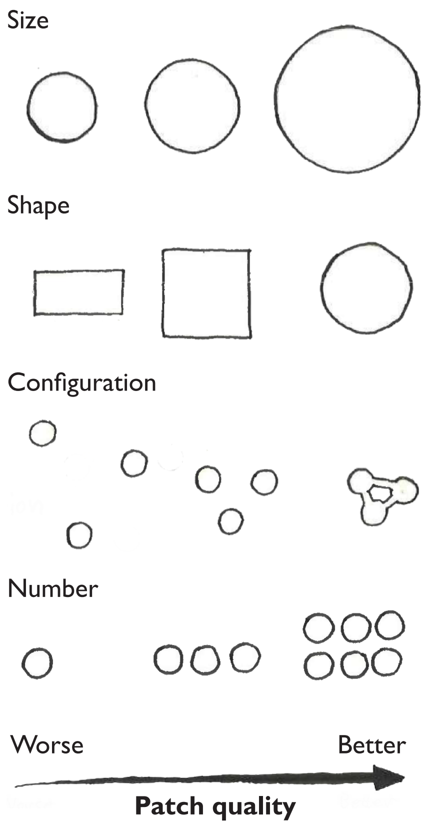


Figure 68.
Patch attributes. Size, shape, configuration & number.

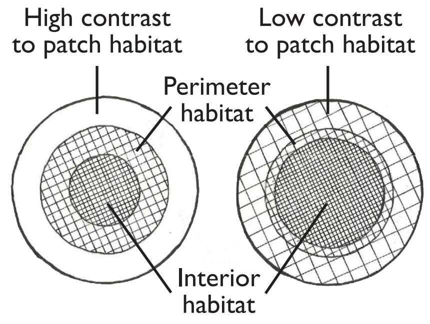


Figure 69.
Interior & perimeter habitat.

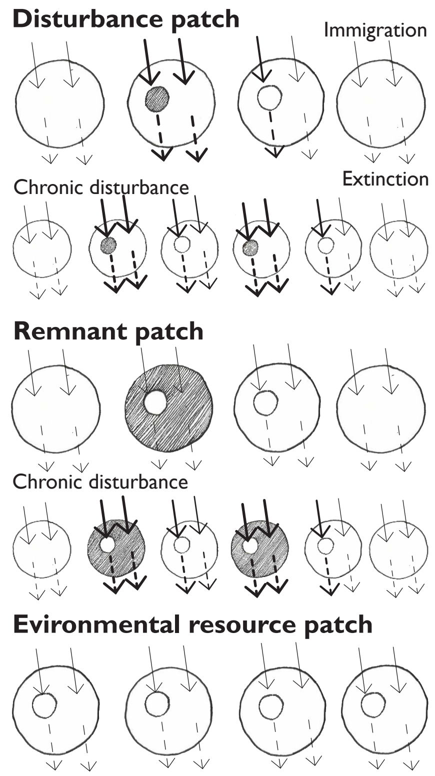


Figure 70.
Patch-turnover rate.

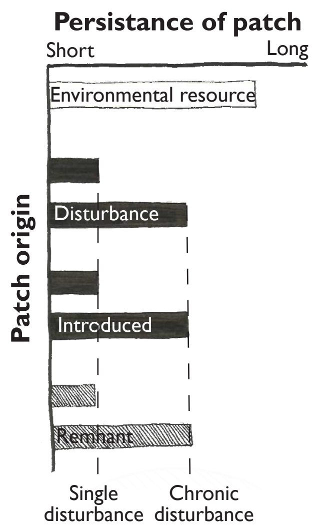


Figure 71.
Stability & longlivity of different types of patches.

Interior & Perimeter Habitat.

A patch is defined as being an area of homogeneous habitat, separated from neighbouring environments and habitats in structure, climate conditions, and disturbance, and they are, to some degree, isolated. The quality of a patch hence refers to its internal quality and how different elements of structure and context affect the habitats within the patch. Different species have different tolerance to disturbance and alteration of preferred habitats. Therefore, a distinction is made between the perimeter habitat, located along the borders of the patch and is affected by the conditions of the surroundings, and the interior habitat, the area in the centre of the patch that is not affected by the surroundings. Species that inhabit the perimeter habitat are often generalist or multi-habitat species that have a high tolerance to a disturbance in habitat and prefer, and benefit from, the conditions along borders of patches. Interior-habitat species, on the other hand, are sensitive to disturbances and need specific conditions to thrive and are often referred to as specialist species, as they have adapted to specific conditions. (Forman & Godron 1986)

Patch Origin & Types.

The origin of most patches is through the alteration of an environment's spatial structure, either through changes in land use or events of natural disasters. It might be the cause of permanent change as geological activity or fragmentation due to construction. These patches are likely to remain the same if not exposed to another change. Other patches may be less permanent and have appeared through a smaller alteration, such as a forest fire or forestry clear-cuts. These will recover after a while and once again, be a part of the surrounding environment. The rate at which a patch appears and disappears is explained through the concept of patch turnover and is a key element when analysing a landscape (Forman & Godron 1986, p.85). The turnover rate of a patch may describe the origin of the patch, how it differentiates from the surrounding, and the role it plays in the ecosystem. Through their origin, patches may be categorized into four different types, disturbance, remnant, environmental resource, and introduced patches.

Disturbance patches are the patches with the highest turnover rate. They are the cause of local disturbance but will quickly start to recover. However, they might still be long-lived if the event of disturbance is repeated. If the disturbance continues to occur, species within the patch will adapt to the disturbance and thus will be permanently different from the surroundings (Forman & Godron 1986, p.89).

Contradictory, **remnant** patches are the cause of disturbance or change in the surrounding environment that damages the overall ecosystem. Because of this, remnant patches become isolated, like islands, in a degraded environment. In this case, it is species from remnant patches that recolonize and help the degraded environment to recover. The hazard of this is that species remaining with only a small remaining population will run the risk of extinction. A prolonged period of recovery will increase the number of species that run the risk of disappearing (Forman & Godron 1986, p.89). This illustrates the risk of relying on remnant patches as a strategy of recovery. As is the case for, large-scale clear-cuts in forestry, remaining forest patches in agricultural land, or parks within an urban explanation. The patch might at first resemble the pre-disturbed habitat but with continuous isolation the patch will degrade, and ecosystem services will be lost.

Another origin for patches is differences in **environmental resources** and abiotic conditions. These patches are all rather stable and occur where there is an uneven and irregular distribution of resources, such as nutrients, water, or soil. Environmental resource patches often have softer boundaries to other elements of the landscape mosaic and hence often have increased biodiversity in these areas as a cause of the concept of ecotone, discussed further in the subchapter about edges.

The final type of patch is **introduced** patches. They owe their existence to human intervention or impact. Introduced patches are generally long-lived because of continuous human maintenance but would without it succumb to natural succession. This is the case with most planted patches such as cultivated crop fields or planted forestry that would without pesticides, clearing of weeds, etc. have a completely different appearance.

In most cases of construction, all parts of ecosystems are erased and then replaced with buildings and the occasional green area. The species reintroduced are often not native to the site and, even when native, groomed and maintained to please aesthetic needs (Forman & Godron 1986, p.95). Rarely are the newly built surfaces used to replace and regenerate the eliminated habitats and ecosystems. Urban areas are progressively becoming more dominated by tall buildings, yet the use of the vertical realm to provide habitats and ecosystem services is neglected. It should be recognized that facades, roofs, and terraces all provide unique opportunities for biointegration and the establishment of habitats and patches. (Yeang, p.96)

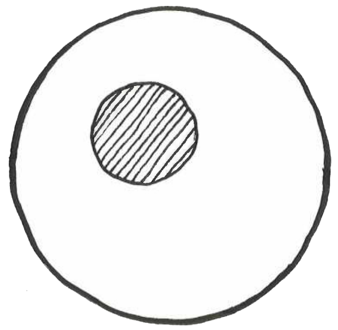


Figure 72.
Disturbance patch.

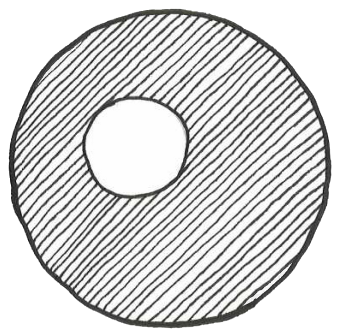


Figure 73.
Remnant patch.

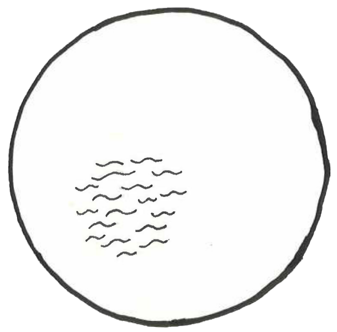


Figure 74.
Environmental resource patch.

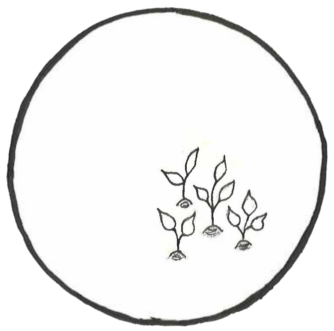


Figure 75.
Introduced patch.

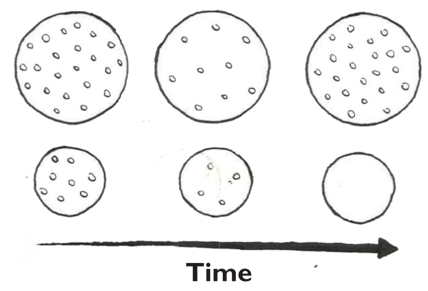


Figure 76.
Risk of local extinction.

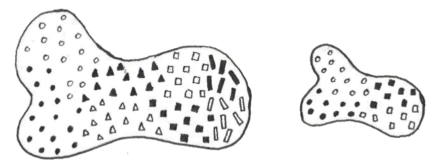


Figure 77.
Probability of habitat diversity.

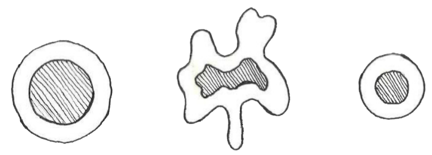


Figure 78.
Different patch shapes.

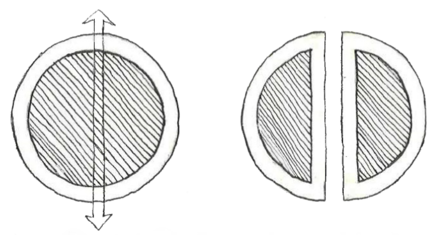


Figure 79.
Patch fragmentation.

-	Length of border and interactions with surroudings	+
-	Probability of barriers present	+
-	Probability of habitat diversity	+
-	Functioning as a corridor for species movement	+
+	Species diversity	-
+	Foraging efficiency of animals	-

Figure 80.
Characteristics of isodiametric & elongated patches

Size.

The sizes of the patches determine how much of the patch is affected by the conditions of the surrounding areas. The consequence of this is described through the concept of edge-effect; a principle that the area surrounding the edge of a patch is impacted by exterior conditions, thus differentiating from the centre of the patch. Yet, the proportion of the edge-effect decreases as the size of a patch increases, since the width of the buffer zone stays the same. A larger patch has an increased probability, of hosting a larger variety of habitats, and therefore a higher number of species. Equally, is the risk of local extinction lower in bigger patches as they can host bigger populations.

Shape.

Secondly, the habitat quality is affected by the geometrical shape of a patch. Linked to the element of size, the shape is also related to the proportion of the edge effect. For example, an elongated patch will have a smaller area of interior habitat compared to an isodiametric patch of the same size. Similarly, a patch with a more convoluted shape will also have a low portion of interior habitat, however, it will have a higher interaction with the surroundings as it presents direction to flows and establishes a more diffuse edge zone. Generally, the most optimal shape is a circular core, with convoluting boundaries and a few narrow fingers reaching out into the surroundings. Also related to the factor of shape is the event of fragmentation when a patch is split into two or several areas. Even if the approximate area stays the same, it might still cause significant ecological consequences as the proportion of the edge zone might drastically increase leading to the extinction of some interior species.

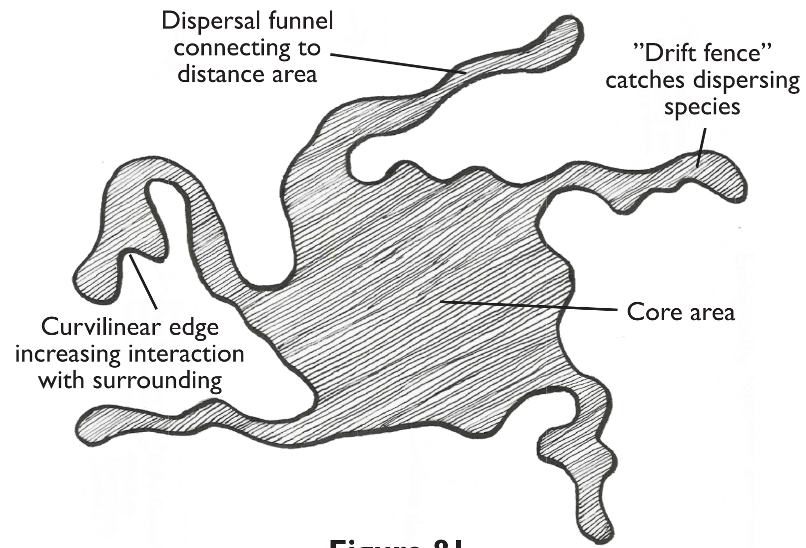


Figure 81.
Shape of ecological optimum.

Configuration.

Furthermore, it is crucial to assess the configuration of patches within a landscape mosaic and in what way a patch is oriented to its surroundings. Preferably a patch should be arranged with its long axis parallel to the border of adjacent patches, to optimise the flows of species and connect ecological processes. On the same topic, the distance between patches ought to be within reach of recolonization and migration, to and from adjacent patches. This principle is especially important for smaller patches as they might not provide enough habitat area but might do so as a group. Linked is the concept of metapopulation dynamics, which describes genetic exchanges and migration between populations of different patches. Within a landscape, there might be several populations of the same species, dispersed over several patches, that together create a metapopulation. The concept is that populations of a metapopulation only occasionally interact, but together support a higher genetic variety and resilience as individuals might repopulate degraded populations. This again, is especially noteworthy for smaller patches with smaller populations as they have an increased risk of local extinction.

Number.

Finally, patches within a landscape work together to establish a network of species, flows, processes, and ecosystems. Again, with this principle, is the concept of metapopulations relevant. If a landscape mosaic has a higher number of patches, and consequently a higher number of populations, the probability of local extinction is significantly reduced. If it would occur, the probability of recolonization would be higher. This results in stability and resilience of the landscape. Furthermore, there is a principle that several smaller patches could replace one or a few larger patches. However, the combined area of the smaller patches generally needs to be significantly bigger than the few larger ones. The case could also be that a few patches with high respective biodiversity could replace a larger number of patches with lower individual biodiversity.

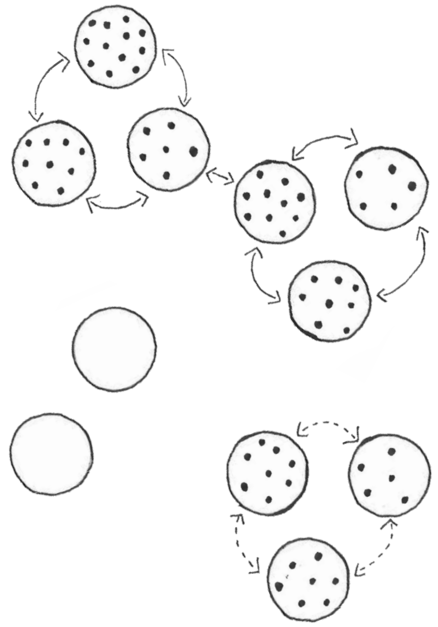


Figure 81.
Metapopulation dynamics.

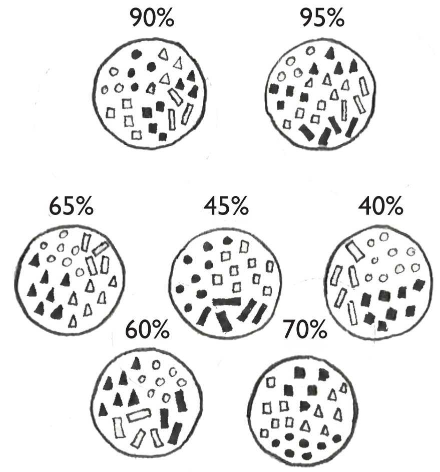


Figure 82.
Few diverse patches may replace many several patches with lower diversity. Precentage indicating divesity.

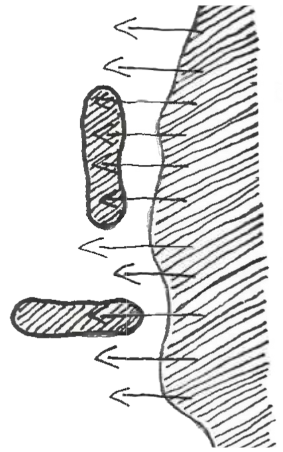


Figure 83.
Patch orientation influense the proability of colonisation.

Figure 84.
Interior habitat of St Hans park, Lund as a result of impact of the surroundings.

The Role of Patches.

The shaping of patches is a valuable tool for designing green areas with high ecological quality. If the principles of patches are applied to urban environments, it will be evident what actions are necessary and which areas are of lower importance. They could also be used as a tool to make improvements in specific areas and increase ecosystem services within cities. Patches play an essential part in the landscape mosaic as they provide for different habitats and increase biodiversity. There is not one correct way to design a patch. Different species depend on patches of distinct structure and form. It is, however, important that patches complement each other and work together in the landscape to create a network that provides a habitat for a greater variety of species.

Urban Interiors.

One of the most key aspects of patches is the existence of interior habitat or adequate proportion of edge to interior habitat. When designing green areas within cities this is one of the elementary principles to define. The principles of size and shape directly relate to this with an isodiametric and large patch being ideal in terms of edge-to-interior habitat proportions. A circular park will be better than a narrow rectangular park if its attributes are the same. However, a consideration rarely taken, especially in the case of parks, is that it is not only the other perimeter of the patch that will impact the existence of the interior habitat. Parks are often designed with elements such as pathways, playgrounds, plantings, etc. These will all, to varying extents, disturb the existence of internal habitat due to the emergence of a buffer zone. Because of this, it is not enough to provide a large green space. It is also necessary to consider the structure of the space. Every path, and other elements, within a park, will, somewhat, fragment the park into several patches. An example of applying the principles of patches to the design of a park could be to divide the park into separate parts; some being more protected and designed for nature, and others with amenities, paths, etc., and designed for humans. This exemplifies the need of looking at patches within patches, with the park being the patch, and the parts of the park patches of the patch. The same principles go for all types of urban patches, so be it a park, a building, a courtyard, or a green roof. Allowing undisturbed habitat in the middle of a patch is the main value for establishing interior habitat.

Stability of Urban Patches.

Patches are the result of disturbance and consequence of an area being separated from another. The same is the case for urban patches, they are the outcome of construction and design of the built environment. In natural environments, patches follow a turnover rate in which they disappear and change due to regeneration after disturbance. In urban environments, patches are often managed and controlled with their existence depending on human influence. Nature has through evolution and ecological processes reached an equilibrium of stability. It implies an ability to recover after naturally occurring disturbances and is thus not changing notably. The urban environment might seem permanent and stable, but it is at the same time everchanging and continuously renewed. In Sweden and Europe, the lifespan of a building is only required to be 50 years (Onno 2022). The building is after that expected to be demolished or replaced. 50 years is a short time from an ecological perspective, especially with the consideration that most construction completely removes the ecological systems. The challenge is then to integrate the natural environment within the urban environment without degradation because of change, demolition, and replacement. This will require a longer perspective in planning and design but also solutions that help enable natural systems to stay connected and could help in recolonization.

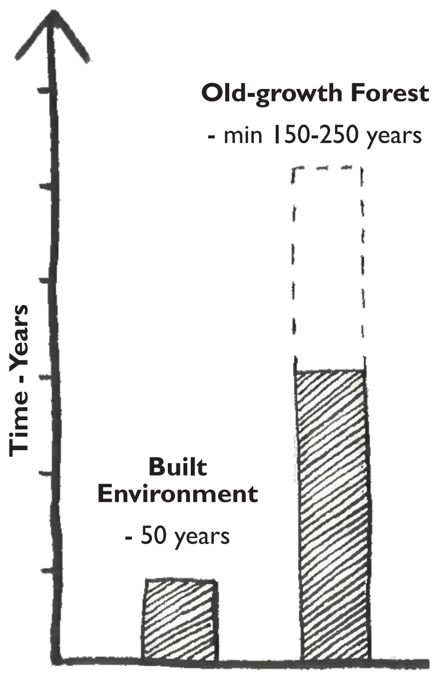


Figure 85.
Longlivity of urban & natural environments.

A Patch Number Strategy.

The use of patch number principles can guide design strategies, suitable for different projects. One strategy is to design only a few patches, that are either large or of high ecological quality, biodiverse, and ideal ecological shape. This strategy would allow concentrating the natural environments to certain areas rather than dispersing them throughout the landscape. Yet, the risk with fewer separated patches is that they become isolated and will still need so connection by green infrastructure.

Another strategy is to design several smaller patches or patches of lower quality. This approach may allow to replacement of a few larger patches if species can easily move between patches and thus reach enough habitat. This would reduce the need for larger green spaces or areas of high ecological quality. The consequence of this strategy is that it may not provide enough interior habitat and might therefore have lower biodiversity.

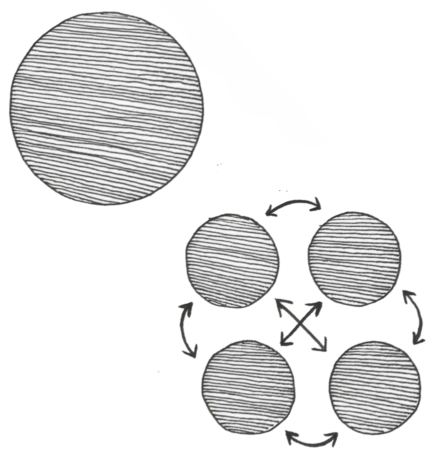


Figure 86.
One big or several small patches.

Connecting Urban Green.

As briefly mentioned above is the fact that patches run the risk of degradation if isolated from each other. This is why the configuration of patches is especially notable in urban environments where there are many disturbances and barriers. The main issue in this is the principles of metapopulations and the need for separate populations to interact to be able to sustain each respective population. It is therefore important to locate patches within proximity or by other means, by optimal shape or green infrastructure, to enable movement between them. Figure 81, of optimal ecological shape, shows an example: Designing urban patches to extend into the surrounding will increase the opportunities for interaction with other green areas.

Connectivity.

Corridors & Stepping-Stones.

Connecting the Landscape.

Discussed in the previous subchapter was the element of patches, areas that are distinguished from the general environment. Patches are of high importance as they provide for biodiversity, however, they are dependent on other patches to sustain the population and create stable and resilient ecosystems. Thus, is the concept of connectivity highly integral, and its principles are linked to all other landscape elements. Connectivity defines the conditions that allow species to move and interact between elements in the landscape mosaic. It establishes flows of resources and creates connections between populations and species, which continuously increases the stability of the ecological systems. The quality of connectivity is mainly dependent on three factors: the distance between patches, the structure and quality of dominating environments, and the different species of the environment. These are individually varying factors, making connectivity a complex but influential part of the landscape mosaic.

Gaps.

Connectivity is mainly described through the elements of corridors and stepping-stones that link different parts of the landscape. Corridors are continuous bands of habitat, whereas stepping-stones are smaller areas of habitat dispersed in the general environment, like islands, and provide a route for movement. Linked to the elements of corridors and stepping-stones is the aspect of gaps, simply the distance between patches. A long gap result in low connectivity, consequently, isolates the patches from each other. Whereas a fully connected corridor, with no gap, is of high connectivity and hence of ecological benefit. In the case of stepping-stones, several smaller patches establish a connection in the gap between two larger patches. Subsequently, a landscape mosaic often consists of a gradient of different linking elements and routes, from fully connected corridors to sparsely placed stepping-stones.

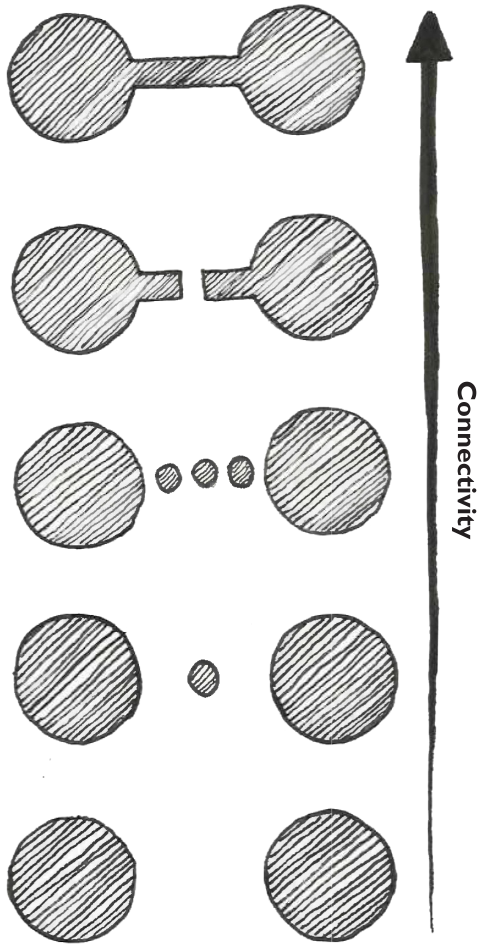


Figure 87.
Connectivity by gap structure.

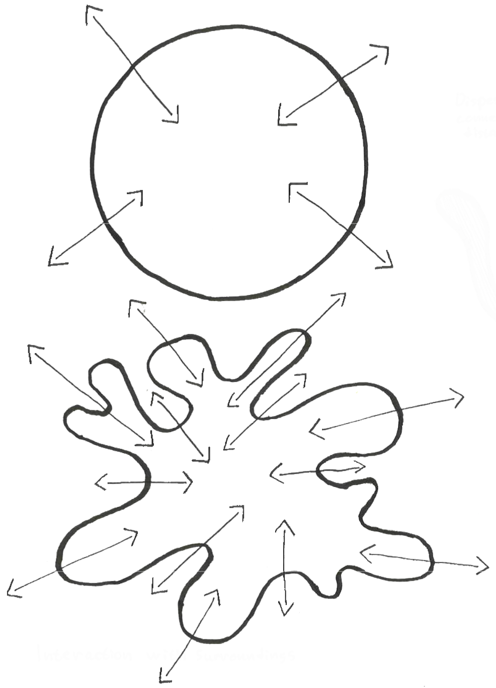


Figure 88.
Connectivity in relation to shape of patch.

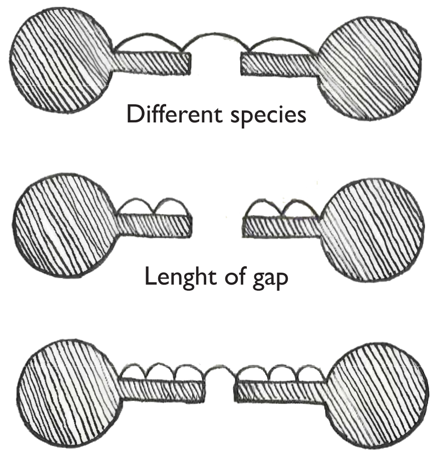
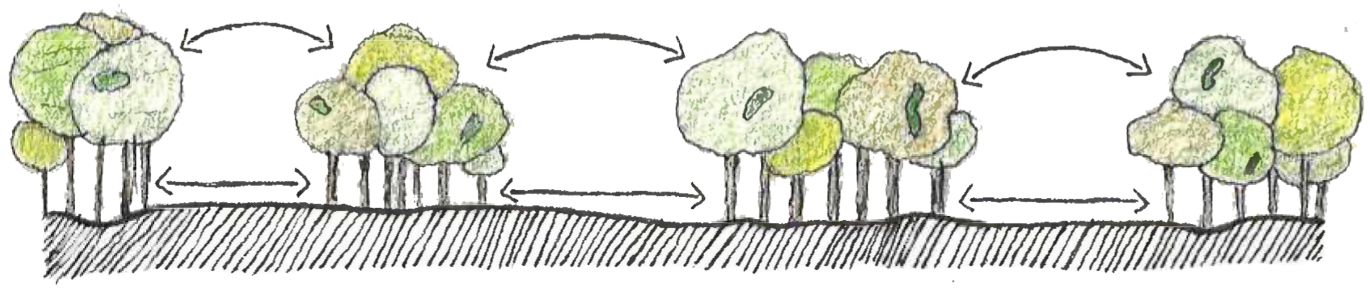


Figure 89.
Gap dimension in relation to species.

Figure 90.
Visual & physical connection.



Structure of Connections.

However, it is not simply the distance between patches that influence the connectivity. The width and dimensions of corridors and stepping-stones are equally essential. Wide and generous connections can host similar habitats to patches allowing more sensitive interior habitat species to use them. It likewise provides for freer flows of resources and species, preventing the risk of local declines and extinction in either linked area. Nevertheless, establishing a continuous corridor is in many cases difficult due to barriers separating two patches. This could for example be a road or a river and make the creation of a corridor difficult. Yet, with an accurate investigation of species and flows, stepping-stones might prove a useful alternative solution. Altogether, the principle is the fewer and smaller gaps the better, and a gap preferably needs to be connected both through air and land. It is furthermore the case that corridors have been straightened due to efficiency in planning, transport, drainage, etc. Even though the calculated distance of a straightened corridor is shorter than a curvilinear corridor, and hence provides for faster movement, the negative ecological impact is significantly larger for a straightened corridor as the structural diversity is lower and consequently also the biodiversity (Forman & Godron 1986, p.126).

Species.

A similar aspect is the fact that the local species composition alters the connectivity demands. Airborne species, for instance, are less affected by the conditions of the ground and mainly need a visual connection for movement. Land species are, on the contrary, highly affected by land use and permeability and might be completely stopped by barriers such as roads or rivers. The flow of some species, for instance, many plants, is dependent on the flow of other species, seed dispersal, etc. Likewise, many ecological processes are reliant on flows of many scales and species to function. Hence is it crucial to consider connectivity for several species when regarding the structure of corridors and stepping-stones. Accordingly, wider corridors have a higher probability of fulfilling the needs of a greater number of species due to generally having increased structural diversity. Similarly, it is a good strategy to create a cluster of stepping-stones and loops of corridors, establishing alternate routes of movement. This principle makes the connection, and the ecosystems, more resilient to change and disturbance, for instance when a stepping-stone is removed, or a corridor is blocked by a predator.

The Dominating Environment.

Another factor impacting connectivity between patches is the quality and properties of the dominating and governing environment. An in-between environment of higher quality may reduce the need for a continuous corridor and could allow for a strategy of more sparsely placed stepping-stones. For instance, a grass field between two patches of forest is easier for species to pass through than a body of water. In this example, water is described to have a low permeability while a grass field has a high permeability. The permeability is not only dependent on the type of habitat but is also affected by the land use and disturbance of the environment. An environment with a continuous disturbance will have a lowered permeability as it poses a danger to species traversing it. The land use change might therefore have major consequences on the overall ecological system, even though the environment itself does not host a biodiverse and important habitat.

Corridors.

The major characteristic that defines a corridor is that is a narrow strip with different habitats running along either side. The principle of corridors primarily relates to connectivity as an element that connects patches of a certain habitat. Categorizing corridors is done similarly to defining patches. Differentiating elements from the surrounding context, whereas corridors are described by liking other elements of the landscape. Another similarity to patches is that corridors owe their origin to the alteration of the pre-existing environment. They are also remnants of changes that have formed their current shape and are often dependent on maintenance to keep their shape (Forman & Godron 1986, p.124). For example, a remnant strip of forest in an agricultural mosaic owes its existence to human impact, clearing, and cultivation of the land, and without this continuous disturbance, of agriculture, the species of the corridor would spread into the cultivated land. There are also some cases of regenerated corridors, corridors that have been established. Examples of this are hedge rows in agricultural land and green infrastructure within urban environments. Regenerated corridors often play a very key role in ecosystems as they become unusual landscape features, described earlier.

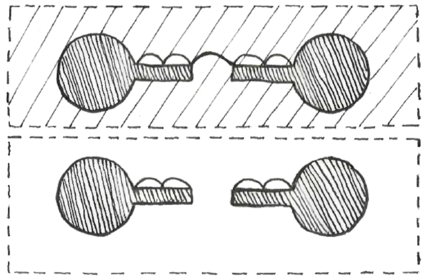


Figure 91.
The in-between environment affects the perception of gaps.

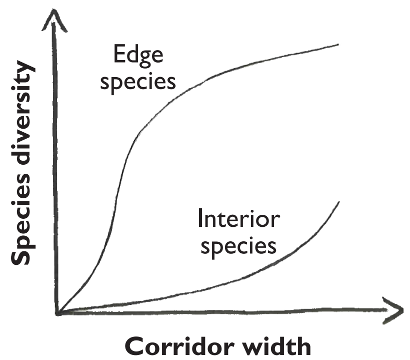
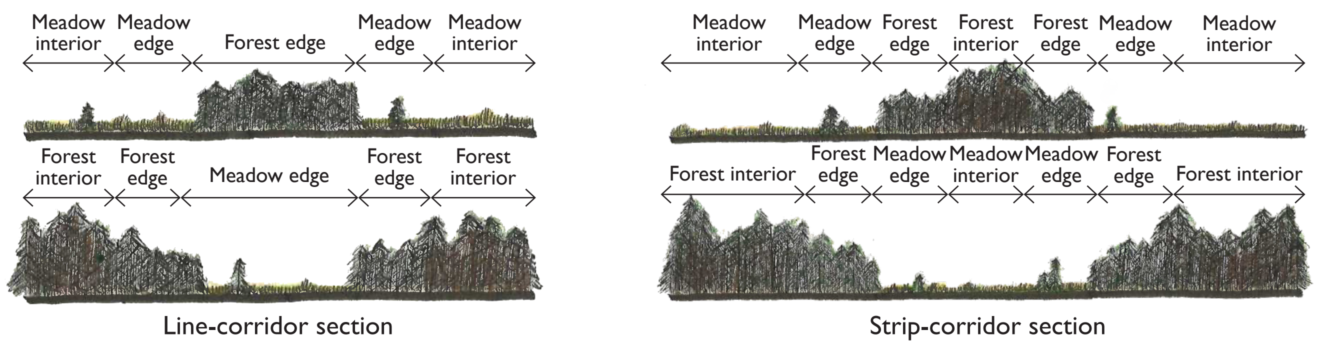


Figure 92.
Graph showing the corridor width to species diversity.

Figure 93 & 94.
Line- & strip-corridor sections.



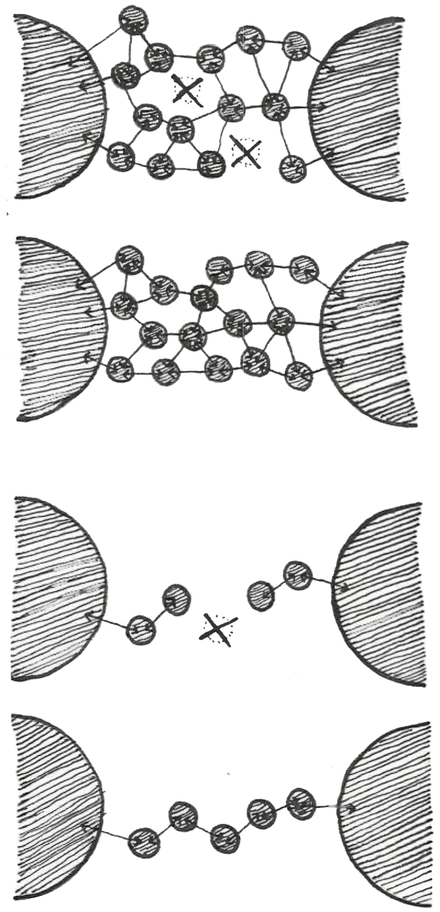


Figure 95.
Risk of different stepping-stone configurations.

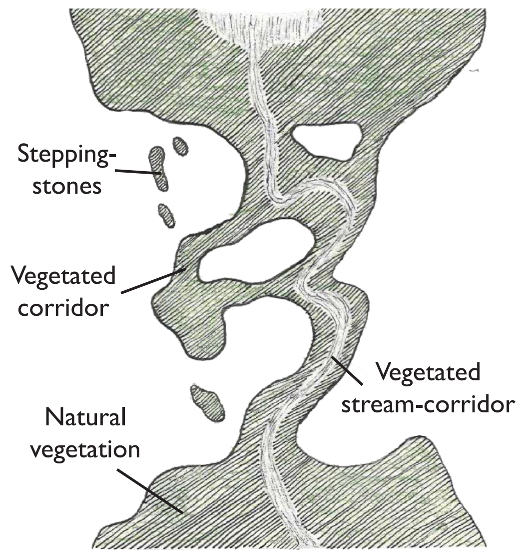


Figure 96.
Networks & alternative routes increase ecological resilience.

Furthermore, there are three separate categories of corridors, line corridors, strip corridors, and stream corridors. The primary structural and ecological difference between line and strip corridors is that strip corridors are wide enough to have a buffer zone on either side but still contain interior habitat in the centre (Forman & Godron 1986, p.142). Line corridors on the other hand are narrow and are seldom inhabited by interior habitat species. This differentiation in biodiversity is described by the concept of width-effect. In very narrow corridors, for example, a line of trees or shrubs, there would only exist a few edge habitat species (Forman & Godron 1986, p.136). As the width of the corridor increases the amount of edge species will increase until the corridor is wider than the buffer zone created by the edge-effect. When the width has surpassed the buffer zone on either side, a microclimate favourable for interior habitat species will result and further increase the biodiversity of the corridor (Forman & Godron 1986, p.144).

The last category of corridors is stream corridors. They have characteristics that could resemble both line and strip corridors but are formed around a waterway. Stream corridors have a strong connection to principles of scale, as waterways travel and affect larger areas and are an essential part of transporting nutrients and controlling the accessibility of water. They provide a natural route of movement and play a major role in different ecosystem services. Hence, stream corridors are of special interest as their conditions and state have major implications on a bigger scale.

Networks.

One focal aspect to identify within a landscape mosaic is networks. This relates to how patches and habitats are connected and to the structure of the overall connectivity. It is a principle that includes concepts of environment permeability, gaps, and barriers. In the overall structure is it possible to identify networks for movement and flows by identifying the corridors and stepping-stones connecting different patches. A research observation identified that networks with alternative ways for movement, for instance, loops or clusters of steppingstones, have an increased usefulness as they reduce the negative impact of barriers such as disturbances, gaps, and predators within linking routes (Dramstad et al. 1996, p.42). A continuous network of alternative routes and loops will increase the stability of an ecosystem and it will become more resistant to disturbances. This concept could be resembled by the strategy of green infrastructure in urban design. Green connections between green areas should include alternative routes for movement to avoid the risk of isolation and degradation.

Intersection-Effect.

Landscape mosaics with intersecting corridors, loops, and alternative routes are shown to have increased biodiversity in areas intersecting. The reason is that these areas have an increased rate of flow and movement, but also structural differences from the connected corridors. For example, an intersection will have a small area with a different microclimate due to its more protective structure. Examples of this are reduced wind speed, more shade, higher moisture in soil and air, and less temperature variation. These microclimate conditions are more resemblant to conditions in interior habitat and therefore intersections will have an increased biodiversity due to the occurrence of some interior habitat species. (Forman & Godron 1986, p.178-179)

Overcoming Barriers.

The main challenge of establishing good connectivity in a landscape is to overcome the elements of barriers. A simplified measure of connectivity is by quantifying the number of gaps per unit of length, as this will in a simple way describe both the conduit and barrier functions of a corridor. Constructions such as roads, canals, or even paths may prevent species from moving between different areas, and even a corridor itself could be a barrier by separating two areas of habitat. It is important to identify the flows and routes of species, to be able to break these barriers and design alternative routes. These could include elements of a denser network of stepping-stones, narrower gaps, or implementations of built constructions such as eco-bridges or eco-tunnels. Connectivity is the base for healthy populations and ecosystems, many species need to move between areas to sustain themselves, and other symbiotic species. Accordingly, a landscape mosaic could host higher biodiversity by simply increasing its connectivity. (Forman & Godron 1986, p,127-128)

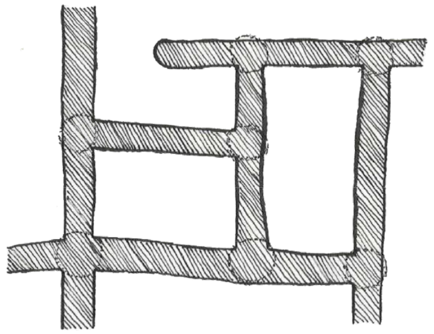


Figure 97.
Intersection-effect, an increased biodiversity at intersections.

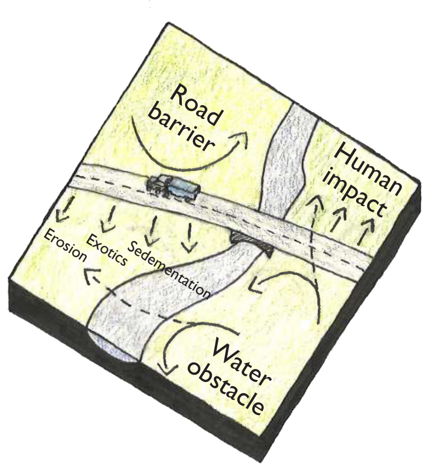


Figure 98.
Barriers in the environment.

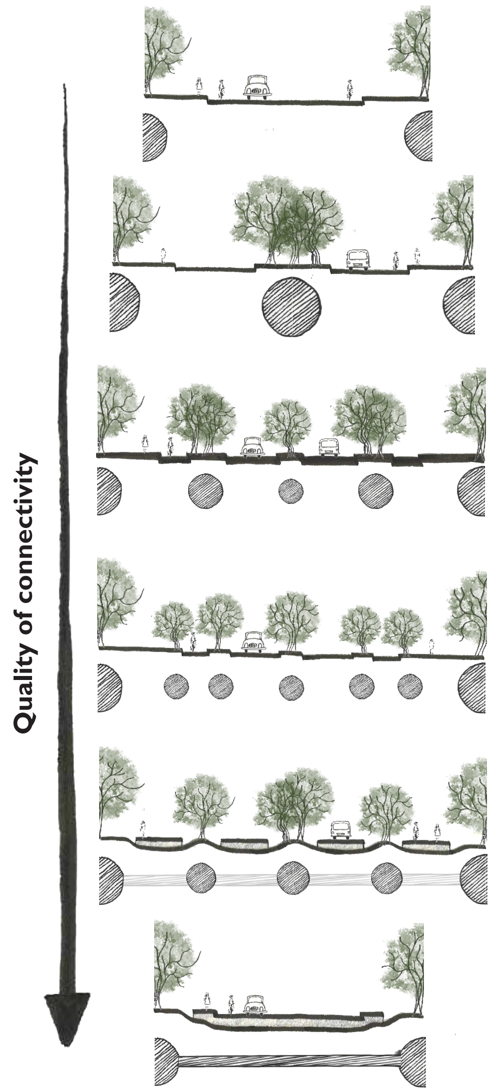


Figure 99.
Different examples of green elements in street design.

Green Streets.

One of the more used strategies for connecting green areas in cities is plantations and trees along streets. These green streets could be designed in many ways and be a very useful tool for increasing green infrastructure. Connecting back to the discussion on line-, strip- and stream corridors, shows that a corridor could be structured in different ways. A street with a narrow band of trees on each side would mainly resemble two line-corridors running along a barrier. If the street has a wider green strip with trees in the middle it is then more resemblant of a strip-corridor, and similar could the inclusion of water, such as in bioswales or streams, create characters resembling those of a stream-corridors. This showcases the importance of designing the green along a street and knowing the importance of the connection. If the green street link two valuable green areas, it is of significant interest to create a well-functioning corridor for the species who are going to use it. It is also relevant to look at the dimension of a street in terms of it being a barrier and obstacle for species moving over it. In this case, it is mainly a discussion about gaps and how to bridge them. For example, having several rows of trees along the street will act as stepping-stones allowing species to move to one row at a time rather than having to cross the street in one go. In this regard, it is also more beneficial to have a row of trees in the middle of the street rather than on the edges. The dimensions of the street thus become very important, as the width of the lanes and green areas will directly affect the connectivity between the areas on either side of the street. It is preferable to have a green space between every lane, as shown in Figure 99. A corridor with a wider green space in the middle will increase connectivity along it but still lack connectivity over it if the lanes on either side are wide or highly trafficked.

Urban Corridors.

Within the urban environment, there are many different examples of green infrastructure and urban green corridors. One perception is that if they are green, they are good, which is not always true. Most often 'green' solutions rely on trees to act as corridors for species between areas. While trees might be of use to airborne species, such as birds and some insects, it does not fulfil the needs of species moving on the ground. A corridor of trees might look green and nice from above it is in many cases surrounded by hard pavement, all the way up to the stems of the trees. Urban green corridors like this will have good connectivity for some species while neglecting others which has the risk of destabilizing the ecological systems as only some species can move between areas. It is therefore vital to design a variety of corridors that enable different species to use them. With this concept, it is possible to combine the use and character of different types of corridors, using line-corridors for quicker and alternative routes, strip-corridors for extensive and strong links, and stream-corridors for integrating blue systems and establishing buffer zones.

Figures 100-102.
Examples of urban corridors.
Top: Green alley (Gärdenfors 2022)
Mid: Row of trees (Gärdenfors 2022)
Low: Canal (Gärdenfors 2022)

Eco-Infrastructure.

In urban environments, the main aspect affecting connectivity is the creation of barriers. Hard pavement, streets, and high walls are all examples of how design creates obstacles for species and disconnects areas. Depending on level of disturbance and risks presented, strategy of connectivity varies. The most effective way of overcoming a barrier is to create an alternative route. In terms of ecology, this could be described as increased eco-infrastructure. This entails designing alternative ways for species to move, avoiding the risk of crossing, for example, a road. Eco-infrastructure includes elements such as ecobridges and ecotunnels, construction that let species pass either over or under a barrier. This has already been implemented and shown to be an effective solution to increase connectivity and relink populations and habitats. Ecobridges is of main use in three-dimensional context with topography or elevated buildings. Ecobridges are used to bridge habitats over major roads and infrastructure and could in a similar way be used to link and overcome barriers on a smaller urban scale. Creating ecobridges, in combination with pedestrian use, over highly trafficked streets in urban areas will benefit both the urban and the natural environments. Ecotunnels work in a similar way by creating paths underneath the barrier. This strategy also benefits from topographic differences but could also be implemented without major construction if designed with smaller dimensions for smaller species. At the scale of a building, ecobridges could be used to link green roofs enabling a wider area of connected habitats. In this way, a system could be created using ecobridges, green walls, and roofs to create a biodiverse and connected natural area.

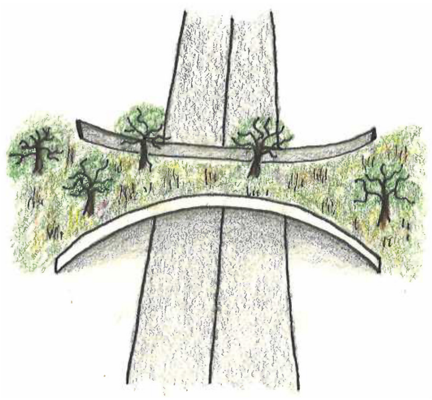


Figure 103.
Ecobrige.

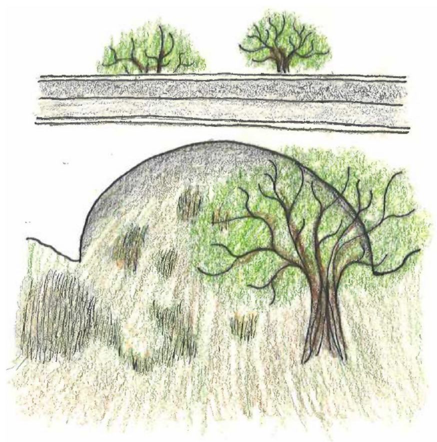


Figure 104.
Ecotunnel.

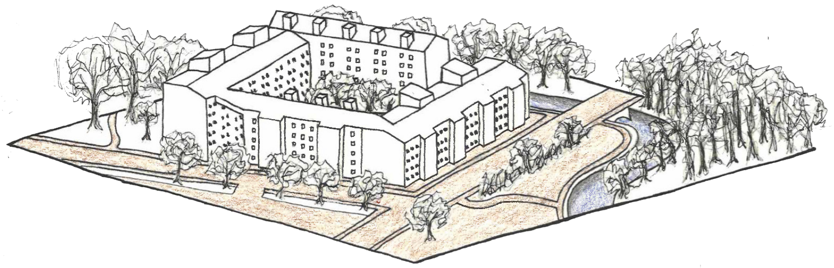
Figure 105.
A network of paths allows human movement. A green network allows other species to move. (Dronepicr 2015)

A Green Network.

In most cases is it not enough to connect a patch with a single corridor or route. The reason for this is the risk of disturbance or blockage of the route and the patch will consequently start to degrade. Disturbances will happen and is a part of the natural process, they might be only short term, for example, a predator occupying the corridor, or more long term, as in the event of structural damage caused by construction or disease. Relying on one route is therefore uncertain and might alter the movement patterns of species as an effect of not regularly being able to access a route. This emphasises the need of establishing a network of corridors and stepping-stones with several alternative routes and loops. The system will then become more stable and resilient to change and disturbances and will also recover quicker after degradation. Creating alternative routes is not to say they all need to be the same and of high quality, it could be beneficial to have a variety in connecting routes as this would increase the structural diversity and maybe even the biodiversity.

Matrix.

The Governing & Donimant.



Defining Matrix.

In most landscape mosaics there is one element, one environment, that is more dominant than the others, this is what defines the matrix. The term in-between might be used with some accuracy to describe the matrix, however, this definition has some flaws and needs to be used with caution. The patches of a landscape mosaic are generally approached as areas of importance, and correctly so as they define the more unique habitats and therefore have an especially focal role in the ecosystems and biodiversity. Nonetheless, is it the matrix that has the dominant role of the landscape and it is by the matrix character the condition of the landscape is determined. It might even be the case that the habitat of the matrix is of higher ecological importance than that of the patches, but as it is the most extensive and well-connected environment of the landscape it is often of more interest to look at the uncommon features of the mosaic. However, it is sometimes difficult to distinguish the role and relative proportions of different elements of the landscape, but still, the rule is that the matrix plays the role of being the primary determining element of the landscape. (Forman & Godron 1986, p.159)

Figures 106-108.
Examples of different matrix.
Top: Agriculture (Formulanone 2013)
Mid: Suburbia (Waits 2011)
Low: Roofscape (Sam-H-A 2017)

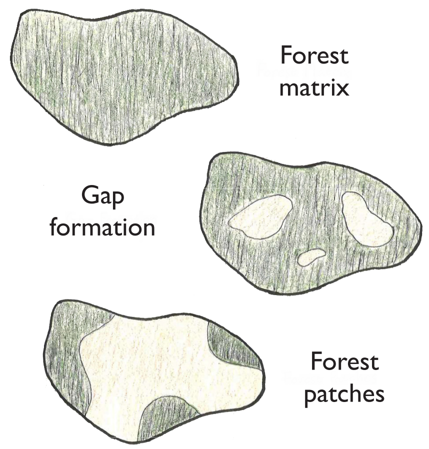


Figure 109.
Transformation of matrix over time.

The Governing Role.

By the definition that the matrix is governing element of the landscape, the concept of relative area seems to be a logical approach to determining which environment constitutes the matrix. In an area with an evidently dominant environment, this makes up the matrix. This is because the species of this area will be predominant in the whole landscape, and similarly the dominant environment will shape flows and events of disturbances (Forman & Godron 1986, p.160). Though, there are some cases where the relative area may not be the most accurate way to describe the matrix. In the case of enclosed areas, the matrix might have a smaller relative area but still, be the most connected and determining factor in the landscape. In these cases, connectivity characterises the matrix rather than only the area itself (Forman & Godron 1986, p.162). It is by controlling the dynamics in a landscape that makes the influence of the matrix principal, it shapes the conditions and largely alters the basis of all other elements in the landscape.

The Time Aspect.

Landscapes are dynamic and change over time, through changes in land-use or by disturbance. As seen in the case of patches and corridors, they have often been established through the event of structural alteration or fragmentation. It might even have been the case that the habitat of the patches once formed the matrix but through fragmentation and gap formation a new matrix has been formed. For example, this is the case with deforestation and agricultural development, and these examples show that even though the matrix is the governing element of the landscape it might not be the natural state, even though it determines its dynamics and processes.

Connectivity.

The matrix's influence on other landscape mosaic elements is closely correlated to its permeability. Permeability describes the capability of a species to physically travel over or through an environment. Connectivity, on the other hand, is defined by the overall rate of dynamics, flows, and interactions, of which permeability is a part. A permeable matrix can be seen as a background habitat in which species of other habitats still have use of it and in some sense depend on it. The matrix then itself becomes a part of the connectivity allowing species to move through and flows to be continuous. On the other hand, a matrix with low permeability disrupts flows, making the need for alternative connectivity such as corridors and stepping-stones bigger. The permeability of the matrix can therefore both enhance and prevent the general connectivity of a landscape and might reduce the pressure of patches to carry the entire load of ecological responsibility. Furthermore, the quality of the matrix also influences the edges and the buffer zones created around them, the edge effect. As mentioned in the discussion about patches, the edge zones are affected by the conditions in the surrounding which are made up of the matrix. Because of this, a high-quality matrix can reduce the impact of the edge-effect by making the differences in conditions smaller. This means that the greater the difference between patch habitat and matrix will lead to a higher edge-effect and consequently a bigger buffer zone.

Species of Urban Environments.

One significant element of the governing role of the matrix is how it affects the species composition. The species that can utilise and benefit from the conditions of the matrix are the ones that will occur most frequently in the matrix and will accordingly determine which species that can live in symbiosis in connected habitats and patches. For example, in urban ecology species are categorized into three groups depending on how they relate to the urban environment. Urban avoiders it the species rarely found in or even around urban areas as it lacks the necessary requirements and might experience excessive disturbance. Urban utilisers are the species that sometimes are found in specific areas of the urban environment, areas that match certain requirements that allows the species to utilise it. The last group is urban dwellers and is the species that greatly benefit from the urban environment and that did not exist in the area before urban development. (Yeang 2020, p.92) Similar categorization could be done with any environment and knowing the species composition of the matrix could guide the design of implementing environments of 'matrix avoiders'.

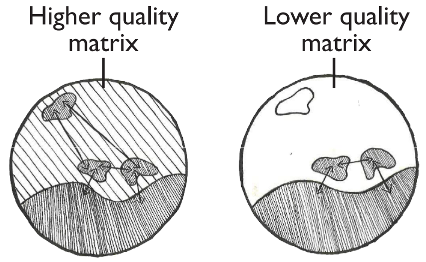


Figure 110.
The quality of matrix is related to the risk of isolation.

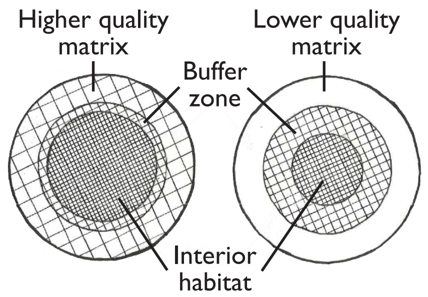


Figure 111.
The width of buffer zone relates to the quality of matrix.

Urban Avoiders
Species that avoide the urban environment due to lack of natural habitat and increased disturbance
Urban Utilisers
Species that can inhabit the urban environment as it mathces certain requirements
Urban Dwellers
Species that prefer the urban environment over the natural or may not have existed in the area before urban development

Tabel 5.
Categories of urban species.

Figures 112-114.
Urban obstacles.
Top: Roads divide green areas (Dreamy 2013)
Mid: Hard surfaces stops the spread of plants (Gärdenfors 2022)
Low: Walls limit the access to water (Gärdenfors 2022)

Grey Control.

We as humans have learned to control and change most environments and even created our own, the built urban environment. Within cities, it is the constructed and built that creates the conditions and govern the ecological systems. They are built and optimised for human activity and efficiency. The urban environment is defined by hard surfaces of roads, buildings, and paths, they make up most of the urban fabric and are evidently the matrix of the urban landscape. In recent years an increasing amount of research has been done on the topics of urban microclimates and the consequences of this. A hardscape matrix increases the effects of events such as urban heat islands, water run-off and floodings, and wind funnels. These alterations of the microclimate are often problematic and will affect the species composition as it increases the contrast to the surrounding environments. The species that inhabit the urban environment have had to adapt to these conditions and thus it has its specific species composition. Architect and designer Ken Yeang explains the reason why some species avoid urban environments is because of the lack of suitable habitats (2020, p.93). If the design of urban environments includes a higher variety of habitats, it will increase the biodiversity of cities, as it would have more urban dwellers and utilisers and less urban avoiders. However, to achieve this there is a need to have knowledge about the species composition of the urban matrix and then design complementary environments accordingly. The contrast to the surrounding environments needs to be smoothened to allow species from the surroundings to utilise and inhabit the urban environment.

Role of Gardens.

Outside of the most densely built urban areas, such as the city centres, the role of the gardens is more influential, and in suburbia, it often plays the role of the matrix. Gardens are significantly more permeable than hardscape environments and allow species to move more freely between patches. Gardens are therefore a strong strategy for combining social and natural qualities and could be used to increase the connectivity of a landscape. Yet, the quality of habitat gardens provides is debatable. Gardens are controlled and managed by people, groomed to fit their aesthetic idea and interest, and could therefore be of big difference in appearance and structure. In general, the aspect of diversity is good, but the biodiversity of gardens is often made up of non-native species that do not contribute to the overall ecological system and stability and might even be a threat to it if the species are invasive. Nonetheless, it is generally assumed that if the garden has native species, even if only a few, it be of benefit to the surrounding environments. However, this might not always be the case.

> *Native plants are adapted to specific 'native' conditions of soil, hydrology, temperature, and trophic status. If removed from these conditions and treated as in any other horticultural introduction, they may be no more adapted to urban conditions than are any other introduced species from another continent.* – Martin F. Quigley (2011, p.88)

Plants in gardens, and of urban environments in general, need to be chosen with knowledge of the existing conditions and to benefit the surrounding. If allowed time nature with achieve this naturally through colonization, otherwise supported choices need to be made.

Furthermore, are gardens often controlled and managed in terms of cutting, fertilizing, planting, and in the worst case treated with pesticides. This will prevent natural species to establish and move over the garden matrix. It is therefore important that architectural and urban design include designated areas for native species, switching the focus away from the exotics and controlled and starting to appreciate the beauty of the natural and local.

Figures 115 & 116.
Some gardens are strictly planned, others are more wild.
(Top: Brown 2017,
Low: Gärdenfors 2018)

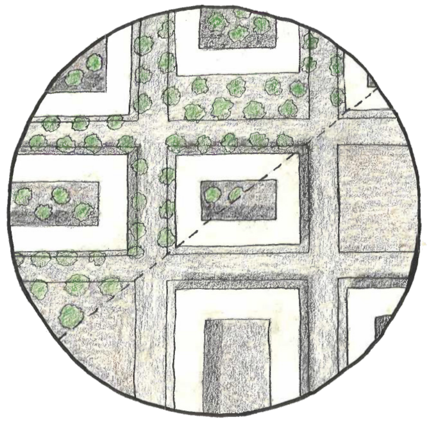


Figure 117.
Concept of reforesting the city.

Reforesting the City.

Creating a permeable matrix is not necessarily about completely changing the structure of the urban environment, it is rather about implementing features that improve its quality and reducing the contrast to connected natural environments. As discussed earlier is that gardens are a higher quality matrix than hard surfaces of streets and buildings. But the reason behind this is the density of planning, as the density of a city centre contradicts a matrix of gardens. Instead, elements and solutions need to be implemented into the matrix that will increase its permeability without compromising density and function. For example, imagine a tree being planted in a grid of five meters, only broken by buildings and infrastructure. This would greatly benefit the ecological system and provide for ecosystem services by mainly using the in-between space that already exists. Similar benefits could be achieved by turning all roofs in a city into green roofs. Going further and creating bridges and connections between roofs as well as habitat diversity will completely transform a hardscape matrix, with low permeability, into a green biodiverse matrix, with high permeability, that will support and improve the state of all connected patches and habitats.

Edges.

Structure, Edge-Effect & Ecotone.

Edges in the Mosaic.

The definition of mosaic is a pattern made up of a range of patches of different shapes and attributes with the consequence of creating a variety of edges and boundaries. It is the same within any landscape, where patches, matrix, corridors, and stepping-stones meet. However, in a landscape mosaic these meetings, borders, and edges are significantly more complex as different elements of the landscape influence one another and create buffer zones and gradients. The description of an edge often includes the area affected by the exterior conditions, otherwise characterized as the buffer zone. The structure of the edge also has implications on the movement of species and ecological flows and includes properties such as width, soft or hard, straight, or curvilinear, and length of gradient.

Edge-Effect.

The conditions in the centre of a patch have a very different environment than the zones around the perimeter of the same patch. This is because climate conditions, such as wind or sun, outside the edge penetrates and affects the habitat along the perimeter. The consequence is that the edge zone, often referred to as the buffer zone, has a different microclimate and structure than the interior habitat. Because of this, the edge zone has a different species composition, consisting of edge habitat species and fewer interior habitat species. This is called the edge-effect and occurs to some degree along all edges of a landscape (Forman & Godron 1986, p.108). If the contrast between environments is big there is more likely to be a wider buffer zone, while a small difference will create a narrow buffer zone. The impact the edge-effect has on a patch is closely correlated to the size and shape of the patch. The general rule is that the buffer zone is of the same width along all parts of the patch if between the same habitats. The exception is for exposed edges facing strong wind, or other climatic conditions, which could result in a wider buffer zone.

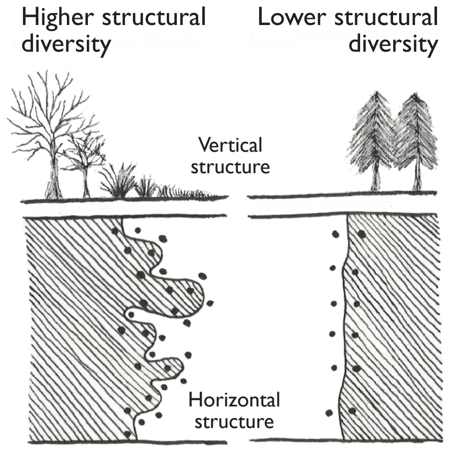


Figure 118.
Structural diversity of Edges.

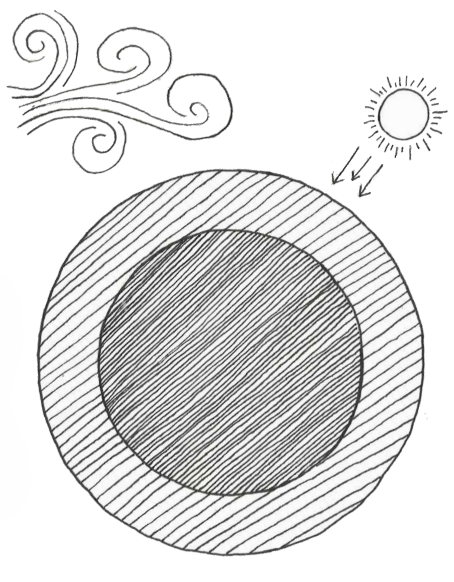


Figure 119.
Edge-effect.

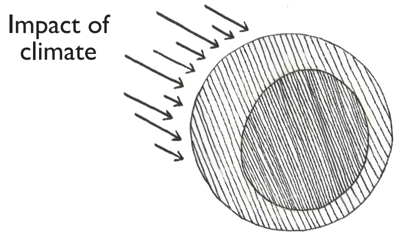


Figure 120.
Width of buffer zone depends on prevaling direction of climate impact.

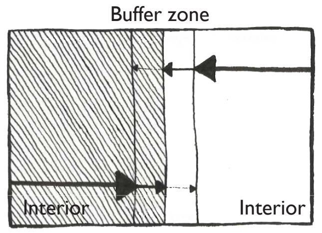


Figure 121.
Edge as a filter.

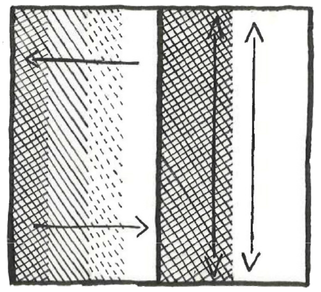


Figure 122.
Edge abruptness.

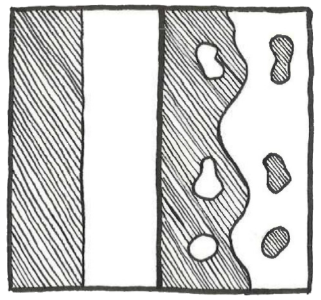


Figure 123.
Edge soft vs hard.

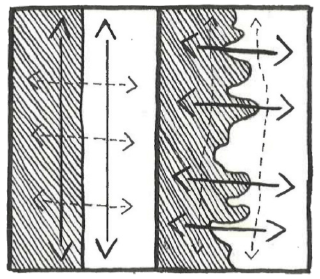


Figure 124.
Edge straight vs curvilinear.

Noteworthy, is that the edge-effect is not necessarily a negative outcome, given that the patch is big enough to have a sizable portion of interior habitat. For bigger patches, it might even be beneficial as it increases the biodiversity of the patch. Similar benefits could be seen along the edges of wooded patches, they might have denser vegetation along their perimeter because of higher light availability (Forman & Godron 1986, p.100). Furthermore, a buffer zone could occur along a stream corridor as some species are more sensitive to flooding than others. These buffer zones are often wide and with a high structural diversity and biodiversity. (Forman & Godron 1986, p.148)

Edge Structure.

The structure of an edge can vary in many ways. The most common is a sharp border from one area to another, this is especially true in human-designed urban environments where most edges are sharp, hard, and simple. However, in nature, it is more common with soft, curvilinear, and complex borders. For instance, a hard and straight border tends to increase the movement along the edge, while a soft and curvilinear border favours movement over the edge, consequently increasing flows between systems. A hard edge defines a border with a direct and visible change in habitat without a gradient between, hence it is almost always a straight edge. A soft border, on the other hand, is defined as having a structure that dissolves the clear edges of either habitat, either by a wide gradient or by a broken or curvilinear shape. The general concept is also that the longer the border the more interactions occur. This principle explains why curvilinear edges have higher rates of flow, and more interaction with the surroundings, than straight edges have (Forman & Godron 1986, p.177). The shape of the border might also give evidence of expansion patterns, whereas areas with convex edges are expanding while areas with concave edges are shrinking. (Forman & Godron 1986, p.175)

Ecotone.

Two further factors that greatly impact the properties of the edge are the width and sharpness of the gradient. These two factors are closely related and often go hand in hand, a wide edge means a longer gradient, a soft edge. The impact of an edge may both be negative and positive, it relates to the size of the patch and the quality of the matrix. A wide edge generally harms smaller patches as the proportion of interior habitat is significantly reduced. However, a soft gradient may have a very positive impact if it is an edge between two different habitats or with a high-quality matrix. The edge then becomes an area with high structural and habitat diversity, and consequently with high biological diversity. This principle of a soft edge, wide and with a long gradient, with high diversity, is called an ecotone and is a concept for integrating and increasing biodiversity. The concept of ecotone is especially interesting in relation to design as an approach for a spatial integration of areas with overlap and mixed-use. Architects and urban planners have for a long time been focused on single-use areas which create sharp edges with little exchange and mix. Sim Van der Ryn and Stuart Cowen describes the issue in designing for the object, it, and neglecting the borders and places where functions meet, edge, 'Architects are still designing for the it, and seldom the edge, even though it is at the edges, or ecotones, where the richest exchanges and interactions take place' (1996, p.132-133). Creating edges that are overlapping in the sense that they consist of elements from two different areas will greatly increase the diversity, both in regards to nature and species, an ecological ecotone, but also in structure, amenities, and social elements, an urban ecotone. Designing an ecotone will increase interactions, establish new connections and structure, and create new healthy areas.

> *By designing ecotones rather than hard edges, we intensify interactions. We bring together a greater diversity of life in an ecological ecotone, and we encourage greater cultural and economic diversity in an urban ecotone. In doing this we facilitate the flows of materials, energy, and information that can catalyze self-designing processes.* - Sim Van der Ryn and Stuart Cowen (1996, p.134)

Figure 125.
Ecotone, element of both environment, in plan.

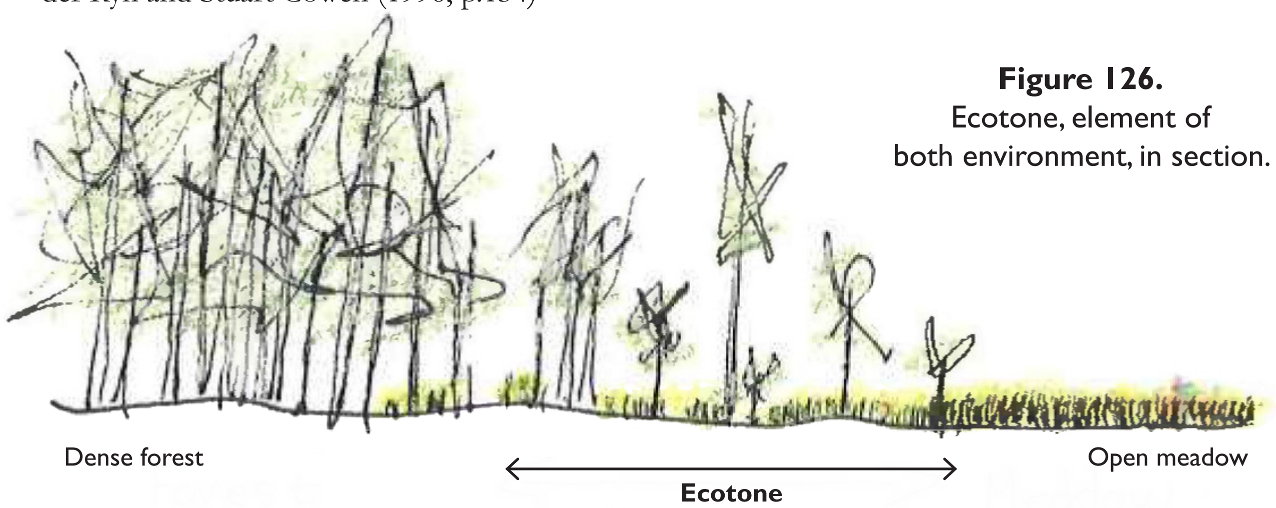


Figure 126.
Ecotone, element of both environment, in section.

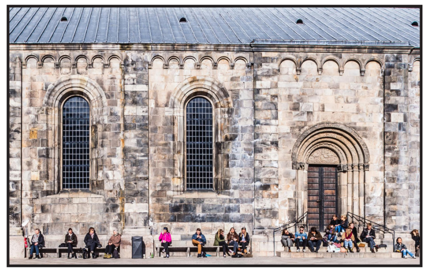


Figure 127.
Benches, stairs, & niches breaks fasades and becomes places to be. Domkyrkan, Lund Sweden. (Spencer, no date)

Figure 128.
Patterns in pavement directs movement & uses. Dublin Docklands. (Gärdenfors, 2022)

Broken Edges.

The structure of edges impacts movement along and the experience of edges. An abrupt, sharp, and straight edge will direct movement along it and are not perceived as a place to stay or that sparks interest. Straight edges do generally not have any niches or spaces to stop or that create a sense of enclosure. It rather emphasises the sense of scale and makes the space feel bigger. (Clemente & Erwing 2013) This could be exemplified in the use of different pavements to direct movement or the big continuous facades to guide visual connection towards a monument or along a boulevard. On the contrary, a curvilinear, broken, or soft edge is a method to break movement and spark interest. It invites the observer to stop or slow down and even promotes movement over the edge. Breaking a continuous facade with setbacks and other structural differences is a strategy used to attract interest and activate streets. Pockets in the edge allow for enclosed spaces to stop out of the way of movement, creating a diversified pattern of movement. Breaking movement patterns is key to increase the interaction of both natural systems and social settings. It creates complexity in not only structure but also in flows and interactions.

Urban Ecotone.

The concept of urban ecotone, introduce earlier, could be developed into a strategy of how to integrate different uses and areas of a city. Having areas with strong characteristics could be of benefit in gathering and connecting people and uses of the same type. This could for example be areas with a high density of restaurants and bars, sports facilities, urban farming etc., functions that benefit from being clustered. Nonetheless, is it important to mix the uses of a city, allowing for integration and interaction that will activate and diversify areas. Following the principle of the natural ecotone, where two contrasting habitats meet and establish a wide edge zone, with the character of a soft gradient, that has high ecological and structural diversity, is it possible to create urban areas that gradually change in from one use to another and at the same time creates a diverse mixed-use are in-between.

Buffer Zone.

Some areas of the urban environment cause disturbance to their surrounding areas. This could be infrastructure that produces noise, waterways that flood, or even unwanted visual connections. Areas surrounding elements that cause disturbances will need to have a buffer zone to filter and absorb the disturbance. In nature, this is the cause of edge zone and in urban environments, this often leads to controlled solutions such as the construction of walls or planting of vegetation. It is important to note that disturbances might be of social character, affecting human comfort, or natural character, affecting ecological systems. Some might be affecting both others only one of them. Knowing what could cause a buffer zone could help guide designs that utilise the different abilities of natural and urban elements. For example, vegetation is not affected by noise in the same way as humans and could therefore act as a good buffer for noise, while vegetation is sensitive to trampling and it might therefore be of use reduce land-use to prevent damage.

A Living Wall.

Urban environments are built to accommodate humans and to some degree their pets and cattle. Some species, urban dwellers, have managed to prosper in the urban areas and areas now mainly dependent on it. In recent years the question of providing habitats within the constructed environment has been discussed. The example of a birdhouse has existed for long and insect hotels are becoming more and more common. In the city of Brighton in the United Kingdom it is now a requirement to implement bee bricks and birdhouses in new buildings (Frearson 2022). The bee brick is evidence of how buildings can become a part of the living. Designing elements and buildings that become a part of nature is an essential part of bio-integration. Imagine a building with a lush green roof connecting to a porous wall that provides support and nets for flora and fauna. The edges of protected homes can in this way become complex structures providing for high biodiversity, literally coexisting, and sharing homes with nature.

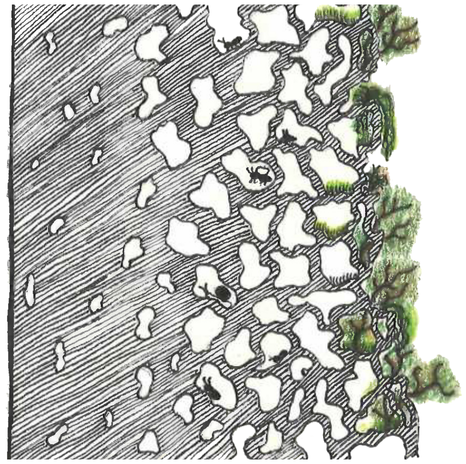
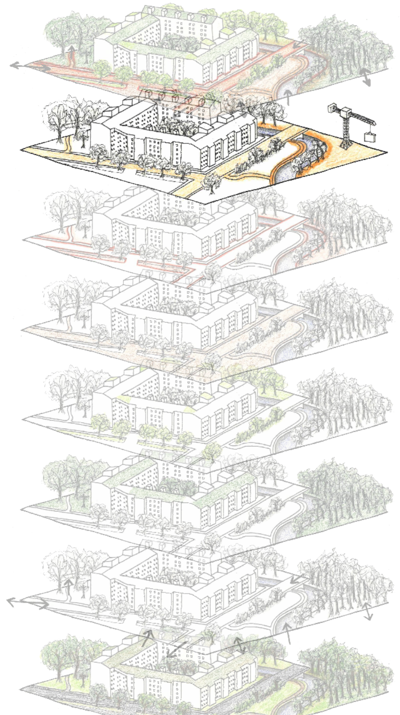


Figure 129.
Abraction of the Living Wall.
Porosity creates habitat for
both flora & fauna.

Disturbances.

Management & Control.



Perception of Disturbance.

In the human-designed environment, the approach is to try and avoid disturbances like flooding, fires, and droughts, and increasingly have become more successful at doing so. There are barriers to prevent flooding, fires are prevented and quickly put out if ignited, and water our gardens. At the same time, humans disturb some environments on a too frequent basis, for example, the damming of rivers, the moving of lawns, and the planting of monocultures. Humans have become the rulers of disturbance and are managing it to our advantage, either if it is by preventing or enhancing disturbance. Combined with climate change and global warming there is now a situation where disturbances occurring are either of major impact and destruction, such as extensive fires or droughts, frequent floodings due to extreme weather, and changes in seasons and more extreme temperatures, or the disturbances as small and easily managed, watering during smaller droughts, damming of waterways, and pesticides to prevent pest on agriculture. The maintenance of urban life and built environments is in many cases relying on mitigation techniques, for example, extended drainage systems or flood protective walls, rather than adapting and designing systems that could naturally deal with disturbances, such as permeable surfaces and water reservoirs within cities or natural buffer zones for flooding.

Figures 130-132.
Lawn mowing, prevantion of forest fires & damms are examples of regulated disturbances.
(Top: Prasannanossam3 2016)
(Mid: Sullivan, no date)
(Low: Baumeler 2019)

Succession.

The establishment of a natural system follows the stages of succession, where an uninhabited area gets colonized, after time species get replaced, and subsequently, the system reaches an equilibrium of species and ecological processes. Succession starting from nothing, except an abiotic foundation, is called primary succession and mainly has its relevance for newly created islands but might have relevance for some newly constructed urban environments. These processes start with the colonization of primary species, such as lichens and mosses that are not dependent on soil to colonize. After time this will lead to the creation of organic soil and more species can colonize, which further changes the conditions and changes the species composition. This process continues until the rate of recolonization and extinction are at a level and the structure and conditions of the ecosystem are stable, it has reached its equilibrium. If a system in equilibrium is exposed to disturbance the ecosystem will jump back in succession because of destruction and extinction of some species. However, some fundamental species and some elements such as soil are preserved which leads to a secondary succession rather than a primary, and hence will have a shorter regeneration process to, again, reach equilibrium. Different stages during a succession process will have a different species composition and landscape mosaic. If a landscape mosaic has areas and environments at different stages of succession it will generally have a higher biodiversity than a landscape with areas and environments at the same stage of succession. This is due to the difference in species composition and structural diversity of environments at different stages of succession.

Similarly, it is possible to find environments and areas with parts of succession within their natural structure. An example of this is stream-corridors exposed to flooding, and the occurrence of flooding is repeated and frequent. Most times the flooding will only reach a standard level and the species that inhabit this area are adapted and dependent on the event of flooding. Sometimes, however, the flooding might be bigger and reach further in the riverbank and consequently affecting species not as well adapted to flooding, however, they are still probably tolerant to the occasional flooding. Even further away from the water, where the water very seldom reaches, live species that might be sensitive to flooding. These different areas could then resemble different stages of succession as the habitats and species are adapted to different levels of disturbance, and consequently, the biodiversity will be higher. (Forman & Godron 1986, p.148)

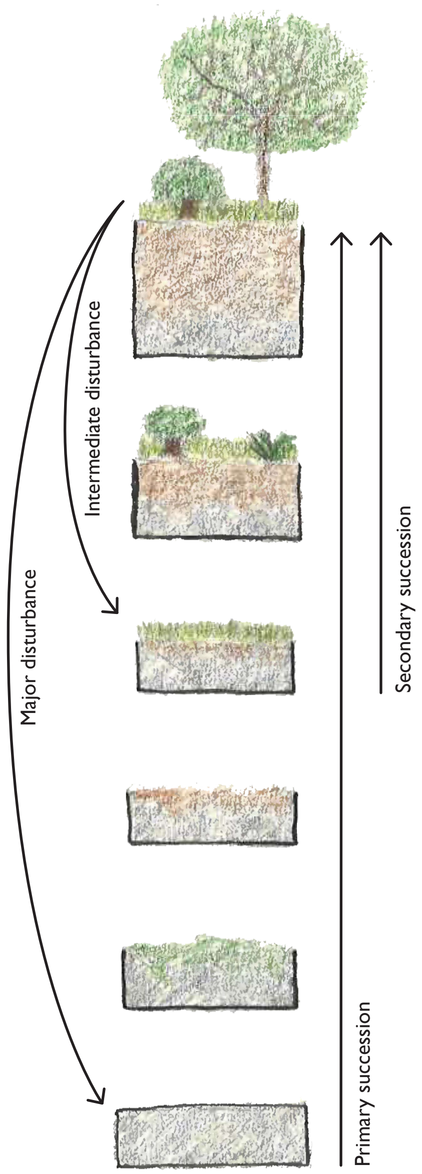


Figure 133
Primary & secondary succession.

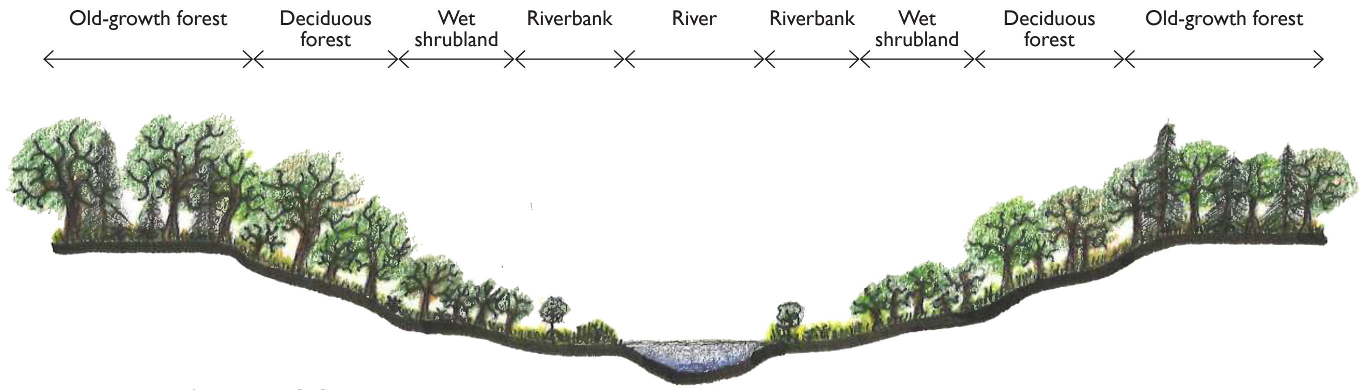


Figure 134.
Stream-corridor section illustrating different habitats along the riverbank.

Intermediate Disturbance Hypothesis.

Natural environments have for most of their history adapted to a situation without regulation and are in many ways dependent on some disturbance but at an intermediate level. The result of this is highly diverse ecosystems. This theory is called the intermediate disturbance hypothesis and suggests that the highest level of biodiversity is reached with intermediate disturbance. It means that ecological systems need some level of disturbance to govern their species composition, to prevent one, or a few, species to become dominant. At the same time, the disturbance cannot be too frequent as the species need to be given the opportunity to colonize. It is also defined by the principles that the disturbance cannot be too big, destroying the ecosystem, too small, not enough of an impact to change the conditions, or too frequent, the system has not been able to recover. It also derives from the concept of difference in species in terms of colonization and competition, some are quick to colonize but get outcompeted by more specialised species.

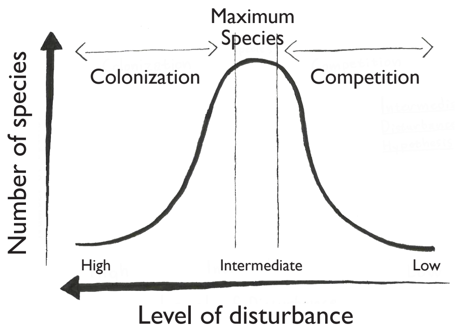


Figure 135.
Intermediate disturbance hypothesis

Disturbance on Patches.

By the intermediate disturbance hypothesis, patches should be exposed to disturbance. The isolation of a patch is related to the rate of colonization and competition, if a patch is very isolated the rate of colonization is lower, and the competition will also be lower. The risk this presents is that if an isolated patch were to be exposed to a disturbance, the rate of succession will be slow because of slow recolonization, and thus run the risk of not fully recovering until another disturbance occurs. It also runs the risk of not being exposed to disturbance and consequently, a few dominant species would become dominant. On the other side, patches within proximity may easily spread disturbances between each other but will have a quicker succession, if not all patches were degraded. The configuration is therefore closely related to the impact of disturbances and a mixture of patch types, in structure and habitat, might be an effective barrier and mitigator for patches within a close distance (Forman & Godron 1986, p.119).

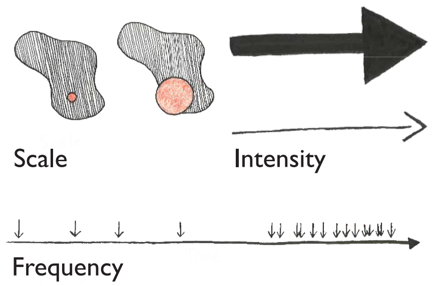


Figure 136.
Three aspects of disturbance: Scale, Intensity & Frequency.

Ecosystem Services.

In the concept of disturbance, there is a need of allowing them to happen without causing too much damage to its structure. Nature is adapted to deal with change and disturbance and could therefore be a helpful tool in the future regulation of environmental disturbances. This is one of the main concepts with ecosystem services, that implementing natural elements in the built environment will help to deal with and mitigate disturbances while at the same time providing for biodiversity. However, it is then vital to know how these processes work and how the design of environments could allow these processes to occur. There is a focus on technocentric solutions rather than ecocentric solutions, with the consequence of mitigating the problem to other parts of nature rather than dealing with the cause at the site. Currently, humans do not have the technical ability to efficiently replace many of those processes naturally occurring in ecosystems. It might be possible to degree find solutions for certain problems but generally at the compromise of other ecosystem services. There is the possibility of using technical solutions together with ecological solutions. However, this approach would still need to be ecocentric, but readapting and reusing existing solutions still be useful. Ecocentric solutions will increase the benefits of ecosystem services and help deal with disturbances at the same time as providing an environment for nature.

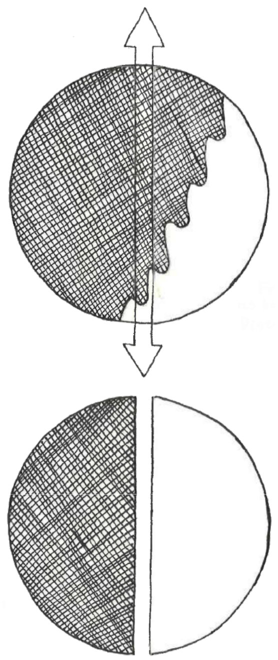
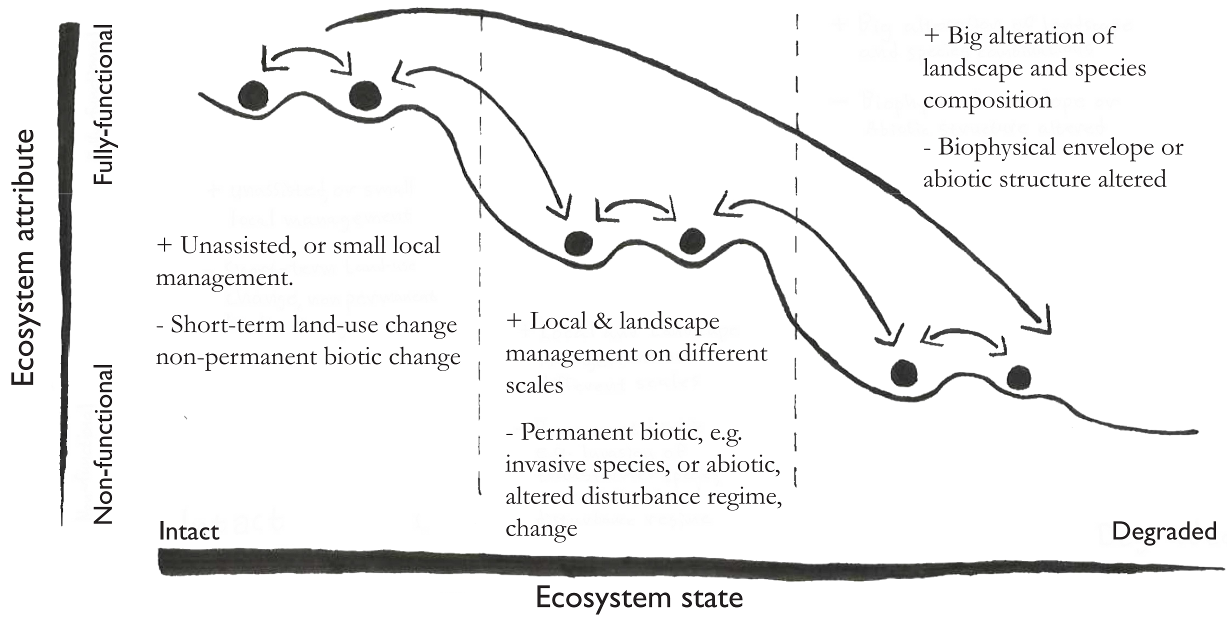


Figure 137.
Fragmentation prevent the spreading of disturbance.

Ecological Resilience.

Different disturbances in an ecosystem may destabilise and degrade its function and overall state. Any landscape at any scale has thresholds of how much impact it can deal with and from what it can recover. A simple example of continuous degradation is the event of desertification of previously fertile land. Cultivation of the fertile environment has led to soil depletion, and a threshold is reached. If the degraded patch is surrounded by healthy land and if land-use is stopped, it still might be able to recover. Yet, if the size of the area is too big or the cultivation continues the dynamics change and the temporary disturbance might become permanent (Forman & Godron 1986, p.166). The environment has now become arid and unfertile and would need a major effort to restore to its original state. However, disturbances and changes might also help an ecosystem to recover, if unusual, and work to improve conditions to reach a threshold. It is therefore important to know the conditions of an ecosystem to be able to prevent and act on changes and degradation. This will improve the overall resilience of the system a resilient system is more stable and provides ecosystem services at a more predictable rate.

Figure 138.
Ecosystem resilience.



Built Succession.

Nature has an extraordinary ability to persist and recover after disturbance. The principle of succession is a way to describe both how an ecosystem originated but also how it recovers from disturbance and degradation. A similar pattern is observable in the development of urban environments. A primary natural succession starts from nothing, a blank dead surface, while a secondary succession starts a few steps in of the primary succession, depending on the level of disturbance. A built succession is more resemblant to that of secondary succession as it starts with a natural environment, the site of the construction. However, the second step of natural succession is demolition, removing vegetation and soil to create the foundation for a building. This step could also be seen as the disturbance that causes the system to enter secondary succession. Yet, it is a planned and controlled process and I would therefore argue that it is a part of the built succession, mainly because decisions could be made to preserve certain elements of the site. Following demolition is the construction of buildings and infrastructure and can also include the planation of vegetation. When construction is completed natural processes of adaptation begin, these are both of social context, human patterns of use and movement activate certain areas and ecological nature, species form the surroundings colonize and interact with the new environment. In an ecocentric design, this last step is of significant interest because this is when the built and natural environments merge and become on. Designed with ecological principles the area will provide opportunities and habitats for species to colonize and inhabit and hence will continue to change the appearance of the area as a further step of succession. This process is then restarted every time an area is renewed or developed, entering a loop of built succession.

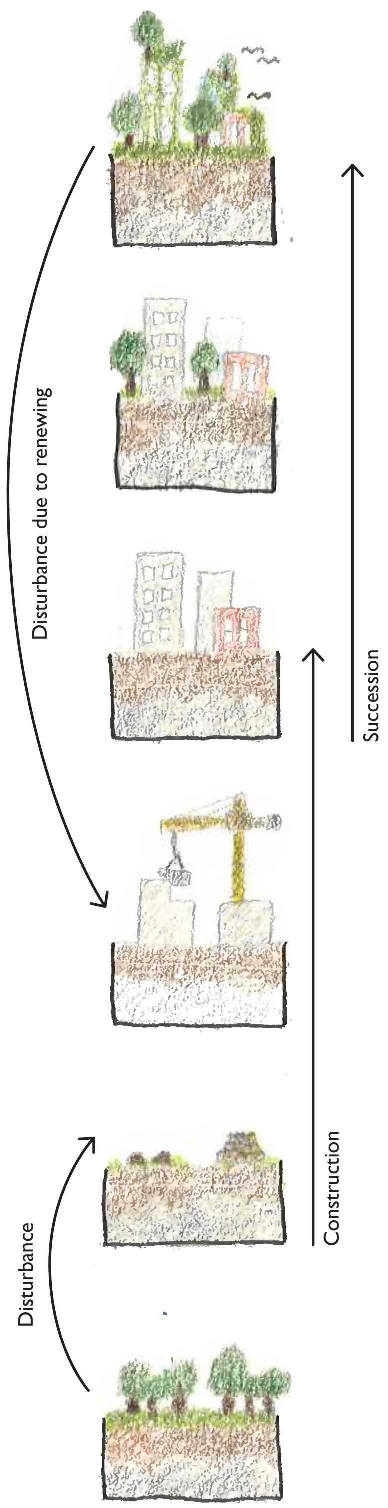


Figure 139.
Construction & renewing could be considered as a uilt succession.

Natural Filter.

Many technical solutions for controlling or mitigating natural disturbances in urban environments have the consequence of preventing ecosystems to benefit from them. As to the intermediate disturbance hypothesis, many ecosystems benefit from the occasional disturbance, and completely removing them from environments could have destructive consequences. It is therefore of interest, both to us humans and nature, to develop and use ecocentric solutions to mitigate and control disturbances. Already existing examples of this are stormwater management through sustainable urban drainage systems that include strategies of how to control the run-off water in ways that could also benefit the ecosystems. One strategy is by constructing wetlands which could be the designing of retention ponds, that allow to be flooded, or bioswales, vegetated run-off canals (Yeang 2020, p.115-116). Other notable strategies are green roofs that mitigate the rate of water run-off, or permeable surfaces that allow run-off water to penetrate the ground and refill the groundwater. The construction of wetlands could also be used to filter and clean water as a natural sewage treatment system. Allowing water to slowly pass through areas with selected plants and structures with clean water without chemicals and at the same time contribute to biodiversity and support other ecosystem services (Yeang 2017, p.184-185).

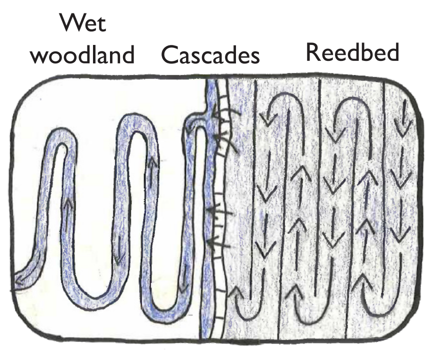


Figure 140.
Plan illustration of initial part of a constructed wetland where the main filtration occur.

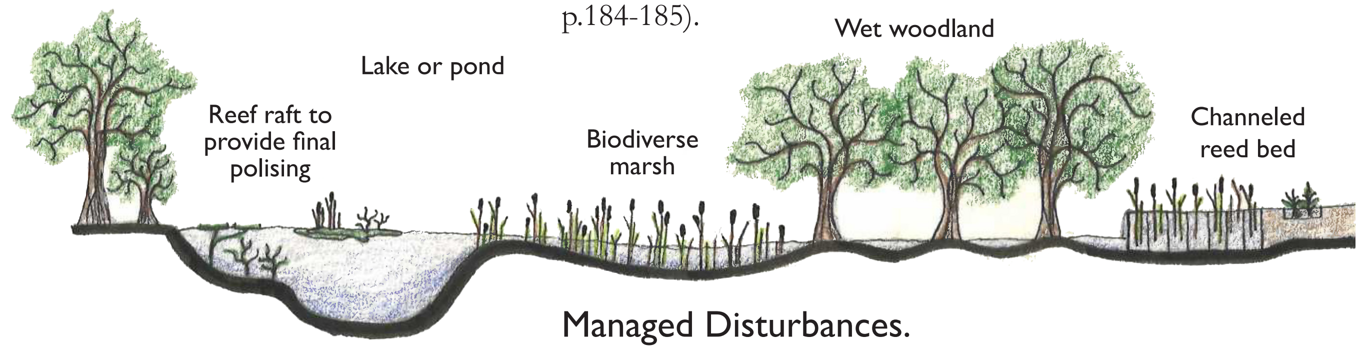


Figure 141.
Section of constructed wetland.

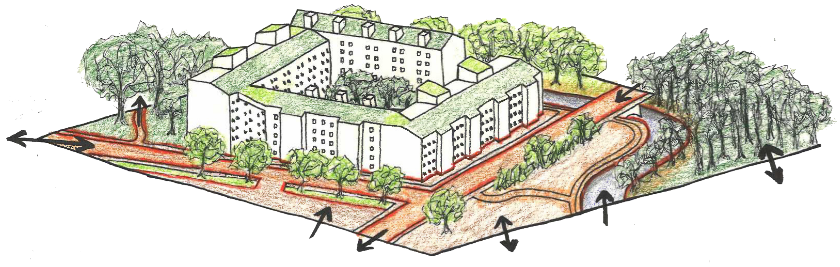
Figure 142.
Traditional hay meadows are scythed yearly which prevents a few species from becoming dominant. (Gärdenfors 2021)

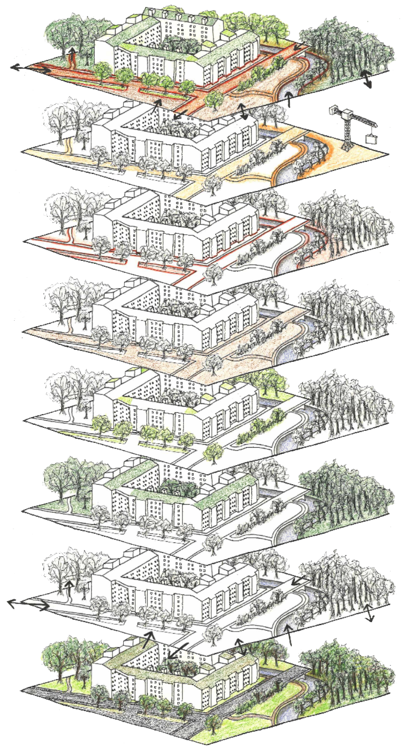
Managed Disturbances.

As a result of human influence some habitats owe their existence to chronic human disturbance and have through long-term development achieved a high biodiversity. In Sweden, one of the most biodiverse habitats is the hay meadow which is scythed once a year. Because of the industrialization of agriculture, these habitats are now disappearing, showcasing the need for human management to be preserved. Another effect on biodiversity as a cause of management is the removal of dead vegetation and rubble from urban environments. The existence of these is fundamental to many insects and other organisms and allowing these to remain in certain areas will help increase the biodiversity of the urban environment. Learning how to manage urban environments to promote biodiversity is a key strategy to integrate nature within cities. This could easily be done by letting rarely used lawns grow into a diverse hay meadow instead of continuously moving it, keeping some dead logs and twigs remain at the corner of a park, and keeping a pile of rubble in the development of a brownfield.

Summary.

Synthesising the Landscape.





A Synthesis.

Again, returning to the layer of the landscape mosaic and identifying the different layers it is made up of and how they affect and interact with each other. With an understanding of each layer is it easier to understand and determine the importance of the different elements in the landscape. This can then be used to determine consequences but also location for future development and land-use.

In the landscape mosaic, it is of primary interest to identify the environment and habitats that have the most impact in terms of biodiversity and that provide high levels of ecosystem services. Generally, the more uncommon habitat, those of different patches, provide for most of the biodiversity, but equally is the occurrence of unusual features important to take into consideration. Yet, the size of the patches, and other landscape elements, is determined by the scale of the landscape and thus might change the landscape mosaic even within the same environment. The spatial pattern of the patches will then need to be characterized on both the main scale, in the frame of the defined landscape, and the scale of the connected ecosystems because these will inevitably be impacted by the dynamics on other scales. The spatial pattern of the patches should be considered with a focus on protecting and improving their quality, their contribution to biodiversity, and ecosystem services. Patches are often interdependent and need to be linked to not degrade and lose their quality.

Therefore, is it important that a landscape has a high overall connectivity that allows species to move between different elements and equally lets the ecological processes be continuous. As discussed, the layer of connectivity includes many different principles and there are many ways a landscape mosaic could have a high connectivity. The strongest spatial element is the principle of corridors, which directly connects patches and allows a continuous flow of species, and its connectivity depends on their

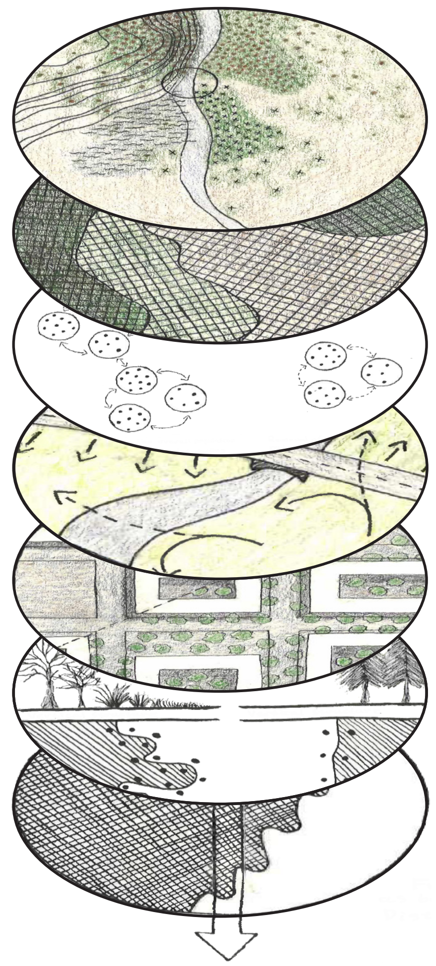


Figure 143.
Principles form different layes work together to provide a more comprehensive approach.

structure in terms of width, length, and gaps. In many situations, a corridor is not possible due to the existence of barriers and therefore the principle of stepping-stones is relevant. Relevant is also the aspect of alternative routes and loops as these both increase the connectivity but reduce the risks of disturbances.

Further, connectivity is strongly impacted by the matrix, its quality, and its structure. Within the defined scale of a landscape mosaic is it possible to identify one environment that is the most dominant, that governs the climatic conditions, main species, and ecological dynamics as disturbances and flows. This environment is the matrix, and its ecological quality is closely related to the permeability of species, impacts of disturbances, and structure and size of buffer zone within patches, corridors, and stepping-stones.

In the intersection where two environments meet, there will be a transition from one environment to the other. Depending on the contrast of conditions of these areas the edge zone will be of different widths, because of the edge-effect. However, it is not only the differences in the environment that determine the attributes of the edge, but also the structure of the edge itself will contribute. A sharp and abrupt edge will have increased movement along the edge. A wide and soft edge will have a higher flow over the edge and could also have an increased diversity by the concept of ecotone. The occurrence and principle of ecotones are of special interest as it is evidence that areas of high ecological quality do not have to be protected as undisturbed areas. It can be highly mixed areas like soft edges or convergency points. This is a concept that could be used as both social and ecological urban design concepts.

Additionally, is it also noteworthy that ecosystems could benefit from intermediate disturbances and hence need to be designed with the consideration of disturbance. Urban environments are the cause of a high number of disturbances, many that do not occur in nature, but are at the same time dealing with natural disturbances in a way that they have lost their positive ecological impact. Considering nature as a part of the urban, or rather the urban environment as a part of nature, will allow the designing of environments where humans coexist with nature.

An Example.

Furthermore, to contextualize how ecology could shape a design development, here follows a simplified example. Given the chronology of urban development and management process, is it possible to define some of the ecological considerations that need to be made. Firstly, it is necessary to view the current state of the site. One aspect is regarding scale, what is the frame and border of the site, how the conditions of the surroundings affect the site, and how it influences the context. Similarly, the is a need of reviewing the history, disturbance, and resilience of the site. This will signify vital dynamics but also indicate the current state of the environment. Then the on-site biodiversity needs to be considered. This includes the variety of habitats and environments, the matrix and patches, and what areas are of special importance, and thus need to be preserved.

As of this, the design and development need to be adapted to fit the ecological structure of the site. Valuable areas will have to be protected during construction, and development should take place during times of the year that have the least effect on vulnerable species. Equally, is it important to make sure of a continuous level of connectivity throughout the development not to isolate vulnerable areas. This could also be done by keeping areas open and connected to the surroundings if they provide healthy habitat.

Development on a bigger scale might allow for the moving, or decreasing the size, of patches of key habitats, if done cautiously and with consideration to consequences. This process could resemble that of remnant patches, that occur by disturbance in the surrounding area. In this case is it especially important to consider time as more species will become extinct as time passes.

If the development itself does not regard the preservation of habitat on site, it will be dependent on the recolonization of species from the surrounding areas. In this case is it critical to design edges that will allow this, that are permeable and promotes flow over. Well-designed edges will also promote resilience and future development of ecosystems within any site, especially if the site is designed to host a variety of habitats and environments. (Bates, Bodnar, Donovan, & Sadler 2011, p.291)

This example only briefly shows some of the considerations of a development process. Every project has different preconditions and contexts, and it is difficult to generalise without making compromises on other ecological functions. The layers of this methodology will therefore take a different shape and role depending on the project, and the different principles will be useful in different situations. It is hence necessary to evaluate the different principles within each project and context, as different combinations and uses might prove useful in a new situation.

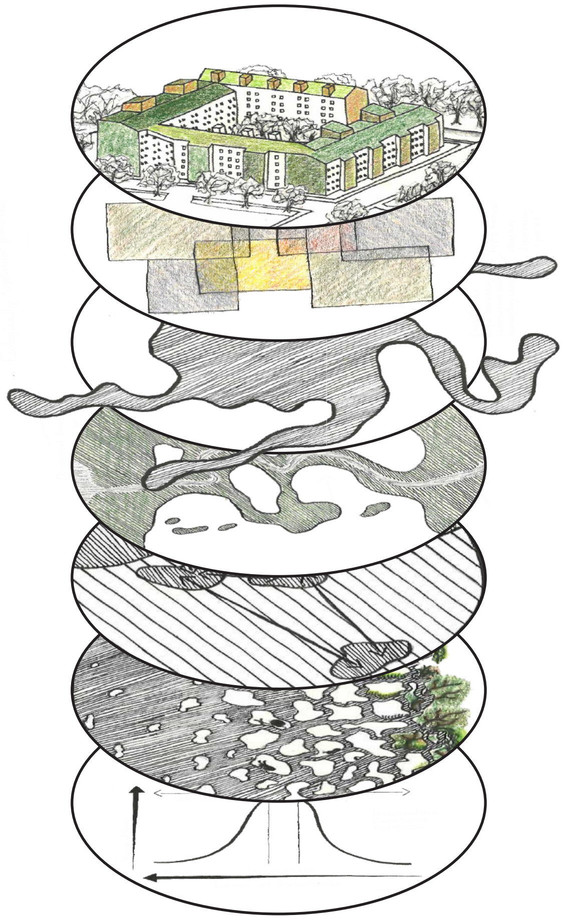


Figure 144.
Each layer presents it own solutions which in turn affect the outcome of other layers.

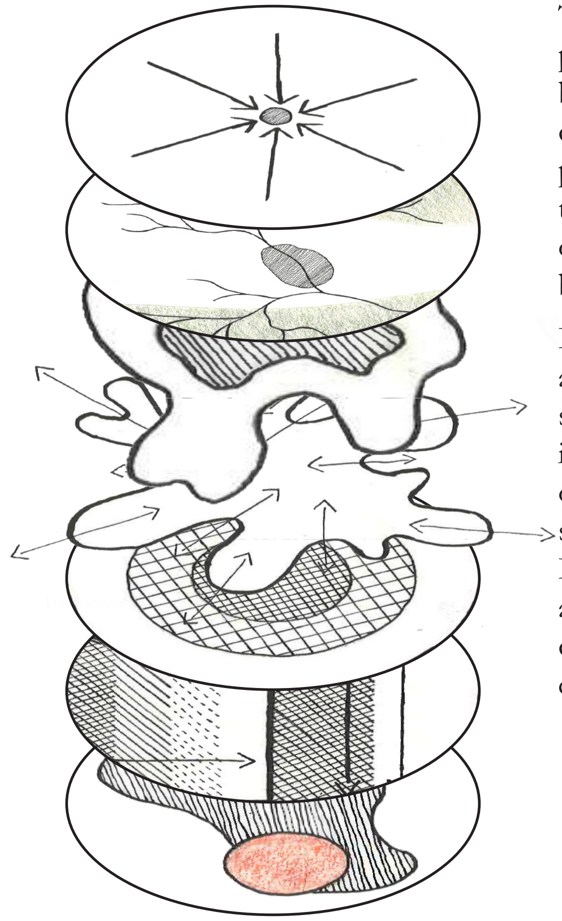


Figure 145.
The principles are tools to guide the design & analyse how the design relates to different ecological values.

The Use.

This ecological design methodology is not a style it is a strategy presenting principles of how the designed built environment could become a part of the natural world. Every environment and area can be described as a landscape and equally is ecosystems always present. Defining the elements of the landscape, understanding the role they have, and acknowledging the needs and dynamics of nature will significantly help improve the quality and state of both the natural and urban environment.

Each layer and principle can be implemented within the frame of aesthetics and social needs. They are tools of ecology showing simple principles that can easily be interpreted and transformed into design. The is not 'one' correct way of using them and many overlap and could be combined, some are even contradicting showing the advantages and disadvantages of the same solution. Ecocentricity is not about finding the optimal, best functioning, and most beneficial solution. It is about being cautious about the choices made, knowing the ecological risk, and supporting the decisions made. Designing for ecology is designing for us.

Part Three.

Discussion & Conclusions.

Discussion & Conclusions.

Critical Reflection.

This thesis aims to summarise and collect different ecological strategies and concepts into one comprehensive but graspable design methodology. It should be easy to use for designers and a helpful tool in the implementation of ecology into the design. My contribution has mainly been in combining, condensing, and interpreting different theories to work together and create an approach to design and a fundament for further discussion. I do not claim to have made up the principles presented. They have been gathered from existing work within the field of ecology and ecological design and have been adapted by me to be uniform and support each other within the context presented.

The thesis presents a few different supporting theories and authors that all present their approach and strategy of how to deal with ecology and design. They have been used to varying degrees depending on relevance and the depth of the work. Due to the complexity of the topic, few theories cover everything in-depth and hence none of the supporting theories used are comprehensive enough to individually support my work. Thus, different approaches have been used to support different aspects of the work.

The work of architect and ecologist Ken Yeang is comprehensive and deals with a broad spectrum of relevant issues of how to implement ecology into the design disciplines. His theories are based on the concepts of ecocentricity, being guided by ecology, and ecomimesis, emulation and replication of ecological systems. 'Saving the Planet by Design' (2020) describes these terms in-depth and elaborates on the role of ecology within design. The ecological design approach presented by Yeang is radical and proposes major changes to the current design norms. Nonetheless, his theories are well-developed and present many interesting concepts of how ecology can play a vital role in future urban developments. Yet, there is an unclarity of how to translate the theoretical work of 'Saving the Planet by Design' into concrete design proposals. Because of the extensiveness of his work, dealing with multiple issues and approaches, it consequently loses its direct applicability. A clear understanding of the concrete application is lost as many of the arguments presented are abstract and difficult to grasp due to being too broad and generalized. This critique is also evident in his realized projects where his radical ideas, from his theoretical work, get lost and are only vaguely represented.

Stuart Cowan and Sim Van der Ryn present an approach that creates a symbiosis between culture, society, and nature but lacks direct scientific backing. Supporting their theories with empirical evidence would make their arguments stronger and more perceivable. They make some great observations in applying ecological concepts within a social and cultural context, but they lack to show the ecological benefits of doing so. Pairing their theories with principles of ecology, of facts rather than theories, creates interesting dynamics and concepts of integration between nature and culture.

In their short publication 'Landscape ecology principles in landscape architecture and land-use planning' Wenche E. Dramstad, James D. Olson and Richard T.T. Forman attempt to summarize and describe different ecological features and principles simply and directly. They are using landscape ecology as a descriptive tool for analysing and designing landscapes. With simple illustrations, they show how key ecological principles become spatial concepts. Many of these principles have been used and developed in the description and discussion of the ecological layers, presented in the methodology, as they efficiently link ecological and spatial concepts. They describe their work as a handbook for planning, but they make it clear that it 'is not a cookbook giving exact ingredients and steps' (Dramstad et al. p.7), showcasing the opportunity for interpretation and freedom in the use of the principles. This publication is a great example of how landscape ecology and design could be simplified into concrete and clear tools for guiding planning and design, though adapted for the field of landscape architecture it is not fully applicable to built environments and within denser urban contexts. Nonetheless, it still has a relevance and is hence a very useful reference in the interpretation of ecological principles in design.

Design Fundaments.

Ecosystem and ecological processes exist in every environment, even in the most artificially influenced and changed urban areas. Nature has an incredible ability to persist even when forced away. However, if degraded it stops providing necessary services, that humans are dependent on, which will have consequences on the quality of life. We as designers of the urban environment, therefore, need to consider ecology when designing as it is the fundament for life and hence needs to be the fundament for designing. If a design manages to incorporate nature within the urban environment both human society and nature will benefit. These ecological layers are a starting point for how to apply ecology to design with the aim of showing simple principles that affect the spatial pattern of an environment and how they can be used to guide design.

Analysis & Design.

The methodology can be used both to analyse and for designing a landscape. Analysing a landscape mosaic is about describing the existing elements within the frame of each layer. This is then used to attain knowledge of the state and dynamics of the environments in the landscape mosaic. Accordingly, analysis is the starting point for designing. Using results of analysis will make it possible to avoid areas of importance, such as unusual features, or rare habitats, and determine areas for improvement, such as preventing degradation, establishing connections, shaping edges, or increasing the size of patches. The process requires alternating analysis and design, investigating how changes in one layer affect the overall landscape mosaic.

Similarly, the methodology could be used throughout the design process. For example, in cases where the existing environment is not of suitable quality or adapt to the proposed development. In this case, the process starts from a blank sheet, in terms of existing ecological attributes. From this point, there are two different approaches to using the layer cake method. The most ecologically beneficial is to use the layers as tools for designing and developing the goals of the project to fit and work with the principles of the layers. This would put ecology at the centre of the design and make sure it is well functioning and in an ecologically optimal state, given the basis of the project.

The second approach is to use the layers as analysis tools investigating how a proposed design answers to the different principles and then adapting according to this. Subsequently, ecology will not be the focus of the design, but rather a subfactor among others, and thus will have compromises on optimal ecological solutions. Nonetheless, it is still a useful method to define how the design is answering to the natural environment, and how it is possible to reduce the impact and improve the conditions of this.

Back to Basics.

Nature is incredibly complex but at the same time, simple to integrate and make use of. If nature is provided with the necessary conditions, it will by itself regenerate and offer benefits. Solutions of biointeragtion are often elemental, it is about going back to basics and providing the space and conditions needed. A patch of the forest becomes most biodiverse when going through natural succession and likewise do every other environment. If when design buildings, green spaces, and urban landscapes with suitable ecological structures and dynamics, nature itself will become biodiverse and resilient. Humans have the technology and knowledge to integrate nature into the built environment. In combination with a well-developed ecological landscape mosaic, there is the possibility to create urban environments that resemble those of a natural state. It is again about considering nature and designing for it, allowing it to be a tool that gives the design a direction and becomes a solution to urban environmental issues such as flooding, urban heat islands, and air pollution.

Limitations.

The ecocentric design strategy will have the issue of lacking solutions for other central concerns, such as social issues, infrastructure, etc. But as mentioned earlier an ecocentric approach needs to be holistic, working with other methods and strategies. Even if the approach is not ecocentric there are still opportunities to incorporate ecological principles without compromising on other qualities. Some development might have a different focus or other limitations such as economy, that might not be fitting with an ecocentric approach. Yet, many of the principles within the different layers provident will not require specific elaborate solutions, they rather describe alternatives and considerations when making decisions regarding the structure of the spatial pattern. The presented ecological design methodology is not a standalone strategy that will solve any design, it is a tool how to integrate ecology into any case of design. Nevertheless, it should preferably be the main strategy but is equally relevant and useful even if only used in a part of the design process.

Re-Greening.

A big part of the future of design, especially in architectural and urban design, is to find new uses and readapt existing areas and buildings. As mentioned early in this thesis, by the year 2060 humans are expected to have doubled the built area. This will mean construction and designing a lot of new buildings but at the same time as many will need to be renovated, retrofitted, and reused. Designing is not only about the new but also about adapting the old to fit the current needs and values. This process will have as much impact, as the number of existing buildings will continuously increase and need renovation. Even more so if the trend of circularity and reuse is continuing. Designers and developers, therefore, need to develop ecocentric strategies for the development of new buildings as for retrofitting existing buildings.

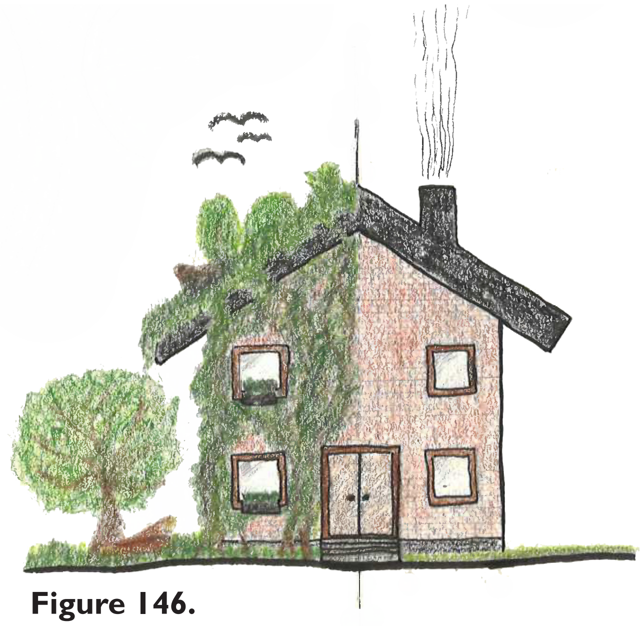


Figure 146.
Ecocentric approach. Current approach.

Aesthetics of Biodiversity.

As briefly discussed in previous the introduction humans '*prefer the orderly and symmetrical over the organic and asymmetrical*' in terms of the aesthetic of natural environments. This, subsequently, creates an issue that the design of green environments aims to be aesthetically pleasing rather than achieving ecological qualities (Quigley 2011, p.89).

> *Neither Dutch elm disease, the Chestnut blight, the Emerald ash borer, or other pests and pathogens that have eliminated vast number of urban trees has been sufficient to change the stubborn belief in the aesthetic requirement for single species plantings.* (Quigley 2011, p.90)

It is not a critique of the current design approach; it is rather a critique of the perception of beauty and aesthetics of biodiverse environments. The concept of natural beauty is counteracted by not preferring or even promoting areas of high biodiversity. By simply acknowledging the need and beauty of biodiversity designers might at the same time change their attitude to promote areas of ecological qualities. It is in the unseen processes and services that the true beauty of nature is found. There is a need to find a way to show appreciation of this, in the awareness of design and aesthetics.

Ecology in Design.

In the discussion on ecocentric design, one of the main points is that ecology needs to have a more influential role in the design processes. It is such an essential part of the world, that it needs to be given the consideration it deserves. Without healthy and stable ecological systems, the world will start to degrade, something that has arguably already started to happen. As designers, we have a vital task to integrate nature into our designed environments, regardless of the urban density. The cities we design should not only be for us, humans, we need to consider how the design of urban environments can become a place where nature will prosper and have its place. It is primarily about utilizing the spaces created and start questioning how design can make them be of ecological benefit. Imagine if all unused roofs in a city were turned into lush and diverse roofs, or if all green spaces were equally designed for the species that inhabit them as they are for us. This would have enormous ecological benefits without compromising the quality of life. Most likely it would improve the quality of life as it would increase the ecosystem services provided. Ecocentric design is putting ecology and nature in the centre of design and humans are equally a part of nature. Designing for nature is designing for us.

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Figures.

Illustrations.

All illustrations have been made by the author, Hannes Gärdenfors.

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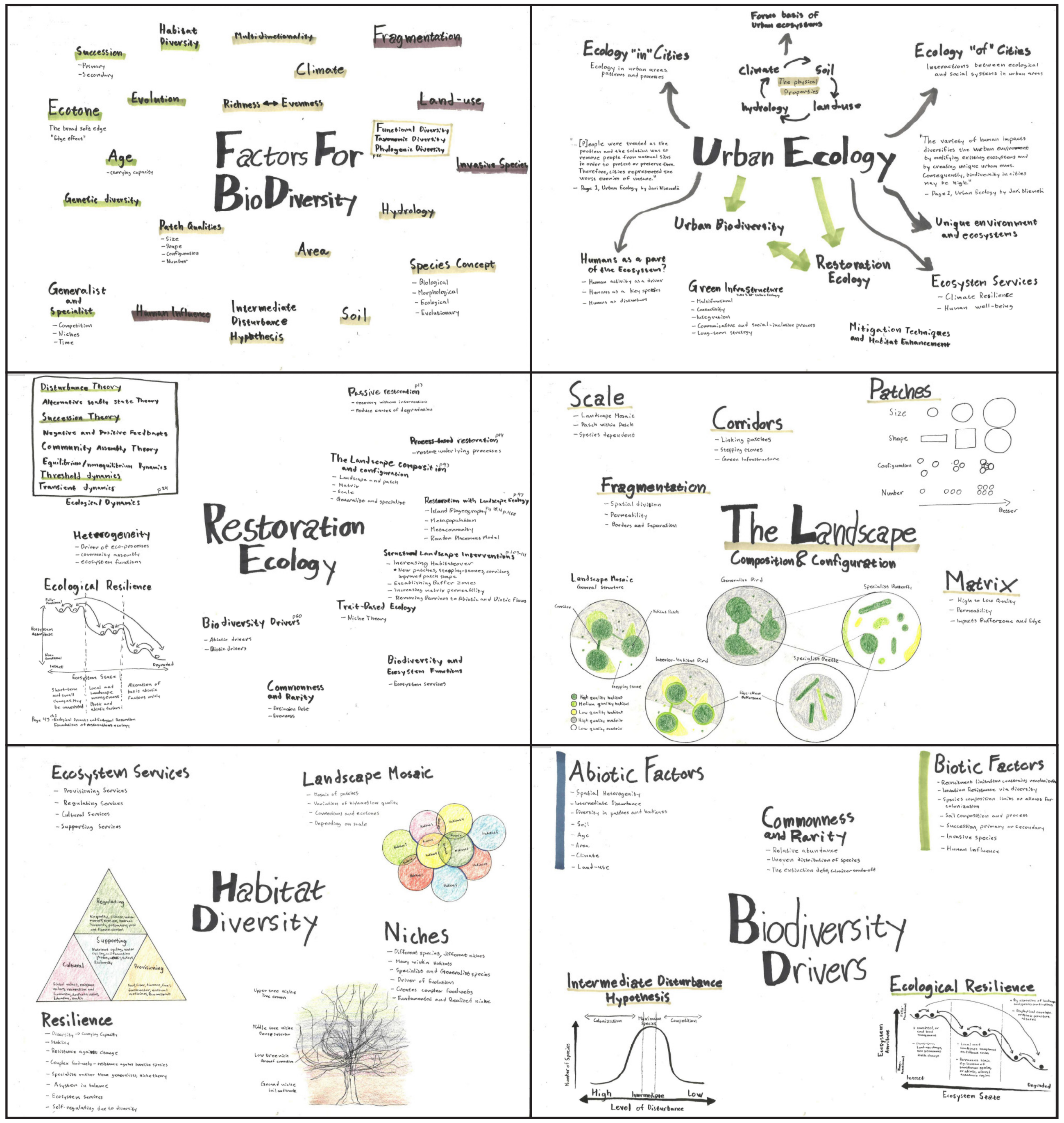
Appendix.

Sketches & Process.

The process of investigation was directed by mind maps, showcasing terms and topics. These were highlighted by relevnce and interest. Below is an extraction of sketches showing the method and development of the work.

Main terms and topics where broken down into principles, concepts and relevant connected fields. Connections were established creating a comprehensive structure for ecological translation and adaptation to design.



Summarized list of how the different topics and ecological layes and principles could have relevance in design. Some of these where developed and investigated further.