SOLARCHIPELAGO

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MSc Thesis Landscape Architecture
Wageningen University
June 2020

Designing energy transition in the IJmeer along ecosystem change

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Abstract

Climate change mitigation calls for a transition towards more sustainable energy sources. However, allocating the space for renewable energy technologies like PV systems in complex and dense metropolitan regions is no easy task. This is the case for the IJmeer between Amsterdam and Almere as well. The IJmeer is also an ecosystem under pressure. The objective of this research is to design an energy transition in the IJmeer that aligns with the way that ecosystems change, such as through the process of succession. A method of research through designing is used to come to useful design principles and guidelines.

The use of concepts like succession and ecosystem change was analysed in literature, both in ecology and landscape architecture. This literature analysis was then synthesised into workable design principles. Design principles for ecosystem change and succession include notions of working with non-linearity, indeterminacy and complexity in ecosystems under pressure by humans. A dual analysis was carried out of both large landscape projects as well as an assessment of the ecosystem status for flora and fauna. Technologies and measures for improving ecological quality and renewable energy systems were analysed as well.

A design for the IJmeer was made using a modular approach. Two modules are presented that combine both renewable energy generation as well providing an infrastructure for succession to occur. Multiple stages of succession simultaneously present in these modules allow for more habitat diversity for flora and fauna. The modules performance is based on constant working principles but include variables as well to provide different system responses. The modules variables and composition can adapt to the characteristics of multiple areas of the IJmeer, while also supporting other metropolitan functions like infrastructure and urban expansion while providing renewable energy. The resulting design guidelines were evaluated together with the principles in the conclusion.

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Preface

This research project is a result of my academic master programme of Landscape Architecture at Wageningen University. Working on this thesis however, I have noticed that the themes and knowledge used go further back than just the last couple of years. This thesis is not only a project done over the course of several months, but also a summary of my development over the years as a designer. My choice for landscape architecture was deeply motivated by a creative mind and a fascination with the natural world. Over the course of my teenage years, I have become deeply interested in studying the Dutch flora and fauna. In combination with my studies, it has brought me a deep appreciation for the unique ecosystems the Netherlands possesses. Over the course of my bachelor and master programme, an interest in ecology and designing for biodiversity has made its return in many university projects. I am glad it did so as well for this final research project of my studies, along with the urgent but exciting theme of sustainable energy production. I have in the last couple of years become more outspoken about the problems our habitat as humans is facing. Landscape architecture has, to me personally evolved to be a discipline of activism. Rather than being the end of my studies, I hope this project is the beginning of a career of changing our livelihoods for the better.

At the time of writing this, along with finishing this project, the COVID-19 pandemic has been in effect for several months already. These times show us that things can change very fast into something unexpected and uncertain. The way in which things can change, and that not everything is in our control is a prominent theme of this project as well. I sincerely hope that after this crisis, we can move towards a sustainable environment, a swift and resolute energy transition and better care for the native flora and fauna of our Dutch landscapes. I also hope that this thesis can be seen as a contribution to these developments as well. The pandemic has also made the last couple of months finishing this thesis very hard. Being alone on this project instead being in the presence of peers has not been beneficial to the ability to keep working on this project. I would therefore like to thank everyone who has been supportive these last months, as well as during the entire period of working on this project.

1

Introduction

The latest predictions and already noticeable effects of climate change have made it clear that mitigation measures must be taken at a rapid pace. Climate change threatens the livelihood of the global population, especially in locations and natural systems which are highly vulnerable to sea level rise and floods (IPCC, 2018). Human activities, through the emission of greenhouse gasses, have impacted the natural processes of the earth to such an extent that we live in the Anthropocene, an era where the earth's processes are mainly impacted by us, humans (Crutzen, 2006). The effect of human activities on the biosphere has, besides climate change, also drastically reduced biodiversity on earth. Intensive agriculture, resource extraction, urbanisation among other processes have driven out many plant and animal species, and it is becoming clear that this will be indirectly accelerated through climate change (IPBES, 2019).

Anthropogenic effects on the environment have been and are still very significant in the Netherlands. The need of mitigation measures here are directly motivated by the country largely being situated below sea level and the large amount of greenhouse gas emissions for energy consumption. Added to that, the Netherlands is a very dense country in terms of population and anthropogenic activity, putting large pressure on its land use and ecosystems. This counts especially for metropolitan regions which have large land pressure and are at the same time large consumers of resources. Dense anthropogenic activities in these regions, such as expanding cities with more built up area and new infrastructure, is also pressuring biodiversity which exist in and just outside these built up areas (fig. 1.1).

The complex nature of metropolitan systems in the Netherlands are a large challenge in terms of the transition ahead of us. Mitigation measures means that these systems need significant change into more sustainable systems. Even though the goals are clear to a certain extent (Klimaatakkoord, 2019), it is an extraordinarily complex process which deals with a lot of uncertainty and complexity. Uncertainty about which systems work and are viable in the long run, uncer-

"Amsterdam wants many more wind turbines and solar panels soon"

NRC, 12 February 2020

"Pleas for accelerated construction of 25.000 houses in Almere"

NRC, 18 February 2020

"Housing plans Almere puts a metro line to Amsterdam back on the map"

Parool, 18 February 18 2020

"Municipalities want to turn Diemer wedge into popular attraction"

Parool, 12 February 2020

Figure 1.1: Several newspaper headlines showing big plans among the complexity of the Amsterdam/ Almere metropolitan region.

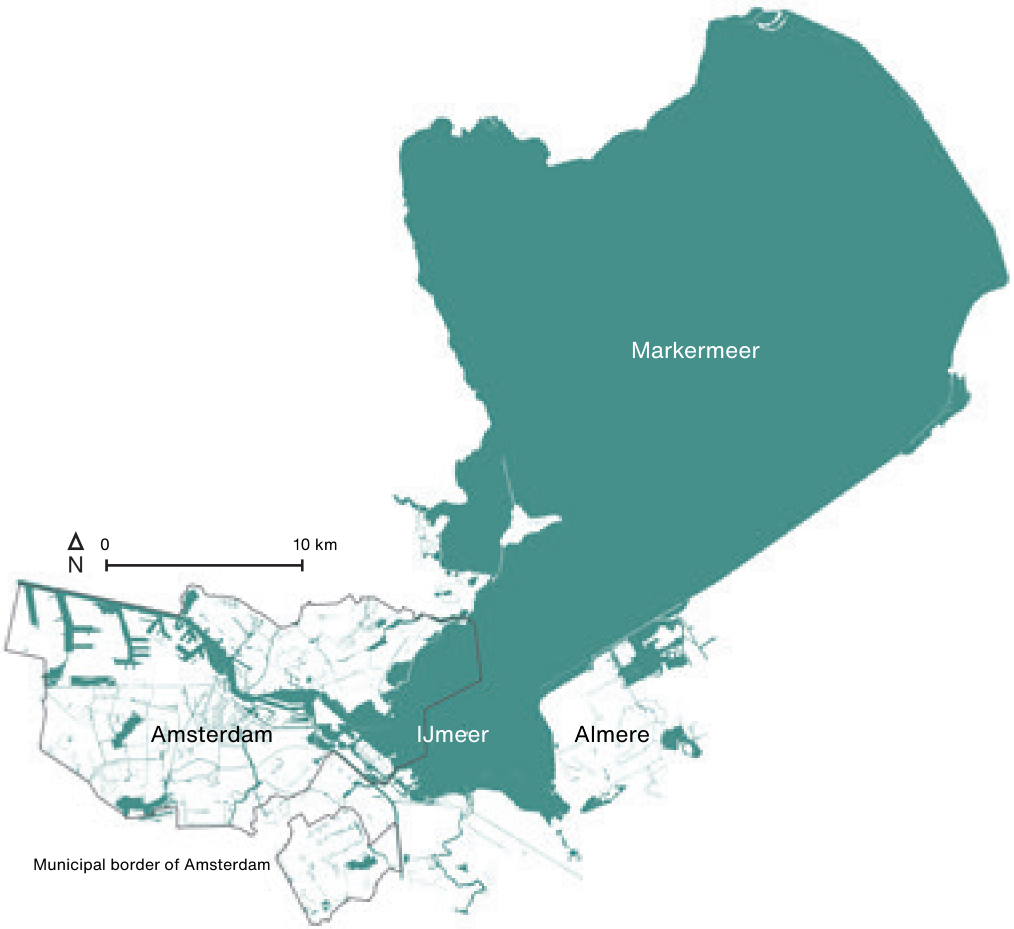


Figure 2.2: Map of Amsterdam, its surface water, the municipal border (in black) and the spatial relation to the IJmeer/Markermeer.

tainty about the amount and how to spend valuable time and resources, and uncertainty about the extent to which our lives will be impacted by a system transition, and the overall overwhelming complexity of changing the system in which we live.

Great landscape projects in the Netherlands have however caused large transitions and shifts in the country during its existence. In this sense, we can look ahead with an attitude of optimism. The Netherlands has a tradition of large-scale interventions that acknowledge the complexity of the landscape, even the complexity of large-scale landscape projects nowadays (Alkemade, 2020). In cities like Amsterdam, energy transition and allocating the space for it may seem inherently complex. However, roughly a quarter of the municipality surface consists of water. A large part of this quarter is the IJmeer, a lake to the north-east of the city (fig. 1.2).

The open water of the IJmeer may seem like it is not under a lot of pressure. However, it is very much entangled in the complexity of urban expansions and infrastructure. Adding to that, the IJmeer is an ecosystem that is already pressured by anthropogenic processes (Waterhout, 2013). Could an energy transition be the incentive that could interconnect solutions for humans, flora and fauna?

In asking this question, we are indirectly asking in what way urban systems and human activities relate themselves to ecosystems, especially in the aspect of time since we are dealing with transitions, uncertainty and changing ecosystems (Sijmons, 2012). Changing systems in landscapes is something we need to do to mitigate climate change and preserve animal and plant species and populations. In nature, ecosystems change all the time, partly through a process called 'succession'. Succession is the sequential replacement of species, that can affect system processes as well. Learning from ecological processes that have resulted highly efficient systems can benefit our understanding of implementing sustainable energy technologies (Stremke & Koh, 2010). In this sense, ecological concepts relating to ecosystem change, like succession, can help with designing with an ecological mindset for complex contexts. Using these approaches and concepts for principles for landscape design, they can be put to the test in providing a landscape design for the energy transition in the IJmeer and a set of guidelines relating to its context.

②

Methodological framework

Context

The IJmeer is the most southwestern part of the large freshwater lake known as the Markermeer in the Netherlands. The IJmeer is to the northeast of the centre of Amsterdam and to the west of the city of Almere. Its proximity to multiple urbanised areas causes it to be situated in a metropolitan context. The Markermeer/IJmeer is an ecosystem on which many flora and fauna depend, especially birds. The ecosystem has been heavily impacted by anthropogenic processes over the past and is still under pressure today (Waterhout, 2013). Municipalities of Almere and Amsterdam are at the same time looking for nearby implementation of sustainable energy technologies, also outside of pressured built-up areas (Gemeente Amsterdam, 2019).

Objective

Sustainable energy systems must sometimes compete with different land uses. Although this competition appears minimal at the surface water of the IJmeer, the metropolitan context and the pressure on its flora and fauna cause generic implementation of energy technologies difficult when facing an urgency for an energy transition. The challenge lies in sustainable energy not affecting the ecosystem negatively, but instead having a possible positive effect. In this sense, we can learn from ecological concepts. Concepts like transitions, ecosystem change and succession share the common principle of development over time. Possibilities arise here to align processes like succession and energy transitions as a hybrid development for the IJmeer. The objective of this research is to design an energy transition for the IJmeer that aligns with the change in ecosystems and while applying ecological concepts. Changes in ecosystems will be explored by the related ecological concept of succession. A design approach will be constructed by several principles and conclusions will be drawn from design decisions in the context.

Concepts

Concepts relevant for this thesis are those using ecological theory and theories of ecological design. Ecology is the study of organisms in relation to their environment, and ecological design is the design practice heavily grounded in this natural science (Crewe & Forsyth, 2003). Ecology studies among other things the functioning of ecosystems. An ecosystem is a defined area that contains interacting biotic and abiotic components that have both interactions within the system and interactions outside the system (Tansley, 1935). Humans, being biotic components themselves, can also be part of ecosystems along with their interventions in the landscape (Golubiewski, 2012). However, the ecologists have also studied the functioning and composition of ecosystems that are minimally influenced by humans, often called ‘natural’ or ‘non-human’ ecosystems. ‘Human ecosystems’ are ecosystems heavily dominated by anthropogenic effects, such as cities (Golubiewski, 2012). Ecosystem change’ is the way the functioning and composition of ecosystem can alter over time. A driver of ecosystem change can be a process called succession, the sequential replacement of species over time (Pickett et al., 1987). These ecological concepts can prove useful in designing sustainable energy systems (Stremke & Koh, 2011).

In order to provide useful conclusions and to efficiently explain and summarise design approaches and decisions taken, this research will result in principles and guidelines as a conclusion. Design principles are abstract, general points of attention for designers to use in guiding their design. Design principles are not place-specific and allow designers to organise design decisions along certain lines of thought. Design guidelines on the other hand are site specific and is the result of the application of the design principles in a spatial context (van Etteger, 2016).

Questions

The main research question for this thesis is the following:

MRQ: *What are the principles and guidelines for designing an energy transition the metropolitan ecosystem of the IJmeer through the concepts of succession and ecosystem change?*

To answer the main research question, several sub research questions must be answered first. The existing use of concepts like 'ecosystem change' and 'succession' in ecology and landscape architecture must be analysed. This knowledge is not place specific and will provide several principles for the design stage, but also for the analysis. This first sub research question will be addressed in the theoretical framework, providing a thematic contextual backdrop for this thesis. The second sub research question relates to the analysis of the site and diagnosing the problems to address for the design This question is place specific as it addresses the IJmeer region directly. The third research question studies the possible technical solutions for biodiversity and sustainable energy. This research question is also place specific as biodiversity measures relate to the specific problems of the IJmeer. This concludes the first part of this report consisting of acquiring the knowledge for design. The second half of this research will focus on creating knowledge through design to fully answer the research question. The design question for this report is similar to the main research question. However, the goal of designing itself is not to arrive at a set of principles or guidelines, but to make a comprehensive, visually supported solution for energy transition. Below, all research questions are listed.Below, the research questions are listed with their corresponding chapters.

SRQ 1: *What are the principles for landscape analysis and design related to succession and ecosystem change? (Chapter 3)*

SRQ 2: *What are the characteristics, constraints and problems in the current ecosystem state of the IJmeer and how did they develop? (Chapter 4)*

SRQ 3: *What technologies and measures can lift the constraints of the IJmeer ecosystem and provide solutions for sustainable energy implementation? (Chapter 5)*

Design question: *How can an energy transition occur the metropolitan ecosystem of the IJmeer through the concepts of succession and ecosystem change? (Chapter 6&7)*

This set up is visualised in figure 2.1.

Methods

This research project will employ a mixed methods approach and assumes a pragmatic knowledge claim. By acknowledging intersections between natural sciences, social constructs and the real-life context of the IJmeer, the principles and guidelines tested in the IJmeer through design can be assessed in an integrated, holistic, 'ecological' way (Lenzholzer et al., 2013). The main research question will be answered by first establishing a knowledge base answering the sub research questions and the design question. These sub questions will inform the design process through several research strategies. Each of these questions has its own methods.

The principles for analysis and design in SRQ 1 will be synthesized by a literature analysis of ecological theory and theory in landscape architecture. SRQ 1 will be addressed as a theoretical framework for this thesis. But because it must address a 'stance' on the use of ecological concepts for landscape design, it simultaneously takes on the form of an essay, critically analysing ecological concepts and their application in landscape design for sustainable strategies. Here, a pragmatic knowledge claim is used as it assesses positivist ecological science, but also constructivist and other pragmatic applications of ecological knowledge.

The IJmeer ecosystem in SRQ 2 will be analysed through reports on its ecological quality and the historical works of its development to provide a context. The analysis will be supported and categorised according to several phenomenological arguments. A phenomenological approach here means that subjective findings are based on experiences (Herrington, 2017). These experiences were conceived by several field trips to the IJmeer and its surroundings by boat, bicycle and foot. The analysis of the IJmeer landscape is meant to find the properties of the (human) ecosystems, along with its constraints and problems. These aspects will be dealt with in the design phase. The analysis will also provide an understanding of a landscape defined by large landscape projects in the Netherlands and the characteristics that they laid onto the landscapes. Experiences on site, or 'landing on site', together with an understanding of historical layering, or 'grounding of the site' will form an important part this analysis as well (Girot, 1999). These characteristics will also be considered in the design.

The technologies and measures of SRQ 3 will be derived through a case study and a literature analysis of landscape projects in the IJmeer and in general. Projects considering biodiversity and ecological quality are either implemented projects or pilot studies in the IJmeer or Markermeer. Reports on the performance of these projects will be the primary source of information here. In this chapter, sustainable energy technologies will also be analysed for application in the design project. These technologies will be analysed through a literature analysis on their performance, but also on their effects on biodiversity in water-rich environments.

The answering of the main research question through the design question involves a method of research through design. The sub research questions provide the base of knowledge for design in their principles, the understanding of the site and the 'ingredients' of technologies and measures that can be designed with. Combining this knowledge into a landscape design will be the base for a method of 'research through designing' (Deming & Swaffield, 2011; Lenzholzer et al., 2013). Research through designing means that an answer to a problem or question is sought by the act of designing itself. Through a projective design 'experiment', new knowledge is generated, in this case both for a specific context as well as generalisable knowledge (Steenbergen in Deming & Swaffield, 2008).

Designing being a very personal and subjective practice proves difficult in validating it as a replicational research method. This project uses design in a generative way, regarding design as an essentially subjective, intuitive and artistic (Deming & Swaffield, 2011). This design research is highly explorative, with its processes adapting to new insights. Designing will not occur through any predetermined method; the design process is highly complex, implicit and iterative and will occur mostly through creative leaps. A creative leap means bridging the gap between the functional design requirements and the formal design structure. In this research, this occurs both by a set of first principles and a set of technologies to combine from applied on the IJmeer (Cross, 2004). Even though these principles imply definition prior to the design, they are informed by cycles of iteration. This is especially true for guidelines, which, although informed by principles, only emerge through creative iteration in the design process on the context of the IJmeer. Design guidelines will be derived from the design itself, 'distilling' the design into place-specific considerations. These guidelines will be categorised along multiple themes of design.

It should also be noted that the sequencing of chapters and themes of this research exists for practical reasons The report is set up to move from general ideas to a more specific design, not to imply a chronological 'journey' of the design process. To summarise, designing has proved for the author to not lay out a predetermined linear strategy and does not mean that every thought, connection or decision can be identified and rationalised through objective criteria. To do so would mean to view landscape architecture solely as engineering rather than its unique position of combining natural sciences and the arts (Koh, 2008).

In the discussion andconclusion, all design principles and guidelines will be summarised and its use evaluated through design reflections (Deming & Swaffield, 2011). The designer will reflect on the synthesising and use of the design principles, and their applicability to the context of the IJmeer. The design principles will also be addressed in their applicability to other contexts. The resulting guidelines and their categorisation will also be reviewed in their capability to give a concise overview of the design choices made in the design for the IJmeer. The guidelines will also be related back to the principles.

Research quality

Research through designing as well as a varied mixed methods approach of the sub research can question the quality of this research in different way. Deming & Swaffield (2011) list several criteria for research quality that will be considered when conducting this research. The truth value of this research will be warranted by the design experiment being conducted according to a real-life context.
The IJmeer will be analysed in its ecological properties and problems, along with real-life measures and technologies to deal with them. The case of the IJmeer makes it somewhat harder to make knowledge that is generated generalisable or transferable. However, the design principles are not place-specific, and several design choices could also be used for similar situations. Considering consistency and transparency, it must be acknowledged that designing is a personal and artistic process as described above. Therefore, the design outcome is not free of any bias, nor is it possible to completely reproduce. These problems will be attempted to mitigate by listing design guidelines as significant considerations for design. Considering the significance for the field of landscape architecture, the theoretical framework will address the place of this research in the context of landscape architecture theory. Together with the designing phase, this research will generate both new place-specific knowledge as well as generalisable knowledge relevant for the discipline. Organisation and efficiency in this research will be warranted in the basic set-up for this thesis, defining both the knowledge necessary for design as well as the knowledge generated through design.

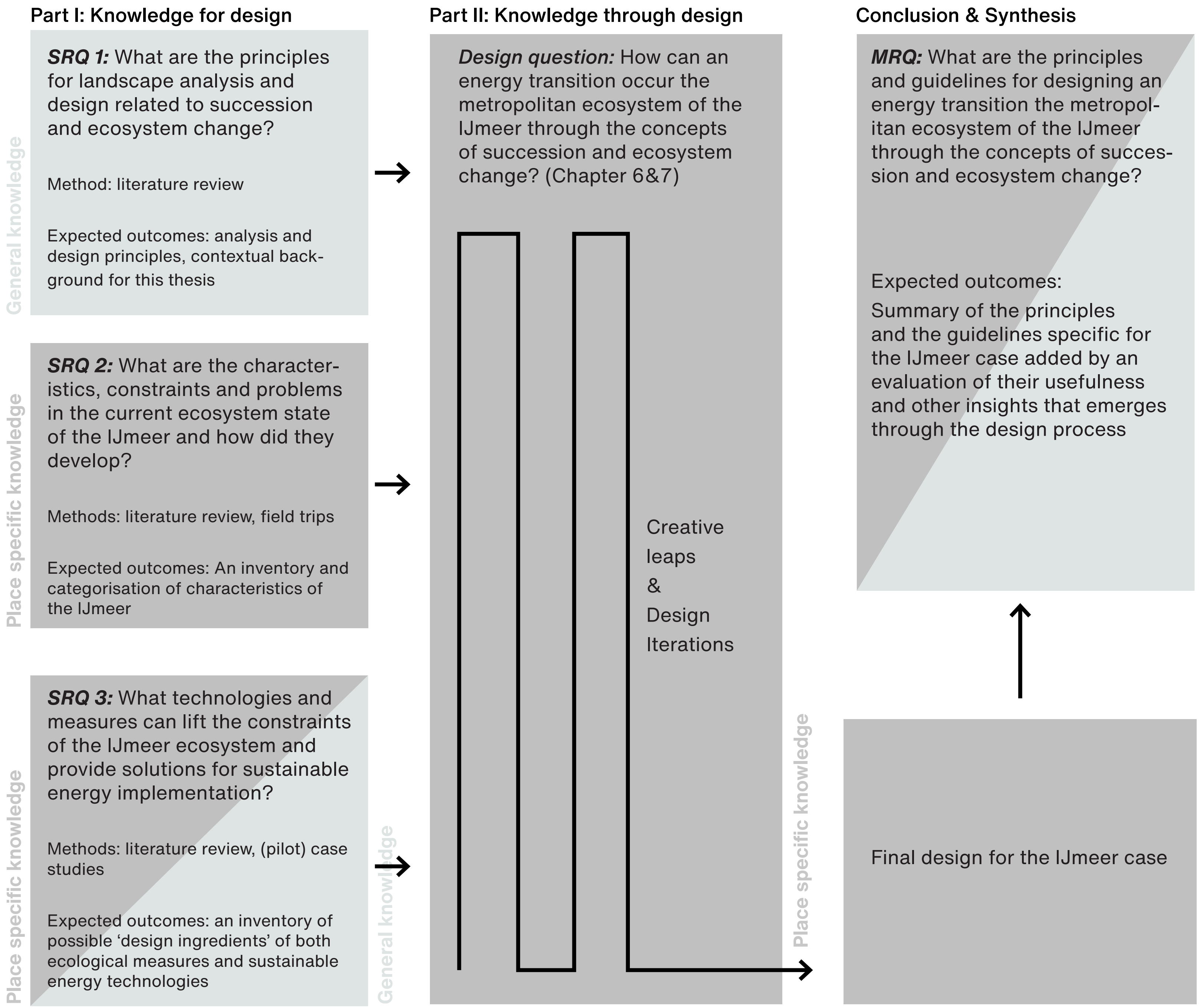


Figure 2.1: Arrow scheme of the methodological framework for this research project

PART I:

KNOWLEDGE FOR DESIGN

③

Theoretical framework

Introduction

The relation of living beings to their environment is a broad topic to study; yet it is the fundamental topic of ecology (Townsend et al., 2008), a relatively young field of study that has impacted many disciplines including landscape architecture. The study of the ecosystem, one of the most important concepts in the spatial sense of ecology, includes a large variety of topics relevant for this research due to its complexity of the landscape system and a transition of that landscape into more sustainable performance. But also, the conversion of energy in a system, flora and fauna and dealing with uncertainty are relevant links between ecology and the context of this research. Ecosystems have evolved over millions of years to create highly complex but highly efficiently and sustainably functioning systems (Stremke & Koh, 2010). The study of living systems has resulted in useful methods in studying these topics but have also provided insights to solve environmental problems. Especially landscape architecture, a field which includes ecological knowledge but also shares the study of the living landscape can benefit from certain ecological principles (Lister, 2015).

However, analysing landscape systems and using ecological insights in relation to succession, development and transition in landscape design does not speak for itself. The purpose of this chapter is to produce a useful set of principles for respectively landscape analysis for the purpose of design and principles for design itself. This chapter will gradually move from more contextual, ecological substantive theory to more procedural theory of principles (Ndubisi, 2002), while addressing several themes of interest.

We first have to acknowledge that and landscape architecture are practically two very different fields of study (Koh, 2008). Concepts such as energy, succession and methods like analysing ecosystems have to be made useful for landscape architects. This means that a clear understanding of the fundamental knowledge and development of ecological knowledge concerning development and succession is needed first. This base of understanding is followed by an overview of transdisciplinary applications of ecological theory, among which the tradition of ecological thinking in landscape architecture and relating them back to ecological science.

Secondly, we need to acknowledge the broader change of context of ecology in studying 'the natural world' to the fact that anthropogenic activities are omnipresent nowadays. Ecological approaches have evolved into holistic notions of everything being connected, blurring traditional boundaries like natural and anthropogenic (Morton, 2010). While analysing ecology and transdisciplinary applications all the way to landscape architecture, a standpoint needs to develop how to deal with human nature relationships in the context of this research.

Lastly, we need to acknowledge that the relation of living beings to the environment is inherently complex. The notion that everything in that sense in some way connected to everything is overwhelming, but there are different ways of dealing with it which will be adressed in this chapter.

Concepts of succession and ecosystem change in ecology

The field of ecology concerns itself with the distribution and abundance of organisms and the interactions that determine distribution and abundance. These interactions also include the transformation and flux of energy and matter (Townsend et al., 2008; Likens, 1992).

Ecology can be studied across multiple scales in the biological hierarchy, ranging from individual organisms to populations (organisms of the same species) and communities (a multitude of populations). These levels of organisations mostly deal with their internal structure or in the case of the individual organism, their relationship to the environment. A spatial environment with different organisms interacting within it can be the object of study in ecology and is called an ecosystem. An ecosystem is a defined area that contains interacting biotic and abiotic components that have both interactions within the system and interactions outside the system (Tansley, 1935). The focus of ecosystem studies can vary from more biotic elements (species, populations, hierarchy) or abiotic elements (biochemical cycles, the effects of hydrology and geology) (Likens, 1992).

Figure 3.1: Succession occuring at Nature Park Schöneberger-Südgelände in Berlin. A former railway yard has been taken over by succession processes. Among the current vegetation of birches, beech saplings are coming up as the next stage in the process.

Ecosystems and the communities within them can change over time. Plant succession, the development of vegetational patterns was already studied at the turn of the 20th century. It is a community process, occurring among populations of different species, and a very observable one. Flowers, grasses and herbs will pop up in bare soil, which will subsequently be replaced by other (often larger) species when those grow, die, spread or be outcompeted (fig. 3.1,3.2). Therefore, succession can generally be defined as the sequential replacement of species over time, which is the basic definition as stated by Frederic Clements in 1916. The study of succession is therefore mostly concerned with the patterns of this change in vegetation. Clements lists five chronological causes in which succession occurs: a disturbance opening the site, migration of propagules to the site, establishment of species, biotic interactions and adaptation of the site by organisms

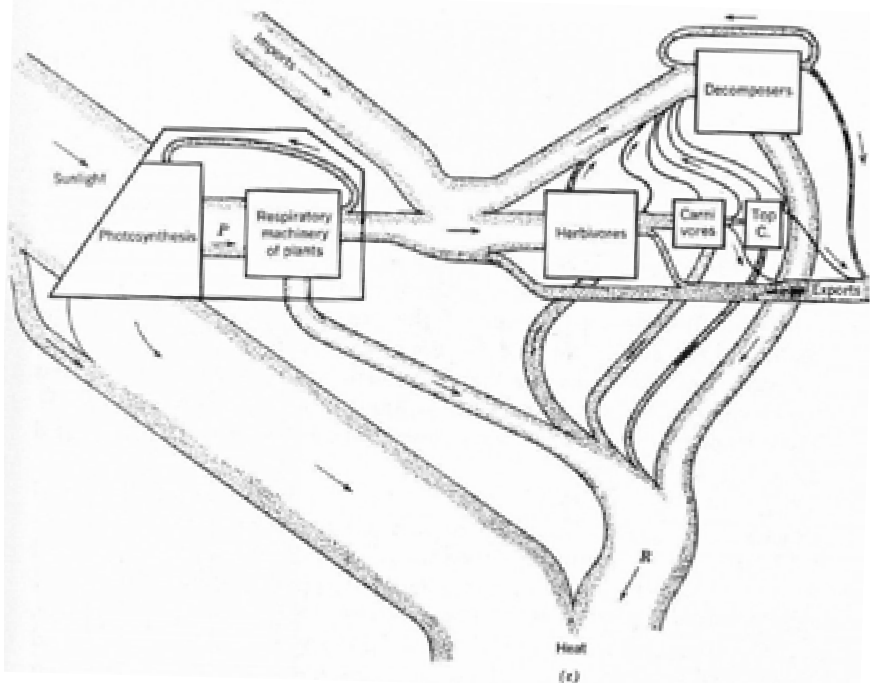
Figure 3.2: Profile of a succession pathway of a pine forest, with the 'early'stages on the left and the 'mature' stages on the right

(Clements, 1916). First is the concept of a disturbance, which is according to Clements a relatively abrupt loss of biomass. This can be an extreme weather event, like floods, storms or forest fires. This disturbance 'opens the site', or in other words, makes it available for propagules, like seeds, to grow and establish a set of species. These species undergo interactions and will eventually alter the site; like enriching the soil with nutrients, cover open waters or prevent erosion of sediment by root systems. The causes of succession by Clements were refined by Pickett at al. (1987) in which causes were reframed as conditions for succession to occur, and to distinguish the functional components of succession. Generally, the conditions for succession to occur is the availability of open sites (usually following a disturbance, but the death of an induvial can also open the site in a small scale), differential availability of species (the ability for different species to move into the site) and differential performance of species at the site (interactions and different behaviours of species at the site itself). Important concepts to then study succession are pathways, which it the temporal patterns of change. The order in which certain species appear and disappear is part of a pattern. Another concept is the cause of this order of replacement; a cause is an agent of change like the amount of light, or nutrients can all be causes in this sense. The mechanisms of succession are the interactions of these causes; these can be competition for sunlight for example. The last important concept Pickett notes is that of the model. Models are the relations among causes and mechanisms that explain certain pathways. Pathways can give an idea of the change that occurs in ecosystems and can to some extent predict the change in ecosystems with similar conditions. Landscape architects should consider the causes and mechanisms of the replacement of species in succession, and the way the site and species relate to one another. However, it is important to not rely to much on predictability and ideas of control when addressing succession.

The 'clementian' theory of succession assumes that succession is directed development towards a 'climax' state, in which there is a definable endpoint of the replacement of species. This endpoint can be illustrated by a forest with fully grown trees like beeches or oaks which will not be replaced by new species unless a disturbance occurs. This caused notions of 'young' and 'mature' ecosystems to come into being in the years after; ecosystems were compared to organisms that will 'grow' in biomass and complexity over the course of their 'lifespan'. The idea of a climax, a final stage in the process and patterns of communities following a disturbance, became heavily embedded in ecological thinking. Mature ecosystems were also described in terms of stability and control, the idea that they came to a point where they are less susceptible to change and disturbance. In the second half of the 20th century, these ideas became more and more contested and eventually proven partly wrong.

In the sixties and seventies, the field of ecology broadened in ways which also influenced the concept of succession and ecosystem change, specifically from an ecosystem perspective rather than mostly vegetation communities. Connections were made between ecology and thermodynamics. Ecologists like Robert MacArthur placed emphasis on the balance of resources like matter and energy in ecosystems, which constantly move towards 'equilibrium' in which all resources in a system are used optimally (Pulliam and Johnson, 2002). A balance approach based on systems with inputs and outputs was also explored by the brothers Eugene and Howard T. Odum. Rather than focussing on individual species or communities in their research, energy and matter was quantified and the system was analysed in terms of its biochemical cycles (fig. 3.3). H.T. Odum described ecology as the study of the structure and function of nature (Odum & Barrett, 1971). This is also illustrated by the approach that everything could be perceived as transformations of initial solar energy into biomass and continuing further along the hierarchy through species interactions (Odum (H.T.), 1988). This approach to ecosystems could also be used in terms of its development over time, in which Euguene Odum lists many different trends related to systematic or community properties. There is an assumption of increased homeostasis as a final stage in its development as the net production (the ratio of production and respiration) approaches a balance. This is the direction in which all processes eventually move to, or as it is called by Odum, 'mature' stages in ecosystems. Production slows down and systems become more complex, there is a peak in biomass (stored energy) and diversity and symbiosis increases. Nutrient cycles close and niche specialisation becomes narrower. Ecosystems become more stable and resilient. This is all opposed to 'developmental' stages where the opposite of these trends occurs. Odum, similarly to Clements, also made the analogy between an ecosystem and an organism to illustrate this 'maturing' of ecosystems (Odum (E.), 1969).

Figure 3.3: Flow diagram of energy within an ecosystem in the Silver Springs study by Odum (1971)



Throughout the course of the decades thereafter, several arguments for equilibria were abandoned leading to a new paradigm of succession in ecosystems. To think there is a single equilibrium and a climax state that can be reached that ecosystems approach is misleading in the context of succession. The environment in which ecosystems behave is too susceptible to change in relation to the complex nature of ecosystems for a single equilibrium that changes over time. This is different from organisms where one equilibrium remains the same throughout its development, like body temperature (Holling & Goldberg, 1971). In organisms, many components such as organisms stay the same whereas in ecosystems, they change over time. Instead of one constant equilibrium, an equilibrium in ecosystems may change over time and can composed of multiple equilibria at the same point in time that effect each other as well. Pulliam and Johnson (2002) summarise three misconceptions about equilibria that were assumed before the new paradigm; the idea that ecosystems are always found at or close to equilibrium in relation to their resources, the idea that ecological patches (an area with certain homogeneous environmental features) are relatively autonomous in terms of resources and equilibrium, and the underestimation of the importance of disturbances.

The new paradigm however considers multiple stable states in ecosystems and communities that dynamically and continuously respond to a large variety of disturbances and have done so over the past. Ecosystems exist and change over larger scale in time than we can observe in a lifetime, but also endure smaller changes over shorter lifespans. Rather than linear developments, ecosystems constantly move through recurring cycles based on four processes: exploitation, conservation, release and reorganisation (fig. 3.4) (Holling, 2001). This process is known as the four-box model or the 'Holling figure eight'. Important to note is that no two cycles are the same; reorganisation means a shift to a new ecosystem state. Ecosystems, being self-organising systems, constantly shift states and are under change, challenging traditional views of resilience. Resilience, which can be defined as the ability to bounce back to former state, was split in the 'engineering resilience' and 'ecological resilience'. (Holling et al., 1973). Engineering resilience is illustrated by a body temperature; it is measured by the return time to a former state after a disturbance, such as the severity of fever or a disease. There are also thresholds to body temperature; above or below means death. Ecological resilience however is, due to its multiple stable states, the severity of disturbance being enough to surpass a threshold and move from one ecosystem state into a different state (Holling et al., 1973; Gunderson, 2003). The new paradigm also considers ecosystems to be not fully autonomous systems but to be very heavily influenced by incoming or outgoing fluxes across system borders (Pulliam & Johnson, 2002). Ecosystems are never devoid of disturbances and external factors and ecosystems are often not in equilibrium in practice, nor do they regularly reach the ideal of a climax state (Gibson, 1996). The enormous complexity of ecosystems and the fact that we cannot fully analyse and know all its details makes us unable to fully understand in which way ecosystems react to disturbances (Jørgensen & Miller, 2000) This means that the predictability of the development of ecosystems is incredibly limited and understanding specific structures and processes is very uncertain.

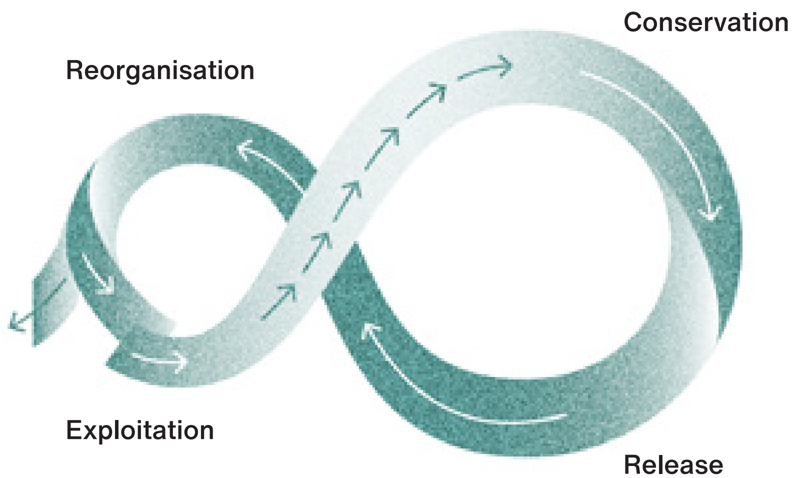


Figure 3.4: Hollings 'Figure 8' model of cyclical ecosystem dynamics

Humans and ecosystems

The new ecological paradigm is further complexified by human influence. The growing impact of humans on ecosystems and the growth of environmentalism made ecology to become a more normative science over the last fifty years (Lister, 2015). Environmental problems made it clear that ecological knowledge eventually had to be used in sustainably managing, planning and designing landscapes (Likens, 1992; Holling & Goldberg, 1971). The increasing effect of humans on ecosystems also questioned the role of human activity in ecosystems, and how to manage them. The idea that human influence on the environment is separate from 'natural' functioning of ecosystem has become obsolete, even though many ecologists before having included human activities in ecosystems. Even the original ecosystem definition by Tansley supports the inclusion of humans and their influences (Pickett & Grove, 2009). Humans are both agents in ecosystem impact and creation, but also participants in those same ecosystems depending on its processes. In fact, humans have become the primary influence on the earths processes, of which they will become the victims as well (Crutzen, 2006). Climate change and species extinction made it clear that ecosystems from this age onward cannot be left alone to develop into resilient systems, as was the incorrect idea of ecosystem management under the Clementian succession theory (Pulliam & Johnson, 2022); we instead have to actively focus on species preservation and their habitats. Not only have the role of anthropogenic effects in ecosystems research grown over the years, they have also led to new classifications of ecosystems, being 'impacted', 'novel' or 'designed'. Impacted ecosystems are ecosystems that endure unintended human alterations to its structure and function, but not to an extend that it reaches a threshold and alters its state. Novel ecosystems have reached that threshold however and exist entirely because of human agency, while being self-sustaining (Morse et al., 2014). A third category is the designed ecosystems. Here, intentional human intervention and maintenance is the driving force. In its development, impacted and novel ecosystems start out from their previous ecosystem functioning, reacting to altering conditions. Designed ecosystems are in its functioning determined by human intention (Higgs, 2017). Especially the last category sets humans apart from other organisms in ecosystems; they can, with the knowledge of systems, intentionally alter system components according to their needs and plan ahead according to those needs. Humans as both the agents and participants of ecosystems blurs boundaries between what is natural and what is cultural or technological from this perspective, especially considering concepts like 'nature-based solutions'. Humans having an overwhelmingly

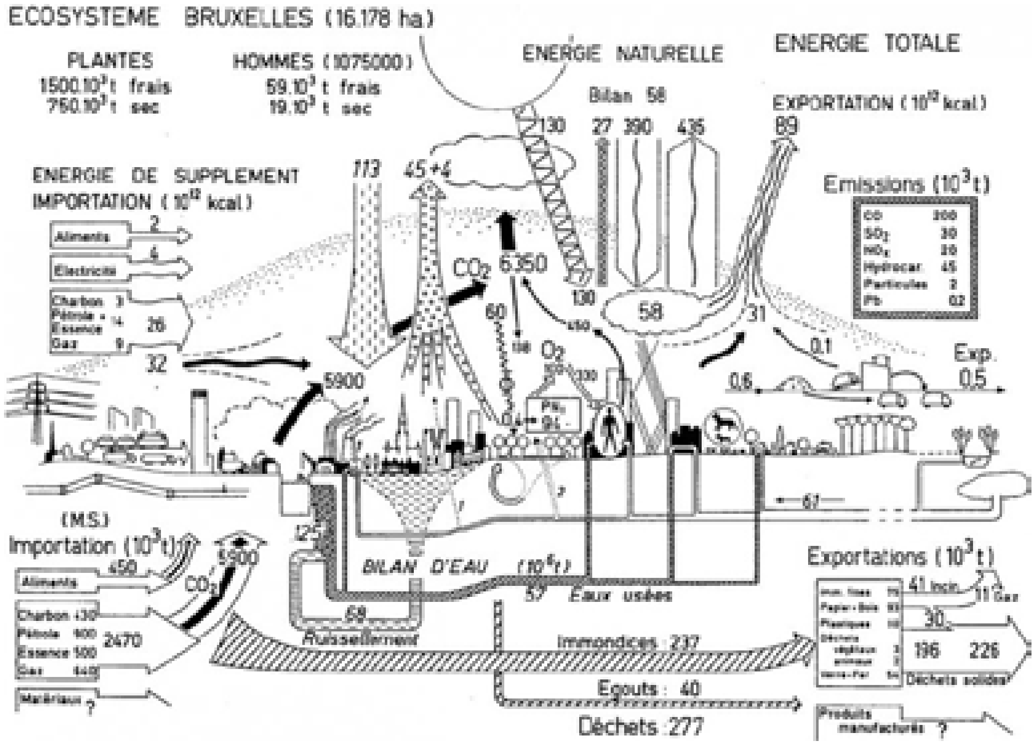


Figure 3.5: Diagram of the 'urban metabolism of Brussels by Duvigneaud & De Smet, 1977

large effect on ecosystems simultaneously questions our involvement. Human intervention cannot only be seen as an organism's involvement in the system, but also as a disturbance. This disturbance can range across many scales; from climate change to land clearing (Zipperer, 2010).

The overwhelming impact of humans on ecosystems made ecological thinking and system thinking popular in other applications than those for natural ecosystems. First, typically 'human' systems could also be described by ecological concepts in a metaphorical or analogous sense. Later, ecosystems that relied heavily on human influence and human systems that relied on natural resources could be studied by ecological modules and concepts (Pickett & Cadenasso, 2002; Wachsmuth, 2012). These approaches could be interpreted from going from 'biomimicry' or learning from nature to a more integrated approach. The idea of 'urban ecosystems' or the 'city as an ecosystems' are popular applications of ecological theory. Cities can be analysed as ecosystems to increase their efficiency and resilience. Transdisciplinary applications of ecological theory on ecosystem change and succession have also become popular in this application as a degree of ecosystem efficiency. This application often goes together with analysing 'urban metabolism', the analysis of cities in terms of biochemical cycles, emerging in the sixties (fig. 3.5) (Wolman, 1965; Pincetl at al., 2012; Zhang, 2013). Many researchers of urban ecosystems consider cities as being in a very undeveloped ecosystems, with little closed material and energy cycles (Decker et al., 2000). Ecological concepts can also be used as analogous to human systems in this sense. Human energy systems can also be seen in this sense as systems that are in their 'early' stages high in entropy and in mature stages high in exergy. Fossil fuels are in this sense an early stage where there is also little self-sufficiency with resource scarcity being a self-induced disturbance (Stremke & Koh, 2010; Stremke et al. 2011).

The view of succession in urban metabolism theory is heavily based on a thermodynamic approach of ecosystem change. Urban metabolism addresses system change as a change of a non-efficient state to a more efficient state, with energy and material flows becoming accounting figures in one and the other. The solution and proposed development are also based on the contested idea that cities increase their resilience by being more like a 'climax ecosystem', including making urban ecosystems analogous to superorganisms. Analogous referencing to ecosystems or organisms in general can conflict with holistic ecological thinking, especially when both are used at the same time. Cities are not just analogous to ecosystems, they are ecosystems under a large human influence (Golubiewski, 2012). The blurring of human systems and natural systems and increasing human influences in ecosystems have complicated the application of ecological theory to other fields, and can also lead to misanthropic and Malthusian assumptions when viewing the city and humans as 'parasites' on the resources around them (Rees, 1997).

Using principles of systems thinking and ecology for sustainable development is a strategy to approach complex ecosystems, which can be called an 'ecosystem approach'. Sustainable developments in this sense can mean sustainable energy systems. The ecosystem approach utilises the contemporary principle of succession and ecosystem development, and approaches ecosystems in a holistic way rather than analogous. Addressing sustainable development of ecosystems requires dealing with complexity and uncertainty. Linear, reductionist approaches focused on a single type of stability fall short when addressing sustainable development; sustainable development means the ability to be flexible and adaptive (Kay, 2008a). Ideas of control, prediction and right answers in complex systems do not apply, as the full functioning of self-organising systems cannot be controlled or predicted. Rather, a mindset of accepting complexity, adaptability and resilience is needed (Kay, 2008b). Humans can impact ecological systems in structure and context; both have a consequence for societal systems themselves as ecological systems provide the context in which they can exist. Being aware of making structural impacts (removing or adding ecological components) or changing the context (changing the context through which components interact), while staying open for feedback loops by the system is important in an ecosystem approach (Kay & Boyle, 2008). An ecosystem approach also means allowing multiple perspectives on problems and human-nature relationships in ecosystems. There is not a 'right' way an ecosystem should be or can be described as (Kay, 2008a).

Ecological thinking in landscape architecture

Landscape architects can often act as the bridge between multiple perspectives and disciplines in projecting possible futures for landscapes and presenting themselves as ecological thinkers. Ecological thinking has had large impacts on the field of landscape architecture. A significant work in this sense is Ian McHarg's 'Design with nature' (1969), approaching ecology as 'not only an explanation, but also a command' for landscape design. Understanding geology, hydrology and ecology of the site became the base for design, a conventional practice today but revolutionary at the time. Designing with the knowledge that natural processes permeate every context for design has grown in the years thereafter. Landscape architects have come to recognise cities as natural environments as well, most notably by Anne Whiston Spirn's essay 'The granite garden' (1984). Both these works are important works in what could be called 'ecological design' as an approach in landscape architecture (Crewe & Forsyth, 2003). This approach draws heavily on using ecological knowledge for habitat maintenance and is mainly concerned with conservation through engineering approaches to ecological problems, but rarely through ecosystem change or succession. The use of ecological knowledge has been fairly narrowminded in landscape architecture and has mostly been instrumental and objectivist in nature (Corner, 1997; Koh, 2008). Examples of this approach are the use of native species in plans and designing shallow banks and meandering courses for rivers and waterbodies.

Some landscape architects however have come to acknowledge the larger characteristics of ecosystems. Barnett (2013) lists several conditions of landscapes to be acknowledged by landscape architects. Disturbance, difference, uncertainty and heterogeneity are in that sense not only conditions to recon with, but also opportunities which can be used in design. Designing encounters in ecosystems between humans and non-humans means that every encounter is different, specific encounters cannot be predicted and each encounter forms the base for further information to occur. Barnett keeps the ecological theory rather substantive and close to its original meaning, implying its use for design to be implicit as procedural theory. His approach is more of an understanding rather than usable principles. More explicit are principles by Lister (2015), who lists several principles of ecosystem change for designing for resilience. The first one being that system change can happen both slow and fasts, with several processes occurring at different speeds. Second being connectedness and modularity within systems, with ability to keep feedback loops to a certain extent controlled. Third, acknowledging that there is no correct state for the ecosystem to exist in and to anticipate change. Fourth, embracing diversity and uncertainty, monitoring change and response, and acting accordingly. Both authors differ to the more instrumental use of ecological knowledge in that they address non-linearity, open-endedness and adaptability in landscape architecture. Design can mean control, but it can also mean a light touch, flexibility and anticipating change.

Figure 3.6: Design visualisation for Freshkills park, USA by James Corner/Field Operations. It's large scale approach in space and time makes it a prime example of Landscape Urbanism

Several paradigms of landscape architecture and landscape architects have approached these principles relating to ecosystems more indirectly. One of these schools of thought is landscape urbanism. The idea of the post-industrial blurring of nature and human society, in the context of the urban and the rural is an important factor in its emergence (Waldheim, 2006). Landscape urbanism takes a systems approach in perceiving sites as open systems and acknowledges a large timespan in which things change (fig 3.6). Ecological and urban processes are considered to be important forces to recon with. The landscape becomes the field and infrastructure in which processes and fluxes perform. In urban environments, spatial relationships are deemed less important than larger processes of economy, regulation and environment (Corner, 2006; Thompson, 2012). We can see similarities between dealing with uncertainty, complexity, and interestingly processes as a recurring theme in landscape urbanism. Landscape urbanism has been a large influence on, or has in other words 'evolved' into 'Ecological urbanism' (Thompson, 2012). Ecological urbanism also uses a systems approach and view urban systems and landscape as a complex network, putting not only an emphasis on the blurring of boundaries between 'natural' and 'human' systems, but also the blurring of the boundaries of disciplines. Ecological urbanism is concerned with the plurality of relationships in contemporary society: relationships between the individual, groups and the environment, of our thoughts and actions and of our responsibilities and respective disciplines. Ecological urbanism proposes intensive collaboration between spatial experts, especially various kinds of designers and ecologists (Mostavi & Doherty, 2016).

However, landscape architects do not necessarily have to take systematic approaches and directly use ecological theory to deal with uncertainty, complexity and change over time. These approaches have been incentives for landscape architects to take a more creative and poetic approach in relation to ecology (Corner, 1997; Koh, 2008). James Corner proposes that ecologists and landscape architects work together, but also that landscape architects should also approach ecology as a way to create imaginative relationships and a culture of 'systematic bewilderment'. These newly found connections can lie within the pulse, change and movement of nature. Corner states that landscape architects should not pursue finished works, but rather design frameworks, strategies, agencies and scaffoldings to respond to the complexity of nature and its continuous change (Corner, 1997). Designing a framework on which processes perform is also related to the concept of 'landscape infrastructure', being an 'indeterminate interface of hard technological systems and soft biophysical processes by design'. In this sense, the landscape intervention provides an artificial base for natural fluxes (Bélanger, 2013).

Figure 3.7: The ecocathedral in Mildam by Louis Le Roy. Nature and human interventions are in continuous interplay with one another

Moving with the continuum of nature can also be observed in the works of Louis Le Roy. Le Roy takes in his eco-cathedral an ecological approach of processes and flux rather than an ecology of specific components (Dagenais, 2008). Le Roy employs a continuous interplay between nature and human intervention; he is constantly building and influencing succession pathways along his constructions, which affect his building vice versa (fig. 3.7). Another approach can be seen in de works of Michel Desvigne. Desvigne does not so much interfere with the process itself but concerns himself with creating the preconditions for successive states. A minimal touch can enhance the beauty of early stages of design, placing an emphasis on the change over time (fig. 3.8) (Desvigne, 2009).

Building frameworks, interplays and preconditions for the processes of nature also questions the meaning of human interventions and their technologies. Especially for this project, sustainable energy technologies function through natural processes, but are nonetheless human systems. Kees Lokman proposes a hybridisation between human and non-human systems to create dynamic relationships of ecosystem processes, called cyborg landscapes. The term cyborg is used to illustrate technology as an extension of natural processes, forming hybrids. Cyborg landscapes also develop as hybrids, meaning that these responsive landscapes cannot be fully controlled and are open-ended in its development (Lokman, 2017). Similar to cyborg landscapes, performative landscapes can keep performing and producing, even during change and development. They are machines not in their 'hard-cast' sense, but in productivity. 'Landscape machines' can have inputs and outputs, yet the natural processes are constantly affecting one another (Roncken et al., 2011).

Figure 3.9: Visualisation of the project 'Oyster tecture' by SCAPE, shown as an example of cyborg landscapes by Lokman (2017). Oysters settle in human-made frameworks

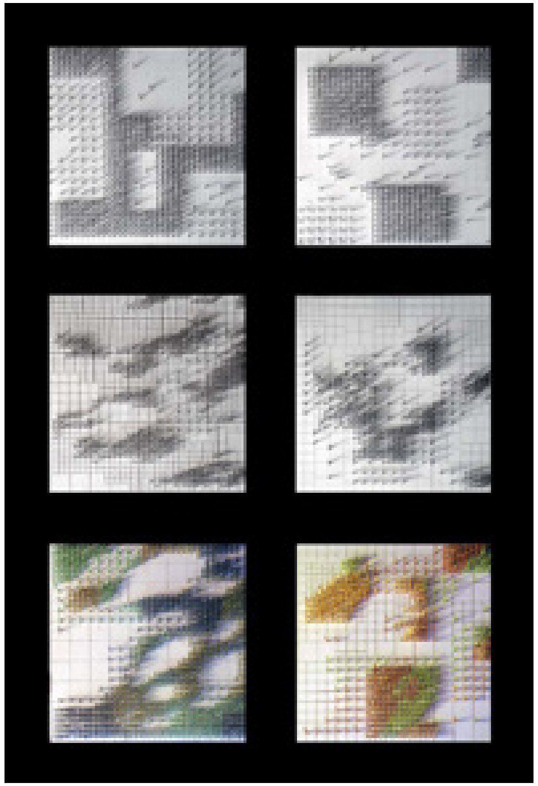


Figure 3.8: Model for the Walker Art Centre by Michel Desvigne. A grid of trees as a precondition will change its composition in the years after implementation

Technologies for sustainable energy production, like wind turbines and PV panels, are of course actual machines, fixed in place with its internal processes staying the same over time. However, different renewable energy technologies have very different characteristics that can be of use considering change in landscape. For example, an individual PV panel is easier to install than a single 3 MW wind turbine. The grain size is therefore important to consider when using sustainable energy technologies in ecosystem change. And even though the mechanics of renewable energy production itself is not necessarily directly available for 'hybrid' opportunities, the aspects of their implementation in the landscape can be. Sustainable energy technologies need to be fixed somewhere where they can make use of wind and sun. They need an infrastructure to transfer energy to substations. Al these aspects can be opportunities for sustainable energy technologies to situate themselves and function 'ecologically'.

The process-oriented and open-ended approaches of the landscape architects above are not solely technical in nature. In their processes and change lies a poetic beauty of observing change but can also possess a sense of sublime as it moves into the unknown (Roncken et al., 2011). At the same time, imagining its change and possible futures can instigate a sense of bewilderment (Corner, 1997). We prefer to have a combination of the known and the unknown, a sense of control and letting go. We prefer messy ecosystems in orderly frames (Nassauer, 1997). The way in which apply control to our design within ecosystems can therefore vary. A new ecosystem approach for landscape architecture synthesised from the above will be proposed.

An ecosystem approach for landscape architecture

Considering our journey from ecology to landscape architecture in terms of succession and ecosystem change, we can synthesize along the lines of this development outlining principles for analysis and design. Some key understandings have to be made clear on the approach on how to use these principles.

First, ecosystems are not separate from human systems; humans exist in them and depend on them for their existence. However, humans have unique and dominant impacts on ecosystems compared to other species. Second, Concepts like succession and knowledge of ecosystem change have emerged through the study of natural systems. Taking analogous approaches to these concepts, especially succession, for human intervention can lead to misinterpretation. Respecting ecology as a specific, independent science that is adopted but not necessarily adapted by landscape architects is important when trying to understand and work with ecosystems. Third, ecosystems have to be understood on a larger scale while acknowledging its unpredictability and complexity. Instrumental use of ecological measures are important as well, but have to be applied within the knowledge of ecosystem characteristics.

We identify three basic principles for understanding ecosystems for landscape design through analysis.

History matters for the abiotic foundations

The current ecosystem state has been defined by geologic and hydrologic processes in the past, creating unique conditions on which ecosystems develop (Pulliam & Johnson, 2000). Landscape history concerning geology and hydrology is an important factor in understanding how the most basic conditions have formed for ecosystems to develop and function.

Identify human systems by large landscape interventions over the past

Human interventions, especially in the Netherlands, have created not only impacted but mostly novel ecosystems by their interventions in the landscape. By identifying several time periods in which large landscape projects took place, we can identify more layers which formed the basics for the current ecosystem state. Large landscape projects also have effects on the experience and historical sense of people in these landscapes.

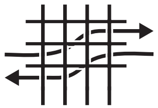
Analyse ecosystem conditions independently from human systems and identify its constraints

Ecological science should in its analysis not necessarily be adapted to holistic notions of human systems. For the analysis phase, knowledge is based on ecological concepts that landscape architects should use to understand the current ecosystem functioning, and by the application of those concepts on the site by ecologists.

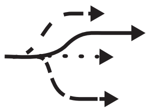
When an ecological understanding is reached of the context to design in, we can synthesize the principles of ecosystem change and landscape architecture approaches into eight design principles for designing with sustainable energy technologies.

1. ***Human agency:*** Humans in ecosystems are both agents and participators in ecological processes. The designer can both shape the conditions for natural processes to occur, with the outcome of those natural processes being part of the design as well. Designers should limit the idea of control on the system but allow for monitoring of the response of natural systems and allow for adaptations later in the process. Let technology and human-made constructions and natural processes undergo hybrid interactions, and regard urbanisation not as a disturbing force in ecosystems, but rather as a process of the holistic system that has to be incorporated within the change of systems over time.

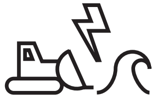
2. ***One system:*** Designers should not try to replace one system with another, or design new systems into existing ecosystems. Instead, designers should seek to thoroughly understand the existing holistic system and work within its processes and components rather than outside of them, paying attention to vulnerable flora and fauna and the processes that they depend on.



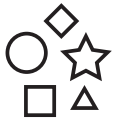
3. ***Frameworks***: Designers can change the context of ecosystems by redirecting flows. The goal should not be to change a self-organising system, but rather letting the intervention be changed by the system processes, and in turn affecting the ecosystem as a whole. By designing a ‘framework’, ‘scaffolding’ or ‘infrastructure’ for ecosystems to act on, this could be achieved. These frameworks can be directed to respond to certain flows but allows its development and outcomes to be uncertain. These frameworks can also act as disturbances, opening the site for new development and allow different pathways of succession. To achieve a significant effect within the system, these frames can be implemented in a modular fashion. The frame can act as creating a precondition for development but can also be a part of continuous involvement along ecosystem development.



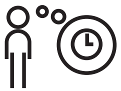
4. ***Indeterminacy:*** Just like non-human ecological systems, there are multiple stable states in which an ecosystem can exist. There is no correct state. Design with an acknowledgement of unpredictability, complexity and open-endedness in ecosystems. Since pathways for sustainable development of energy systems are unclear as well; adapt according to ecosystem responses and related goals. For energy systems to integrate with ecosystems, maximizing efficiency or output is not so much the goal, but rather adaptability and hybridisation of the system over time. Consider the cycles through which ecosystems change, with every cycle being a bit different than the last one, provided by the base of the previous one.



5. Disturbances: Disturbances are a natural part of ecosystems, so designers should not only acknowledge them, but also try to anticipate or even create them purposely. Disturbances can vary in scale, timeframe and origin. There are several ways in which to ‘open the site’ for new succession pathways to occur. Designers should be aware of causes, mechanisms and pathways in the context of their site in order to work in the context of succession.



6. Diversify: Designers should embrace complexity and expect unexpected feedback loops and system responses to interventions. Working with constants and variables and diversifying interventions, designers can increase the diversity of the system responses, learn from them and adapt them to their needs. Diversification is also important in considering ecosystem patches, habitats, and general biodiversity in living systems.



7. Experience time and change in the ecosystem: Designers should not only approach design as engineering, but as landscape architects mediating the relationship between people and their environment. Make change, development and time a factor to be experienced by people, and allow them to both understand, but also imagine possibilities. This also goes for an understanding of human agency in the landscape. Challenge the views of what is ‘natural’ and anthropogenic, providing messy ecosystems in orderly frames.

8. Design in the Anthropocene: Consider the complexity and necessity challenges of today. Landscape architects must take responsibility in mitigating climate change, while protecting and increasing biodiversity. Species conservation is an important goal considering the global decline of plant and animal species. Designing along ecosystem change is not a goal in itself, but more of a method to reach an ecosystem change that benefits humans, flora and fauna alike.

④ Analysis

A history of the IJselmeer, Markermeer & IJmeer region

At the end of the Pleistocene era an ice age ended, causing glaciers covering the northern halve of the Netherlands to retreat. Large, irregular sandy moraines like the Utrechtse Heuvelrug are left that stretch from Rhenen until ‘t Gooi and Muiden. These moraines are present today, but around the IJmeer, this Pleistocene layer can still be found under the waterbed increasing in depth towards the north-east. In the interglacial period thereafter, around 5500 B.C., sea levels rised causing the area that is currently the IJsselmeer to become a large lagoon in which the rivers IJssel and Overijsselse Vecht enter the sea. The IJssel and Overijsselse Vecht carry too little sediment causing the sea erode the soil away into a large salt marsh lagoon. The rise of the sea level however slows down in the millennia thereafter, and in around 1500 B.C. a dune ridge has formed around the trajectory of the current Dutch coastline. This dune ridge protects the lagoon and the rivers take longer to reach the sea, turning the lagoon from a saltwater landscape into a freshwater landscape. Behind the dune ridges, large peat landscapes emerge and in the slightly increased depth of the lagoon, two large peat lakes form. The northern lake is situated around the current IJsselmeer, the southern lake around the current Markermeer/IJmeer. The IJmeer funnels into a river discharging this peat lake, probably following an old sea inlet. This river reaches the sea around 500 B.C. and is nowadays known as the IJ, the water body to the north of the centre of Amsterdam. Around the year 800 A.D. however, the two lakes merge and come under increasing influence of the sea. The sea breaches into the lakes from the north and turns the system from freshwater into saltwater. The area turns into a sea inlet becomes a tidal zone, which is subsequently called the Zuiderzee. The discharge along the IJ slows down and the river becomes an extension of the sea inlet from the north but does not reach the sea near IJmuiden anymore. The influence of the sea into the Zuiderzee grows in the centuries thereafter, flooding the area with fine sediment and clay. Waves, tides and especially large winds cause the water to break down the weak peat banks of the sea inlet to erode. The inabitants of the areas surrounding the Zuiderzee wage a constant battle against these forces by building dikes. Storms, especially storms with a northwestern wind direction, made the situation increasingly dangerous for those living there. In the 20th century, the situation is deemed too dangerous and the sea inlet is closed off by a dam, the Afsluitdijk. The installation of this dam removes the influence from the sea and the lakes become a freshwater system again (fig.4.1) (Palmboom, 2011; Vos et al., 2018; Lenselink & Menke, 1995).

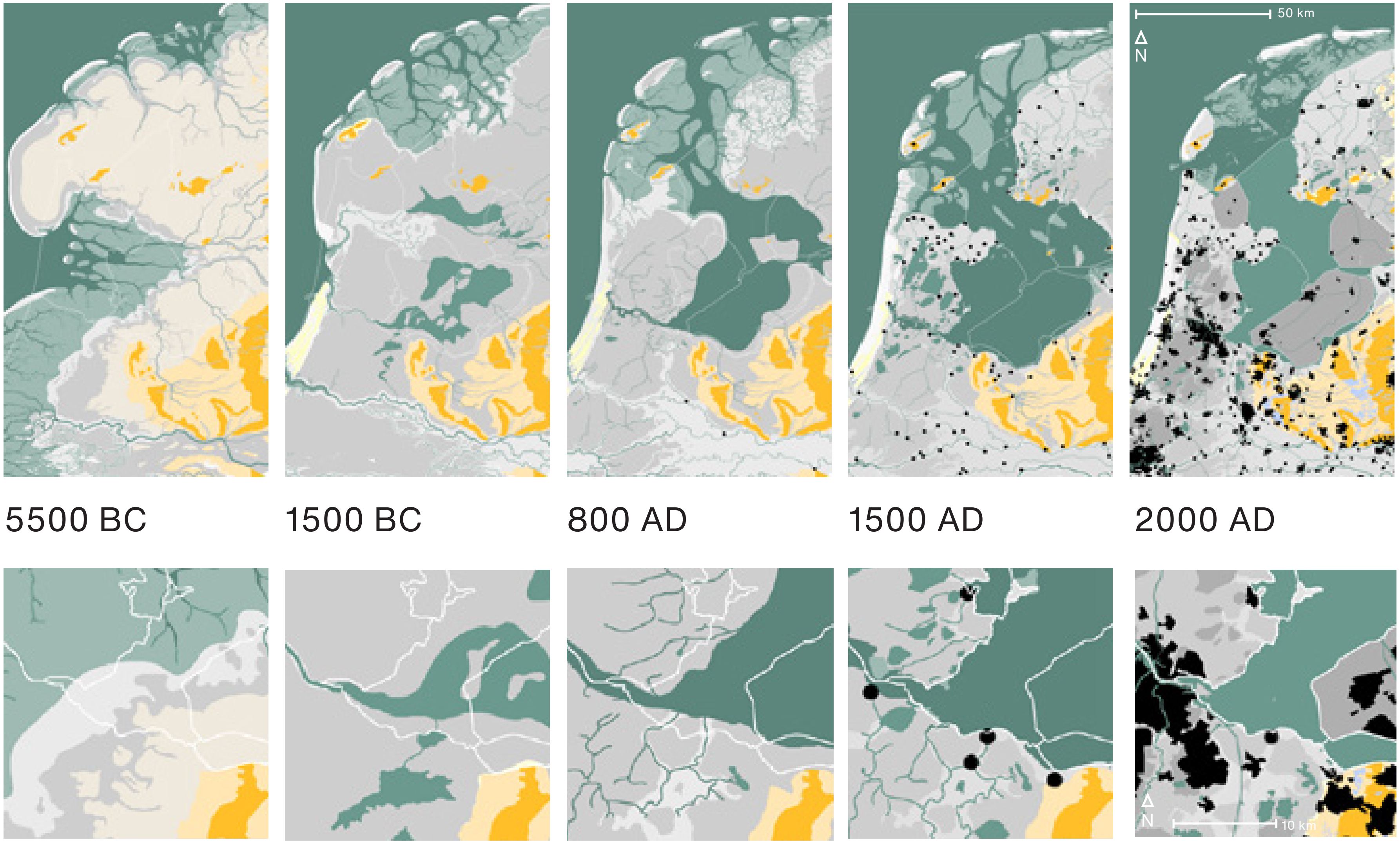


Figure 4.1 Paleogeographical development of the northwestern Netherlands, as well as details on the IJmeer.

Human influence of large landscape projects around the IJmeer

The geological and hydrological processes shaping the IJmeer have rapidly been replaced by human influence. This does not only concern the IJmeer itself, but also what goes on behind its banks. The IJmeer is an interface of water showcasing how humans have adapted the landscape to their needs over time through large landscape projects, which have come to define the Netherlands as a country. This is not only meant in a physical way, but also in shaping the nation state (Meyer & Bouma, 2016). The IJmeer has in that way been of influence to those living around it, and has subsequently been impacted by the Dutch as well. It is recommended that this part is read while having appendix A on hand to relate the writing to places in the IJmeer.

Figure 4.2: Polder IJdoorn in Waterland. The old polder is a protrusion into the IJlake relative to the coastline

Figure 4.3: The fortress island Pampus lies dead centre in the IJmeer, functioning as panopticon

The heritage of the landscapes of the middle ages can very well be observed along the IJmeer coast of Waterland, the rural area north of Amsterdam. This peat landscape has over the course of centuries been turned into an agricultural area by drainage and the creation of polders, the draining of waterbodies turning it into soil for agriculture, most of which created in the 17th century (Leenaers et al., 2010). These polders are often former peat lakes or broad discharge rivers. This has resulted in a very flat and open landscape. Some of these polders and some lakes can be found just behind the Waterlandse Zeedijk, de dike adjacent to the IJmeer. These lakes often emerged after dike breaches, which eroded large waterbodies just behind the dike. The eight-hundred-year-old dike had to be subsequently be fixed by building it up around these waterbodies, resulting in a winding dike trajectory over the course of centuries (fig. 4.2) (van Reijn, 2016). This means that the coastline of the IJmeer at Waterland has many recesses and protrusions, causing the relation to the water to consist of several bays and quays. The area is a popular recreational destination and features cycling and hiking paths along the dike and is dotted by typical linear settlements along the dike, such as Durgerdam.

The dike was a defence line against floods, but there are also sifinifcant military defences to be found in and around the IJmeer. At the end of the 19th century, the Netherlands believed itself to be under an increased threat of war. The need for protection of the capital leads the government to decide on the construction of the Stelling van Amsterdam (Defence line of Amsterdam). This defence-line consisted of a ring of strategically placed fortifications and inundation polders around Amsterdam; the polders could be flooded to withhold a possible invasion. One of these polders near the IJmeer is the Noordpolder east of the fortification town of Muiden. Other land fortresses can be found near Diemen and on Vuurtoreneiland along the Waterland coast. However, Amsterdam was still vulnerable for a naval attack from the Zuiderzee, especially since certain warships could cross shallow waters. This instigated the construction of the artificial fortress island at the Pampus, nowadays simply called Pampus. This island, dead centre in the IJmeer, contained to high end artillery turrets with a reach of twelve kilometers and was state of the art for its time (Speet, 2010). The Stelling has however never been used to fend off enemies and was quickly deemed absolete due to technological advancements in warfare. The Stelling van Amsterdam is now UNESCO world heritage. The elongated circular shaped island of Pampus still exists and is a tourist attraction and event location, with ferry services departing from IJburg, Muiden and Almere. Being on Pampus one can experience the intention of the placement of the island as a 'panopticon', overseeing the IJmeer (fig. 4.3).

Both the Waterlandse Zeedijk and the Stelling van Amsterdam were deemed insufficient to withstand incoming threats at the beginning of the 20th century. The Netherlands were safe from war due its position of neutrality, but it was not safe from floods. It was decided that the Zuiderzee would be closed off and would be divided up into several polders. A major dam, the Afsluitdijk was constructed at the northern part of the sea inlet that removed the influence of the sea on the Zuiderzee, slowly turning it into a freshwater lake. In the decades after that, several polders were constructed to fulfil the need for agricultural land. Subsequently the Noordoostpolder in the fourties, the Oostelijke Flevopolder in the fifties and sixties and the Zuidelijke Flevopolder in the sixties and seventies. The latter bounds of the IJmeer on the eastern side. During this time, the residual water was divided by the construction of the Houtribdijk, a new dam separating the lake into the northern IJsselmeer and the southern Markermeer. The Flevopolders were constructed in a modernist and utilitarian layout, with grid structures for agriculture and urban development. The polders are bound of by dikes according to this grid structure, generously rounded in the corners. The Flevopolders are defined in experience by far reaching views in the agricultural area along tree lanes and planted forests, large agricultural plots and experimental housing types. In the southern part of the Zuidelijke Flevopolder, a new city was to be constructed: Almere (Hemel, 1994).

Figure 4.4: The Flevopolder at muiderhoek as seen from the Dijk, consisting of a strict grid and large plot sizes

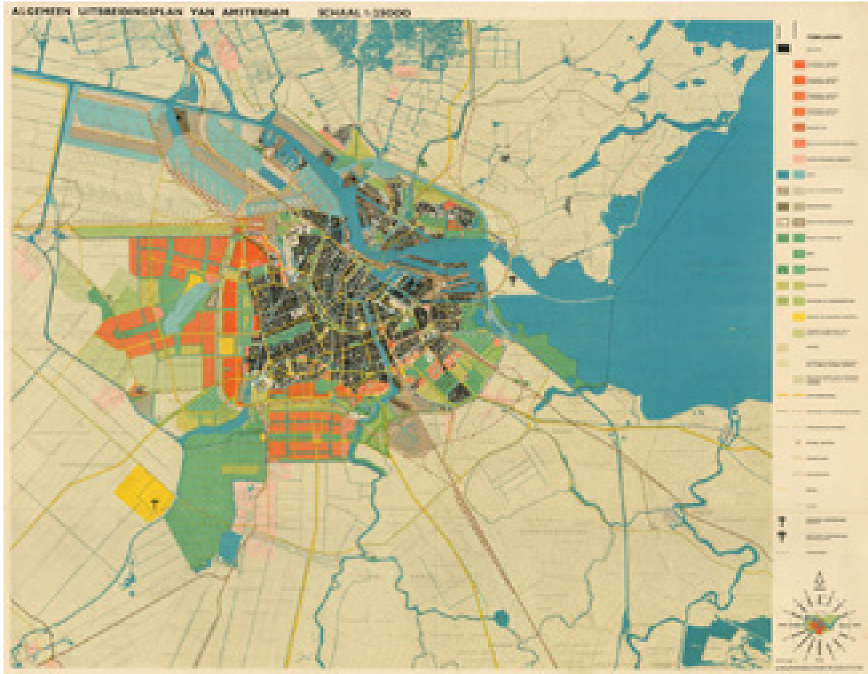


Figure 4.5: The expansion plan of Amsterdam (AUP) of 1934 by van Eesteren, predetermining the green 'wedges' of Amsterdam

Almere was intended to be a suburb of Amsterdam, which had significantly grown during that century. A fairly large impact on the expansion of Amsterdam was defined by the AUP (Algemeen UitbreidingsPlan; general expansion plan) in the 1934 by Cornelis van Eesteren. This plan did not only lay the foundations for the directional expansion of Amsterdam, but indirectly also for the areas to be spared of development (fig. 4.5). The green wedges of Amsterdam as they would later be called made sure that inhabitants had access to nature within 15 minutes of their house (de Hoog, 2005; Feddes, 2012). Around the IJmeer, Waterland and the landscape north of Diemen are examples of these wedges. However, some deem the IJmeer a hidden 'blue' wedge as well (Parlement van de Scheggen, 2019). The IJmeer nowadays is a popular area for water recreation (fig. 4.6). A notable urban expansion in the midst of these wedges is IJburg. The construction of this neighbourhood started in the nineties in by creating an artificial island. The character of IJburg is based on the scales of a 17th century city by the water, following a grid structure and slight variations in density. The character of the inner-city echoes in the grain size and the canals permeating the island, and features a long straight waterfront (de Hoog, 2005; Feddes, 2012).

The post war expansions of Amsterdam and the emergence of Almere increased was also paired with an increase in large infrastructures. The water rich conditions has always played a large role in the infrastructure of the city; it allowed enormous economic growth in the 17th century with ships of the Dutch East Indies Company reaching the city through the Zuiderzee, where they had to traverse the ‘Pampus’, the shallow part where the IJmeer funnels into Amsterdam. In the centuries thereafter however, this route was a large detour for ships. In the 19th century the Noordzeekanaal (North Sea Canal) was constructed to connect Amsterdam with the North Sea in the west. At the ‘funnel’ of the nowadays IJmeer, shipping locks were constructed to regulate the water level in the canal (the Oranjesluizen) (Feddes, 2012). These locks maintain to this day and cause the water in the Amsterdam city centre to be called the ‘Binnen-IJ’ (Inside-IJ) and the IJmeer the ‘Buiten-IJ’ (Outside-IJ). In the IJmeer a dam was constructed to prevent the entrance of the lock filling with sludge that covers the bottom of the shallow IJmeer. Sludge in the canals, harbours and sewage treatment are a general problem nowadays as it has to be dredged to keep them navigable, but there is little room to store the occasionally polluted sludge. The Zeeburgereiland has had the latter function over the course of the last century. The port activities of Amsterdam were moved to the western side of the city along the North Sea Canal, and inland shipping transport goods and fuel across the Amsterdam-Rijn Canal to the east and south of the Netherlands, but also to the north and east across the IJmeer. Large shipping lanes were dug in the shallow Markermeer and IJmeer towards the locks nearby Lelystad, and a slightly shallower lane towards the Randmeren to the Southwest. The shipping lane appears to be in constant use and can be seen as a large linear element above the water level by the string of ships waiting to enter the locks or exiting them (fig.4.6,4.7). Transport on land has mostly converged in the area just south of Diemen and Muiden, with busy highways and railways dominating the landscape here (fig. 4.8). These infrastructures connect to the east and the south of the Netherlands, but also the North through Almere, crossing the Markermeer at the Hollandsebrug. the latter connection being too long to consider Almere as a true suburb of Amsterdam due to its distance. The last type of infrastructure in the landscape is that of energy; the gas-powered powerplant at Diemen provides both electricity and heat , and its adjacent substation is the spider in the web of high-voltage power lines that can be observed across and along the IJmeer (fig. 4.9).

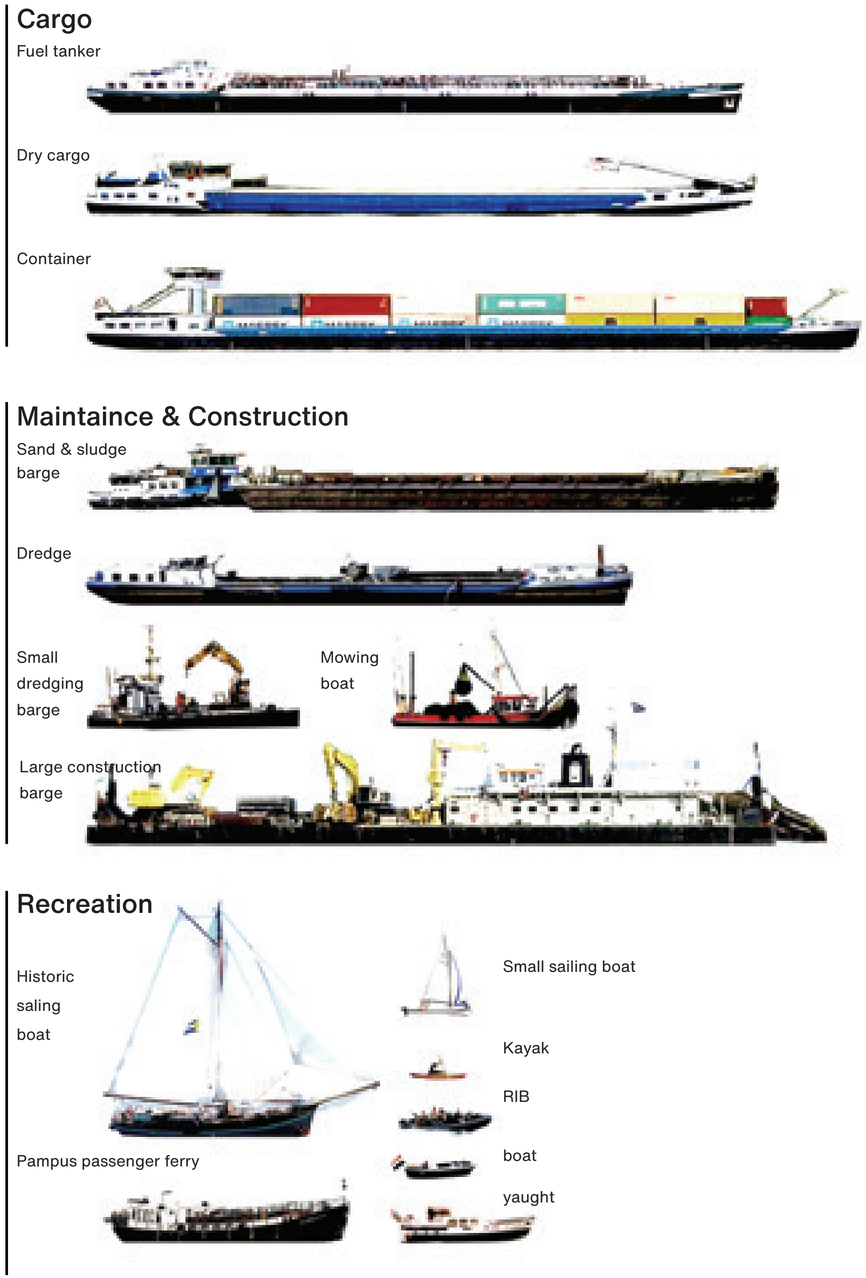


Figure 4.6: Different kinds of vessels that occupy the IJmeer

Figure 4.7: Shipping routes in the IJmeer

Figure 4.8: Converg-ing large infrastructures along an old polder

Figure 4.9: Diemen power plant seen from the IJmeer

Increasing anthropogenic influence along and in the IJmeer has led to pressure on the flora and fauna on the IJmeer and Markermeer. Especially for birds, the area for foraging and resting decreased. Several artificial islands have been constructed to ‘compensate’ loss of ecological value in the area. In some cases, it was the result of a residual product of construction, such as clay and sludge which became available with the construction of the power plant in the seventies. This material was deposited just on the other side of the dike and subsequently dammed off, creating the ‘Diemer Vijfhoek’ or PEN-island (fig.4.10). Other human designed islands focus on reducing the monotony of the large, open waters of the IJmeer and create sheltered zones, such as the series of islands to the north of Muiderberg that have been constructed by armour rock dams. These islands, can in its sheltered zones become partly filled with a shallow slope of sand, providing opportunities for waterbirds to nest and rest undisturbed (Bak et al., 2008). A major artificial island project is currently in construction in the northern part of the Markermeer, named the Marker Wadden. This project is a combination of creating a sheltered zone with a dam while creating artificial islands by filling constructed rings of sand with sludge. Variations in soil type and inclines to the water are made to diversify the habitats. Its development in relation to succession is closely monitored (IJff et al., 2018).

Figure 4.10: The coast of the IJmeer at the Diemer Vijfhoek

Figure 4.11: Isometric view of Plan Pampus by Broek en Bakema, 1965

We can see that over centuries, large landscape projects have increased in size and impacts, together increasing the complexity of the IJmeer. Speculation of large landscape projects can offer new insights and leave a significant mark on the development of areas, even when those plans were never completed. The construction of a fourth large polder in the Markermeer, the Markerwaard, has been present in almost every plan for the Markermeer area in the 20th century, but was never built due to the projected effects of flora and fauna and the general feasibility of the project (fig.4.12). In the beginning of the 21st century it was decided to cancel the plan altogether (Nota Ruimte, 2004). The IJmeer would not become a polder in these plans but was already speculated upon for urban expansions of Amsterdam in the sixties, with a significant contribution by architecture firm Broek en Bakema. This 'Pampusplan' included a series of islands to stretch eastward from Amsterdam, folding around the fortress and connected by a rail infrastructure (fig.4.11). The plan was a sign of the times for ideas of modernism and social democracy during that time, and still speaks to many today (van den Heuvel, 2018). Another one of this type of plans that keep reappearing is Plan Lievense. The engineer Luc Lievense proposed to turn the Markermeer into a giant reservoir lake with a ring dike, dotted with wind turbines. The reservoir would act as an energy storage system by pumping water in and out. It has not been deemed feasible due to environmental problems and safety risks, but has often made a return to the drawing board in these times of energy transitions (Das, 1999).

Figure 4.12: Detail of a plan for the Markerwaard from the 80's

But the pressure on building in the IJmeer has not yet come to a standstill. Amsterdam is currently busy building the second phase of the IJburg project, with new islands such as Middeneiland, Strandeiland and Buiteneiland. These islands are to be completed within the next decade. In a longer timeframe, Almere is also rapidly expanding according to the framework embedded in the grid of the Flevopolder into the reserved areas. These expansions are directed towards the western corner of Muiderhoek as well, with speculations on outer-dike expansions of the Polder (Koolhaas & Marcusse, 2006). These plans are often accompanied by connecting Amsterdam and Almere through a new metro line either across of underneath the IJmeer. Together with the urban expansions of both cities, this metro line can be the link between a new urban axis. However, these infrastructural projects require high investments against a lot of uncertainty (van Hierden, 2014). Moreso, the current connection from Amsterdam to Almere functions for the time being, but current pressure on housing occasionally puts this connection back on the drawing board.

The large landscape projects described above can be allocated to certain areas in and around the IJmeer. The dikes and polders of Waterland, the new polders of Flevoland, the expansion of Amsterdam at the bay, the historic surroundings of Muiden, the military defence at Pampus, and the IJmeer itself being dotted and intertwined through busy infrastructural networks and nature compensation measures. Then there is also the imagined landscape of future developments, but also plans that never came to be (fig. 4.13).

To get a more detailed overview of the characteristics of the entire IJmeer, consult appendix A (fig.4.14).

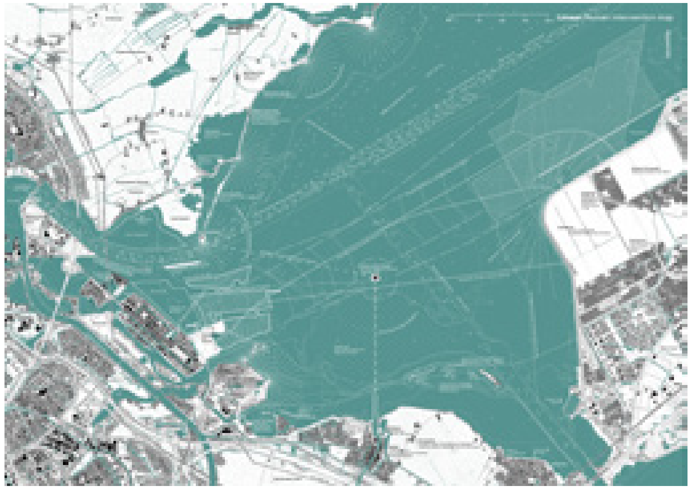


Figure 4.14: Miniature of Appendix A

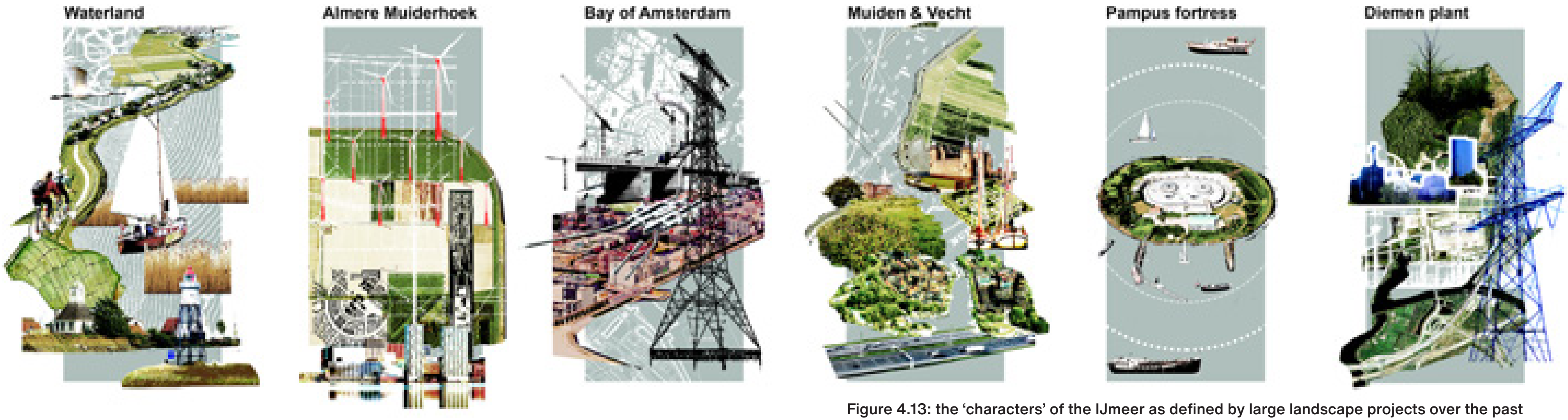


Figure 4.13: the ‘characters’ of the IJmeer as defined by large landscape projects over the past

An ecosystem analysis

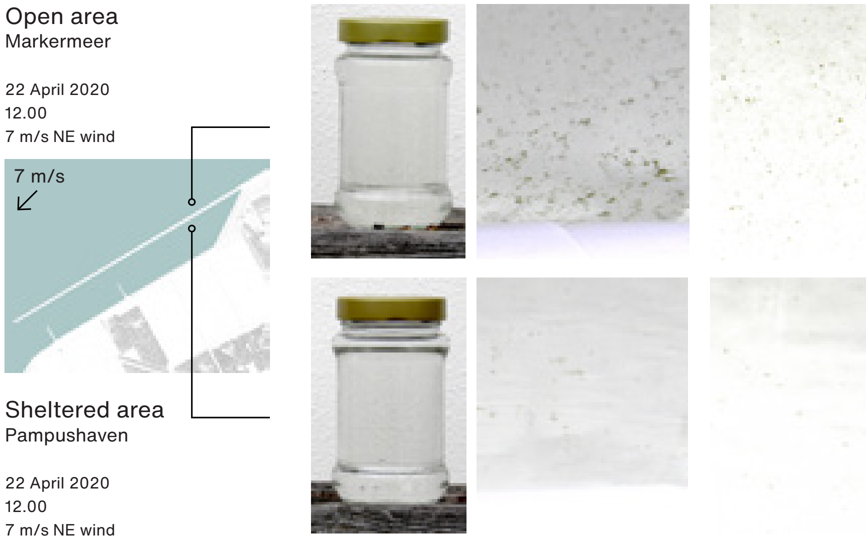
Anthropogenic influences have been a major factor in determining the current ecosystem state of the IJmeer. Some effects on the ecosystems by human intervention were expected and planned for, others not (fig.4.15). The novel ecosystem that has been created has been affected both in its context and components in complex ways. To understand the non-human ecosystem of the IJmeer, reports on ecosystem states will be used to create a comprehensive idea of its problems, limitations and vulnerabilities. To understand situation in an ecological context and use this knowledge for design, this ecosystem analysis is structured along the ecological concepts and questions designers should ask themselves by Pulliam & Johnson (2002). It is recommended that this chapter is read while having appendix B on hand.

To get a concise image of the ecosystem complexity, and in an attempt not to get lost in the distinction between processes and components, this analysis will be guided by the position in the system of a keystone species. This will be the Dreissena polymorpha (Zebra mussel; in Dutch: Driekhoeksmossel). By using the ecological concepts in relation to this species, we will not only get an idea of several ecosystem conditions but also their connectiveness. The Dreissena polymorpha is a non-native freshwater mussel that is originally from eastern Europe. Although the species causes many problems in other countries, the Dreissena polymorpha is an important species for the IJmeer and Markermeer. A keystone species can be defined as a crucial species in the functioning of the ecosystems, and a reduced presence can mean an indicator for poor biodiversity in the system overall (Pulliam & Johnson, 2002). The Dreissena polymorpha can be found on the waterbed on sturdy substrates and feed on phytoplankton. These mussels are especially good in filtering the organic matter attached to fine suspended sediments out of water, decreasing the cloudiness of the water (Penning et al., 2013). This is beneficial for water plants as they can receive sunlight, and for water fauna that are able to see and feed on zooplankton and other fish. The Dreissena polymorpha itself is also an important food source for certain birds. This shows both the processes the mussels takes care of that are crucial for other flora and fauna, as well as its place in the hierarchy of the ecosystem. Dreissena polymorpha affect both the hierarchy level above and below in the ecosystem (van Herpen et al., 2015).

However, the population in the Markermeer and IJmeer is in a poor state, especially compared to the IJsselmeer. This has to do with several abiotic flows that were present in the Zuiderzee but are not present

Figure 4.15: Birds foraging among the breakwater near Muiden

Figure 4.16: A sample was taken on a field trip to illustrate the differences in suspended sediment



anymore in the current ecosystem. The fine sediment, or sludge, on the bottom of the IJmeer is a remnant of the sediment that has moved in and out of the sea when it still had an open connection during the time of the Zuiderzee. Similar ecosystems can still be observed in the Schelde where tides still play a major role. The fine sediment cannot not move in and out of the system anymore, only within the system. The shallow waterbed of the IJmeer consists of a sludge with a large amount of clay, meaning more fine sediment, below. The lake also has with its three to four meters little variation in its quite shallow depth. The wind has a major effect on these conditions. When even slow winds force waves on the water surface, the shallow depth causes turbulence on the waterbed. This turbulence easily suspends the light, fine particles of the sludge, carrying it up into the water. This causes the water to be extremely volatile, murky and cloudy. When winds die down, the fine sediment is partly sinking to the bottom again, covering any animal or plant trying to grow. Even though cloudy waters can be a habitat with positive effects on biodiversity as well, the monotony of this factor throughout the entire Markermeer and IJmeer have caused it to be a limitation for more diverse community (van Riel et al., 2019). Only in the shipping lanes and the Pampusputten, a former sand excavation area, fine sediment can settle for a longer time due to the depth of these locations. The sides of these deeper zones slowly erode in, causing the need for shipping lanes to be dredged from time to time (Kelderman et al., 2012) (fig. 4.17). Submerged flora could be able to cause a feedback loop by slowing down the turbulence in the water (Penning, 2012), but are limited in their presence due to the volatile conditions of the waterbed and limited transparency of the water. Water plants can rarely be found in the more open areas, but they are present in the IJmeer at more sheltered zones due to its comparatively limited size and the proximity to rugged coasts which reduce the turbulence (fig 4.16). In turn, these water plants mitigate the turbulence further to an extent, causing the water to clear. Significant species here include Characeae (stoneworts; in Dutch: kranswier) and Potagometon (pondweeds; in Dutch: fonteinkruid) (fig. 4.18). These waterplants are sometimes so widely present that they have to be mowed to not be a nuisance for water-based recreation. These coastlines with many water plants are also good spawning areas for fish and more favourable locations for the Dreissena polymorpha to settle compared to more open water. However, their gradients are still quite steep, the waterbed still consists of clay and sludge and offer little variation in habitats (Lammens et al., 2007).

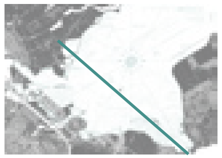
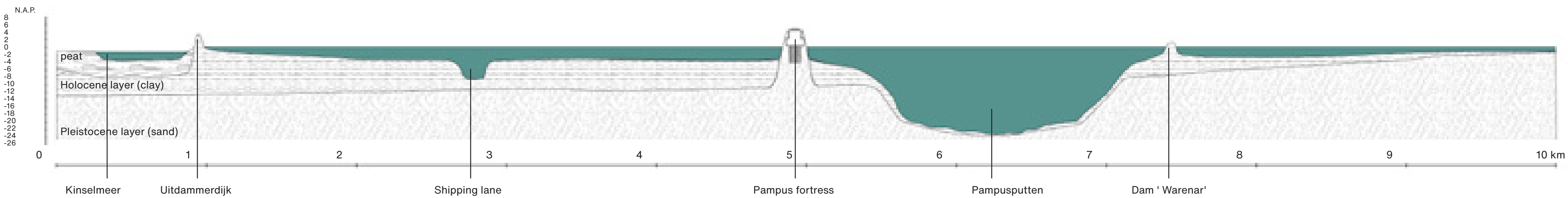


Figure 4.17: profile of the IJmeer riverbed and its sediment types underneath its waterbed



Characeae
Stonewort
Kranswier

Potamogeton perfoliatus
Claspingleaf pondweed
Doorgroeid fonteinkruid

Sterna hirundo
Common tern
Visdief

Phalacrocorax carbo
Cormorant
Aalscholver

Mergellus albellus
Smew
Nonnetje

Aythya ferina
Common pochard
Tafeleend

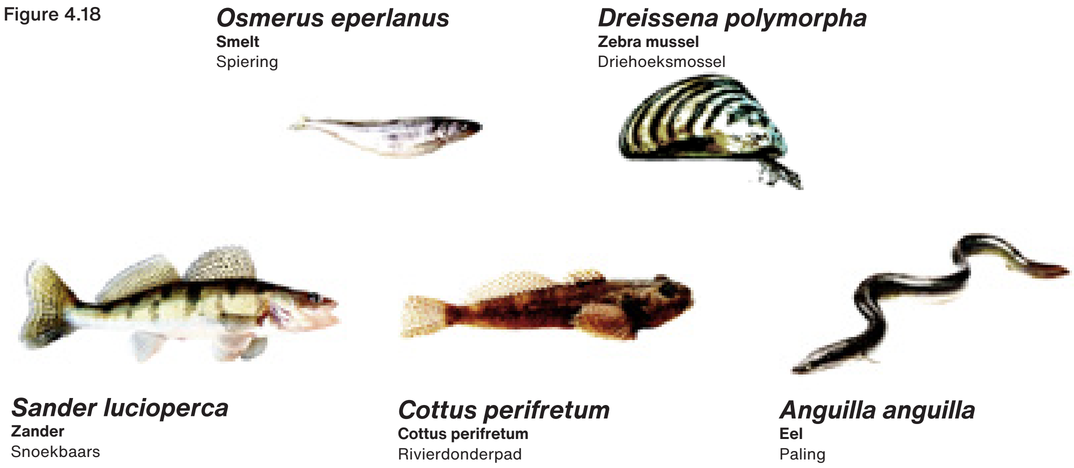
Figure 4.18: Several plant, bird and fish species of the IJmeer. Some of these species populations are however under pressure in various ways.

The Dreissena polymorpha also endures limitations in its presence because of the turbulence and the volatile sediment in the more open areas. The species has a limited ability to use the sludgy waterbed as a substrate, and has trouble surviving when this substrate is moved, or when the species is covered by the sinking fine sediment. The limited permeability of sunlight caused lower quality and amount of the phytoplankton community, which has its effect further up to food chain. The mussel population is smaller, and the individual mussels are smaller in size as compared to the IJsselmeer (Noordhuis, 2014).

The wind that causes turbulence and the presence of suspended fine sediment in the lakes can also be seen as a disturbance, especially since the wind direction varies in strength and direction. The dominant wind direction in the Netherlands is a south-western wind, which cause the amount of the suspended sediment and sediment in total to be higher in the north-eastern part of the Markermeer near the Houtribdijk rather than in the IJmeer. Disturbances and often unpredictable events can occur when strong winds occur from other directions; a storm from the north west can in a short time funnel a lot of suspended sludge towards the IJmeer. Another thing that can occur during strong winds is that not only the sediment, but the water in general is pushed into a certain direction of the IJmeer. This can cause the water level to 'tilt', with the low end of the tilted water level situated in the part of the lake where the strong winds come from. The dominant wind direction causes the IJmeer to often be 10-20 centimetres higher in the north-east than the south-west. This difference can reach up to a meter during storms. The water level also changes slightly over summer and winter. The water level during summer is proposed to be increased to safeguard freshwater availability during dryer periods (Meijer et al., 2009).

Even though many species can be found below the water level in the Markermeer, the end of the food chain is mostly present just above it. The Markermeer and IJmeer is a very important area for migrating birds and birds that stay in the area during the winter, as it is a large sourcing area for food. We can distinguish three different types of birds: fish eaters, benthos (mussel) eaters and plant eaters. Benthos eaters are the diving ducks that use the Dreissena polymorpha as a food source. Examples are the Aythya fuligula (tufted duck; in Dutch: kuifeend) or the Aythya farina (common pochard; in Dutch: tafeleend). These animals are often found closed to the coasts where there are more mussels. Many birds also look for mussels between the armour rock of dams. Notable fish eaters are the Sterna hirundo (common tern; in Dutch: visdief) and the Phalacrocorax carbo (cormorant; in Dutch: aalscholv-

Figure 4.18



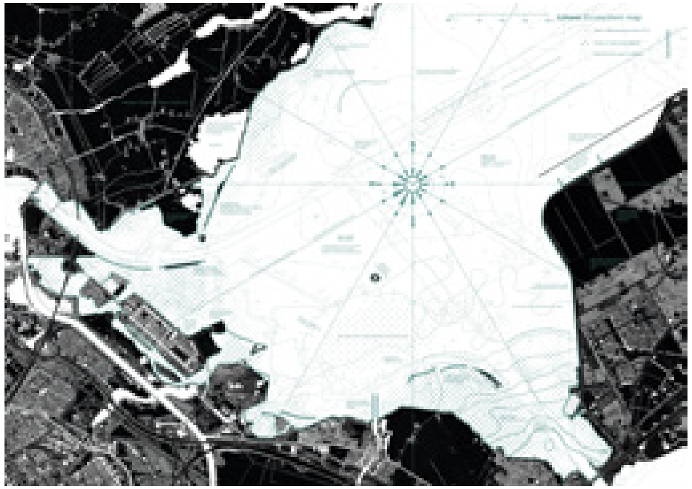


Figure 4.19: Miniature of Appendix B

er). Fish in the IJmeer range from Osmerus eperlanus, mostly in deep waters (smelt; in Dutch: spiering), Sander lucioperca (zander; in Dutch: snoekbaars) and Anguilla Anguilla (eel; in Dutch: paling) (fig. 4.18). Although birds use the IJmeer and Markermeer as a foraging area, they nest and rest in surrounding areas like Waterland, the Vecht area and Oostvaardersplassen. This shows that the IJmeer is an open system and is not only bounded by water. Its connectivity to these other areas could however be improved (de Molenaar, 2005). The canals and water bodies in Waterland offer shelter for many of these birds.

Even though the area is a designated Natura 2000 birds directive; the populations of the birds have been dwindling since the eighties and is barely reaching its targets for indicator species population (Mouissie, 2017). Anthropogenic influences like eutrophication, fishing for smelt, and the large presence of boats have both decreased the food supply of birds and are disturbing their foraging grounds as well. Not only the activities, but also large construction projects like IJburg limit the habitat area of species. More indirect processes like climate change will have an effect as well, such as decreasing the food source for water birds, increasing eutrophication and blooming of harmful bacteria and changing the disturbance regime with higher temperatures (Mooij et al., 2005). Attempts to make the Markermeer/IJmeer more suitable for birds without addressing the food source has resulted into an unwanted feedback loop. Gulls nesting on the Hoeckelingsdam prey on eggs of protected meadow birds in the polders of Waterland (Haaijen in Meershoek, 2016). The hard coastlines of the IJmeer offer very little variation and gradients for different species. General connectivity to other nature areas is also poor due to the missing of gradual transitions from water to land (van Herpen et al., 2015; Zwart, 2008). In general, the IJmeer is in a relatively better ecological quality than the rest of the Markermeer, but this quality is still not optimal in terms of providing habitats for birds and aquatic life already under pressure from anthropogenic activity. The whole water system is very monotone in its conditions and undergoes little change throughout the seasons. Its current state is dominated by the constant turbulence of fine sediment that constantly swirls around in the shallow lake (van Riel et al., 2019). In the next chapter, measures and technologies will be explored to provide more, more diverse and better habitats and living conditions for the species living in and around the IJmeer; along with exploring some energy technologies that can be used in combination with these measures.

To get a more detailed overview of the ecosystem characteristics of the entire IJmeer, consult appendix B.

⑤

Technologies

Before a design context for sustainable energy systems and ecosystem change is proposed, several technologies, structures and other measures to improve on ecosystem quality in the Markermeer need to be explored. By literature analysis, analysing existing projects and pilot projects an overview will be created of useful measures that can be taken, possibly in combination, to improve the ecosystem quality and provide sustainable energy solutions. Linking these measures with the research objective and design principles will provide an onset of the design processes, by assessing these measures in its usefulness as 'design ingredients'. These 'ingredients' are similar to the engineering approach common in ecological design, as previously mentioned in the theoretical framework, but will be combined into hybrid elements in the next chapters.

Figure 5.1: Different stages of a hydrosere, from open waters to marsh vegetation to swamp forest.

Biodiversity and habitat variety

The current situation of the IJmeer is limited in its capability to radically change its ecosystem state through succession. A usual successive process that occurs in stagnant, shallow freshwater lakes is that of a hydrosere. A hydrosere (in Dutch: verlanding) is the process of open water turning into marsh and subsequently into a swamp (fig. 5.1). This happens along the shores, along which a hydrosere moves toward the open water, and succession moves toward the land. This gradient offers a large variety of habitats. Submerged vegetation, floating vegetation, reeds and woody vegetation is the general pathway. Sedimentation of sludge can also be the cause of a hydrosere, or accelerate the process. The size and openness of the IJmeer, its hard banks and its monotony in its waterbed sediments including the dynamic fine sediment are the causes of this process not happening (de Molenaar, 2005). There are however anthropogenic interventions that can be done to create more diverse areas both in open water, as well as opening the site for succession to occur. These measures can also be focused on addressing the root cause, the dynamic sludge in the lake. They can also combine these measures solving multiple problems.

In the open water, variation can be created in the turbulence of the water and its transparency. Placing armour rock breakwaters on sand bases in the open water creates sheltered zones just behind it opposite to the side where the wind comes from (fig. 5.2). Breakwaters shelter these areas from the winds, waves and undercurrents that more open areas are susceptible to. Breakwaters can also function in this sense as wave breakers when placed near coastlines. The larger the unobstructed open water, the more the wind can pick up speed, the more waves it can push upward and forward. Strategically placed breakwaters allow the winds and the dynamics of the sediment to be impacted by a lesser extent as they obstruct the wind and waves from picking up. In the sheltered zones, the water is less turbulent, there are less waves and the suspended sediment has time to settle on the waterbed for longer times. In these sheltered zones, the light can penetrate the water to a further extent, benefitting phytoplankton and macroflora, as well as zooplankton and fish which can in turn feed on these and find their way. The breakwaters themselves also provide positive effects on habitat variety, as benthos like mussels can use them as substrate to grow on, as well as birds using them for resting places or lookouts (Lammens et al., 2007; Bak et al., 2008; van Herpen et al., 2015). Some breakwaters, like the strekdam near the Oranjesluizen, are partly designed to keep sludge out of the shipping lanes. Other breakwaters, such as the dam to the west of Muiden is put down for ecological purposes.

Breakwaters can be added upon by turning them into linear islands by dumping sand in its sheltered area. These islands, such as the Hoeckelingsdam near Durgerdam, includes a shallow gradient over which a small hydrosere can take place. The bare sand allows succession on the soil above the water level as well, as pioneer species can move in and many birds, such as terns, make used of these areas for nesting and resting (van Herpen et al., 2015). Sand is used because it is a very stable material. It also covers the sludge on the waterbed below, which makes sure the sludge can move. Most sand is dug out from soil layers below the waterbed, being remnants of the Pleistocene era moraines. This layer is closer to the waterbed near the Hollandse brug (around 4 meters deep) than to the north-west (13 meters deep). Extracting the sand requires digging through the clay and sludge layer just below the waterbed, which can be troublesome as there is little practical use for the sludge and space to deposit it. The sludge cannot be used as a foundation layer as it is too volatile and too weak to hold the weight above it. Sand has a lot of value as construction sand for urban development, but sand extraction has no use and place to deposit sludge as a rest product. In island construction for building, sludge often must be partially dug out first to provide stability for a sand layer on which construction can happen. Ways to efficiently use both sand and sludge was employed at the building of the Marker Wadden (fig. 5.3). By building rings of sand to stabilise the islands, the filling can be done with sludge. The Marker Wadden has the setup of one large dam protecting a more varied open area with different sediment types and variation in its slopes and water depth. This causes a large diversity of habitats and its development is currently closely monitored (van Riel et al., 2017).

Figure 5.2: Breakwater at the coast near Muiden

Figure 5.3: Aerial view of the Marker Wadden

The Marker Wadden is a pioneering project to improve the ecological quality of the Markermeer. There have been however other pilot studies and desk studies with this goal as well. One of these promising pilot projects is the 'Marker Kwelderwerken' project (fig. 5.4,5.5). This project initiated by Bureau Waardenburg was ran in 2013 and 2014 with two constructions placed alongside the coastline of Waterland. These two constructions consisted of vertical wicker dams made from willow branches secured in the waterbed, arranged in a grid of three by three with a grid size of around twenty meters. The grids, or in other words compartments, were filled with either sand or sludge in different amounts. There were multiple goals to this intervention. Considering the root causes of the dynamic sludge presence, the grid was designed to store sludge and allow the dynamic, suspended sludge in the water to be able to settle. The sludge layer would then grow as it 'caught' suspended sludge, making the water in the grids shallow. The other goal was to provide a casco for ecological processes to occur, such as succession through a hydrosere, and to provide habitat for flora and fauna both above and below the water. Each grid had variations in its sediment filling and were sometimes planted to prevent erosion. The pilot study was a success as it reached both goals. Sludge was 'caught' by the wicker constructions, especially in the grids filled with sludge as an increase of the sludge layer was observed. The area proved to show processes of succession and a higher number of plants and animals were observed as compared to the reference area (Wielakker et al., 2014). This project addressed multiple problems and was for a part self-sufficient in reaching its goals. In addition, it developed and changed over time, making it rather fitting to the afore mentioned design principles. Both measures above, the breakwaters and wicker grid structures, being placed near coastlines can also be beneficial in creating shallow gradients at these coasts in general. Creating 'foreshores' is another popular recommendation found in most studies to improve ecological quality of the lake and can also help as a buffer zone for floor protection (Penning et al., 2016). Foreshores provide more varied habitats and can function as a connective zone to nature areas on the coasts. Another possibility for a connective zone is constructing fish passages between waters such as the IJ, IJsselmeer and to canals in the polders behind the dike (de Molenaar, 2005; van Herpen et al., 2015).

Figure 5.4: The pilot setup of the 'Marker Kwelderwerken'

Figure 5.5: The 'Marker Kwelderwerken' as seen in a sateliite image

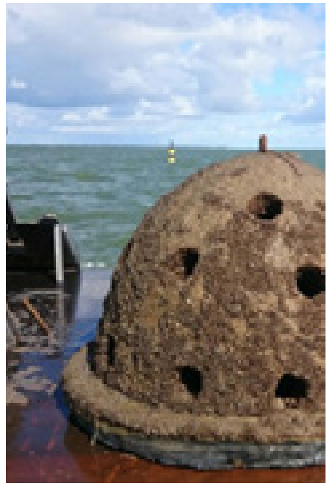


Figure 5.6: Eco-concrete 'reef balls' retrieved from the Markermeer

Other measures can focus more on interventions on the waterbed in more open areas. Sudden depressions in the waterbed, like shipping lanes and sand excavation areas, have shown to both slowly erode on the sides. Sludge that because of turbulence 'rolls' across the waterbed sinks permanently and settles in these deeper zones. Research is currently being done about what the best shape, location and depth is for purposely designed pits in the waterbed by making models and observing existing deeper zones. Their added ecological effect can be that these deeper zones are also cooler during summer and benefit fish like smelt in their spawning capabilities. Combined measures are also researched by modelling the effects of pits between breakwaters with the intention to direct suspended fine sediment into these pits (van Kessel et al., 2009; Vijverberg et al., 2011; van Herpen et al., 2015). However, the volatile nature of suspended fine sediment can cause the behaviour of the sediment to be different in the actual Markermeer-IJmeer.

Another measure that can be taken at the level of the waterbed is to provide variation in substrates for a variety of species. Another pilot study by Bureau Waardenburg involves dropping rough concrete elements onto the waterbed (fig 5.6). The intended purpose is for these elements to act as artificial reefs for mussels and benthos to use the elements as substrates. The perforations also allow other animals to use them as hiding spaces, and for other animals to seek food. This type of concrete elements has also been used at sea and as flood defences, called 'eco-concrete' (Bak et al., 2014; Knoben, 2014; van Herpen et al., 2015). This measure can provide more diversity and greater species populations.

Many measures that can be taken on the IJmeer to improve its quality are not technical in nature but can be achieved by regulation. Fishing, cargo shipping and recreational crafts can disturb certain areas limiting the habitat size for many species. However, spatial measures can also be taken to limit these negative effects on ecological quality. By limiting the influence of large ships on the areas outside of fairways and directing most recreational traffic along certain routes at lower speeds, animal species do not have to endure negative effects of these activities (Groot et al., 2011).

Energy

The IJmeer is situated in the middle of the metropolitan area of Amsterdam and Almere. Urban areas are large, mostly fossil-based energy consumers, but have ambitious plans to reduce energy use and switch to more sustainable energy sources, aiming to be ‘climate neutral’ by 2050 (Gemeente Amsterdam, 2019). High pressure on available land inside these urban zones makes their availability for sustainable energy technologies such as photovoltaic panels (PV) and wind turbines very limited. We have however seen that the IJmeer as an area outside the city is an ecosystem already under pressure. Sustainable energy technologies must be identified that both make optimal use of these conditions as well as mitigate the negative effects on flora and fauna. Proportionality to the ecosystem and the ability to provide a gradual system change as discussed in the theoretical framework are important factors to consider in sustainable energy technology.

In that sense, wind turbines are relatively inflexible in their placing and movement and can have a negative influence on birds. Wind turbines have been in use along the coast lines of the IJmeer to catch accelerated and unobstructed winds but are limited in their amount partly due to the reasons above related to the Natura 2000 status (fig. 5.7) (Winkelman et al., 2008). Solar panels on the other hand are highly flexible in their placement, have a smaller individual grain size and can be implemented in much more diverse ways as opposed to wind turbines. Surface water provides large areas for solar panel coverage and provide several benefits for its power output.

First, solar panels can catch both direct sunlight and indirect sunlight. The highly reflective water surface can add a lot of extra indirect light to the surface of the panels, resulting in an overall higher power output. Double-sided, also called ‘bifacial’ solar panels can even receive a large amount of solar radiation on the backside by reflective water surfaces, especially when those panels have some transparent space between the PV cells. Second, solar panels receive indirect cooling from surface water. High air temperatures on sunny days however can limit the power output of solar panels if they heat up too much. Passive cooling by surface water can decrease the temperature on panels on hot summer days (Cazzaniga at al., 2018; Sahu et al., 2016). Solar panels on water can either be fixed by poles in the waterbed or rely on floating structures (fig. 5.8,5.9) (Trapani & Redón Santafé, 2013).

Figure 5.7: former wind turbine park Jaap Rodenburg at Muiderhoek near Almere

Figure 5.8: Pilot study with floating bifacial PV systems in the IJ in Amsterdam

Figure 5.9: Fixed bifacial PV array above surface water in the US

Solar panel orientation is often highly utilitarian and are placed by their optimal orientation of being oriented southward under a 30-degree angle in the Netherlands, or in the case of roofs, as close to this as possible. When placed in series, there should be enough space for the solar panels not to block the panels behind it, and to allow maintenance to reach the panels. However, solar fields with the orientation as mentioned above have a single peak output at midday when fixed. Solar arrays can also consist of bifacial panels in a vertical position with the panels facing both east and west (fig. 5.10). This array has two peaks in power output during the day, one in the morning and one in the evening. Combining arrays in this sense can provide a better distributed power output throughout the day and the bifacial solar panel output can spread the output further in the mornings and evenings (fig. 5.11).

In terms of their effect on flora and fauna, fixed arrays can often block the sun reaching the ground, or in this case, the water. On the ground, this means that many plants depending on direct sunlight have trouble growing (Boogaard et al., 2019). In the water, it means that phytoplankton and water plants have trouble growing, as well as fauna being unable to see. However, in case of preventing eutrophication, preventing algae growth can also be beneficial (Boogaard et al., 2019; Sahu et al., 2016; van der Zee et al., 2019). These effects are all limited when using a vertical bifacial array. Although darker areas in water are also necessary for habitat diversity, too many dark areas can have a negative effect. A negative effect on birds could be the 'lake effect' of large 'unbroken' fields of solar that birds can mistake for a water body (fig. 5.12). Diving water birds could in that case smash to their death (Visser et al., 2019). Definitive evidence for this effect is still fairly limited and more research is needed for PV panels placed on actual water bodies and for the situation in the Netherlands. A possible mitigation for this effect could be more distance in the bands between rows of PV panels (Grippo et al., 2015). Other negative effects are that large coverages of solar panels on the water surface generally reduce the foraging area for birds altogether (fig. 5.13).

Figure 5.10: East-west facing vertical bifacial PV array along agricultural use

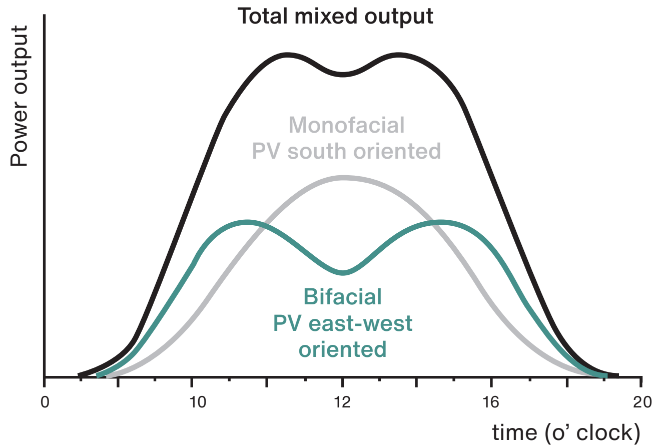


Figure 5.11: Better distribution of power output during the day with a combination of a south facing PV array and a vertical bifacial array.

Figure 5.12: A birdsview perspective of the 'lake effect' on a PV farm in the USA

Instead of fixed arrays, certain arrays can also move according to the position of the sun. An example of these technology are solar trackers, which consist of a large PV surface that is fixed on a single turning point that can move both horizontally and vertically (fig. 5.14). The single turning point is mounted on a solid foundation, which can be in the ground or in the waterbed. The positive effect is that the panels have a longer peak output and are more constant in their output throughout the day. Moreso, the area that is obscured behind the panels changes throughout the day as the panels turn, allowing sunlight to reach these areas. On water, solar tracking can also occur in a single direction by fixing the panels on buoyant structures and letting those buoyant structures turn through a winch system. However, to make efficient use of the buoyant structures in terms of panel coverage, even when these are not moving, the array has to be very dense. Large and dense buoyant solar fields obscure large area of water and ecologists are concerned about the effect of underwater flora and fauna.

Figure 5.13: Floating PV array based on a modular plastic system which is relatively easy to implement, but possible negative ecological effects

Figure 5.14: Example of a dual axis solar tracker

The dual study of measures to improve ecological quality and measures to provide sustainable energy production provides an overview of different components to combine. These components already indicate some overlap in order to provide hybrid structures that can do both. In the next series of chapters of design, a modular approach to these structures will be taken in defining guidelines for sustainable energy generation in the pressured ecosystem of the IJmeer. The modules will contain a factor of transition, enduring a change in its transition over time. The next chapter will provide an overview of how to deal with expected and unexpected processes that occur inside and outside of these modules. In the next chapter the involvement of humans and the role of self-organizing processes will also be addressed in the way the modules can change individually and in groups. The application of the modules and their transitions will be put into the spatial context of the IJmeer in both a regional approach, identifying certain areas where these modules will be placed. These subareas will be explored further as to find out what their specific attributes are in local conditions and characteristics, but also keeping in mind future developments which can be linked with the characteristics of the modular transitions.

PART II:

KNOWLEDGE THROUGH DESIGN

⑥

Module

To provide an energy transition through design, a modular approach will be used combining PV and ecological technologies and structures of the previous chapter. A measure for improvement of ecological quality will be used as a base for sustainable energy technology and vice versa to create hybrid structures. A modular approach allows possibilities for a transition by being able to adapt certain variables in the module, as well as being adaptive in its application on the site. Two different standardised constructions with adaptive internal characteristics will be presented in this chapter. These modules will be the frameworks through which system process and change can occur, which will be discussed in the next chapter.

Wicker dam grids

The first module is based on fixed photovoltaic panels and the technology of the Marker Kwelderwerken, the wicker dam grids discussed in the previous chapter. The basic principle here is that the wicker dams provide foundations and fixtures for the solar panels to be mounted on. In other words, large vertical foundations in the waterbed rise above the water and provide the attachment base of the solar panel, but also provide a wicker structure between them below the water surface, which add to its stability as well. These are the basic principles which can vary along multiple parameters, to allow a different system response (fig. 6.1,6.3).

First, the wicker between the foundations is made from flexible willow branches (fig. 6.2). These branches can be partly regionally sourced from knotted willows present in the Vecht area or the polders of Waterland. The module grid is a square set up with a grid size of 15 to 20 meters. The first variation is in total square size, being either 40 by 40 meters, 100 by 100 meters or 150 by 150 meters. The module also varies in its orientation. The grid can be either laid out diagonally or horizontally and vertically in relation to the south (fig. 6.4). Lastly, the grid can vary in the density of the willow wicker. The willow wicker can be very thick and impermeable, or thinner and allowing small animals to pass through. These variations will likely affect the ability to slow down turbulence, accumulate suspended sludge and the location of that accumulation. The variation in wicker density can be a variation for habitats as well, as certain fauna can either pass through the wicker or not.

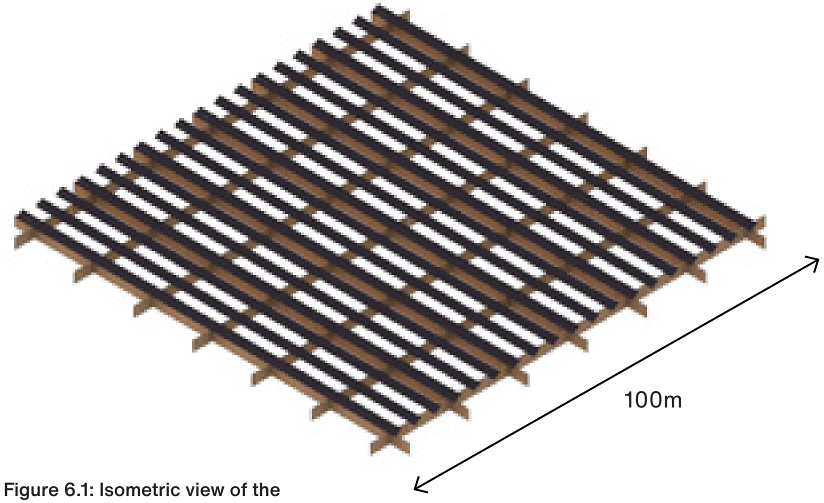


Figure 6.1: Isometric view of the wicker dam grid

Figure 6.2: Detail of a willow branch wicker

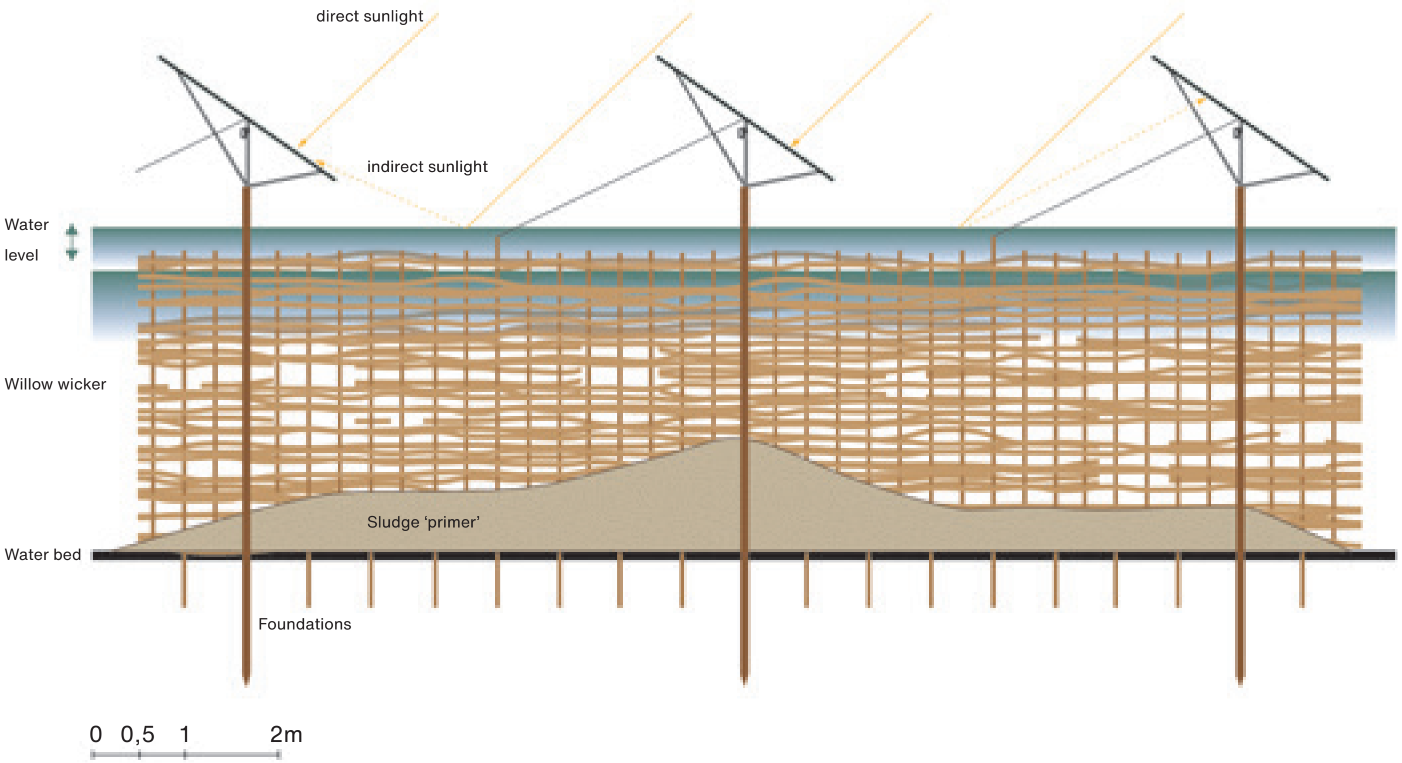


Figure 6.3: Detail of a section of the wicker grid module.

The second set of variation lies in its partial filling of sediment. This filling can consist of either sand or sludge and clay, or a mixture of the two. Sludge and clay are often undesirable residual after sand excavation, dredging shipping lanes, or preparing building ground for urban expansion into the water. The wicker grid module will make use of this 'waste' product. Therefore, sludge and clay will provide the main fill, also because of the need for valuable sand elsewhere. The sludge will provide a shallower water layer in which suspended sludge can possibly settle, accumulating and 'catching' more sludge over time. The filling of the grids can also differ in location on the grids, with an uneven fill more to the middle or the sides. To differentiate between the filling of the grids done by humans and the accumulation done by system processes, the purposeful preconditional filling done by humans will be called the 'primer' (fig. 6.3). Sludge can also be added later to top up the already present sludge, or can be mixed with sand to create more diverse areas. It should also be noted that a large amount of unwanted sludge around Amsterdam comes from polluted harbours and sewage treatment. This sludge cannot be used in open contact, or semi open contact with the water of the IJmeer due to its toxins.

The last set of variables lies in the use of mounted PV panels. PV panels can be mounted on the foundations in a modular fashion. This way they can be removed later, which will be further discussed in the next chapter. Two different types of PV arrays will be used. One is an east-west oriented row of south facing panels under a 30-degree angle. The other array type is a north-south oriented row of vertical bifacial panels. Different types of panels provide a better distributed power output, but also provided different shade patterns on the water surface having different ecological effects (fig. 6.5). The solar arrays can also vary in density, effecting the shade patterns on the water surface. The rows of solar panels are not completely optimalised in their density and are somewhat generous in the space between the rows. This is to allow some more light to reach the spaces in between and to prevent a 'lake effect' for water birds.

Finally, there is a constant in orientation of this module. Due to orientation of solar panels and their fixtures, each grid is oriented perpendicular on the south (fig. 6.4). This also allows them to be placed more efficiently in series. This produces a very rigid, technical geometric structure as a framework. However, the varying responses to ecological processes will cause each module to be different from one another. Messy ecosystems, orderly frames (Nassauer, 1995).

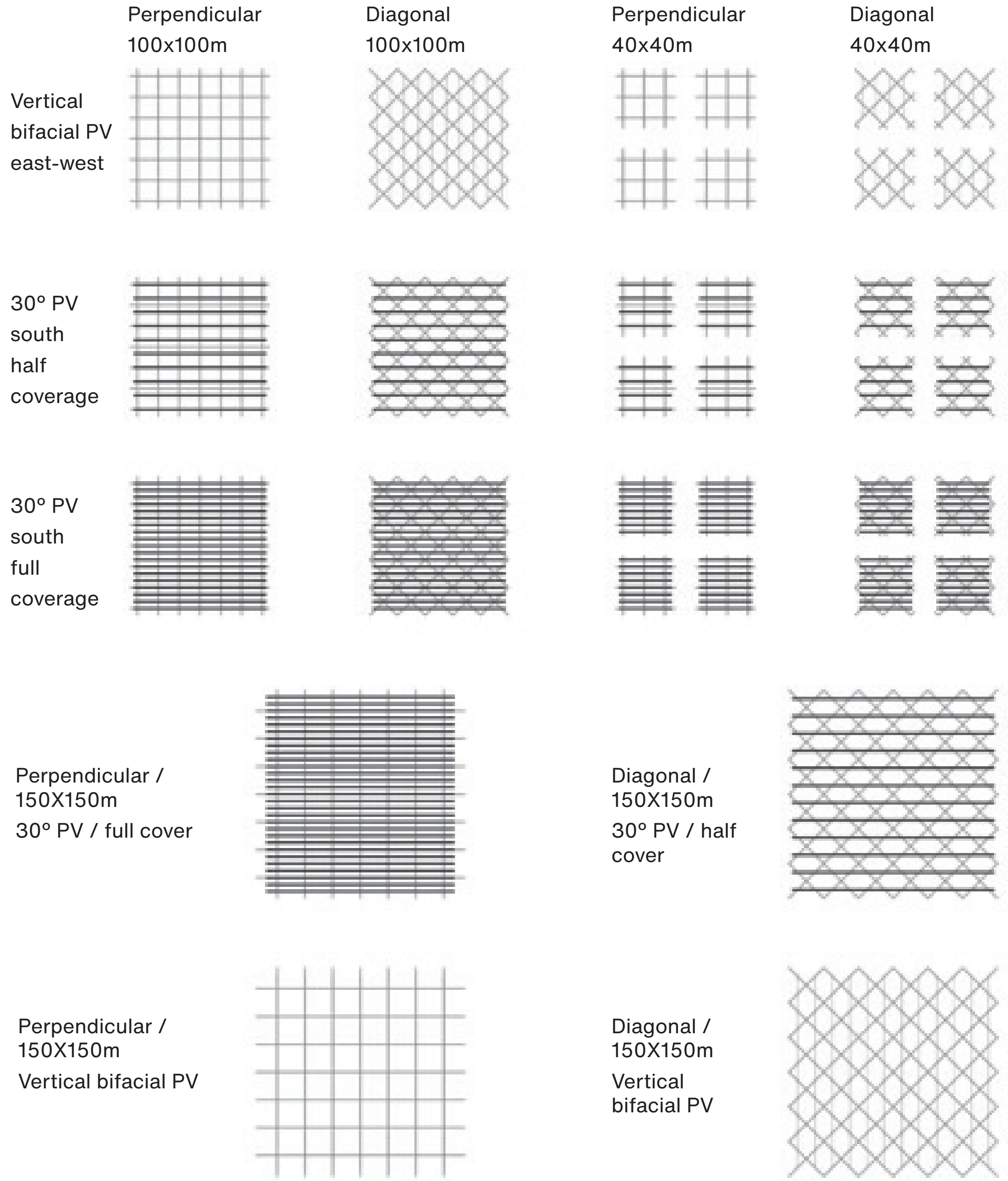


Figure 6.4: Different variables in wicker orientaiton, size and type of PV array

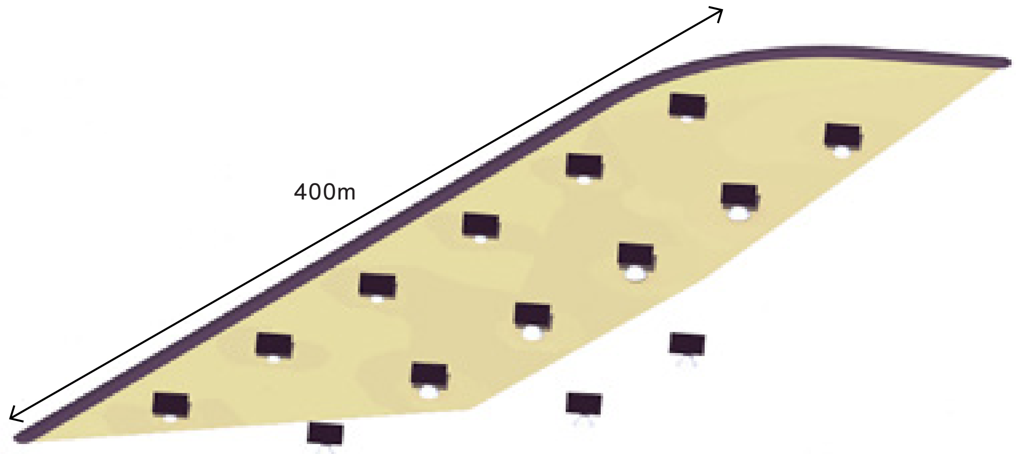


Figure 6.5: Isometric view of the breakwater module

Breakwater dams

The other module has more of a supporting role to the wicker module. This module is based on the implementation of armour rock breakwater dams combined with a sandy gradient, eco-concrete and the technology of solar trackers (fig. 6.5,6.9). The wicker dam grids cannot withstand large waves, nor can they be placed in waters that are too open and exposed. A linear breakwater will provide the necessary protection, as well provide a sheltered zone right after behind it. The dam also provides the energy infrastructure for the solar panels on the wicker modules to transmit energy to the mainland. The sheltered zone features a shallow gradient made from sand. In this gradient, solar trackers will be placed on an eco-concrete base, allowing the foundation to perform for biodiversity (fig. 6.8).

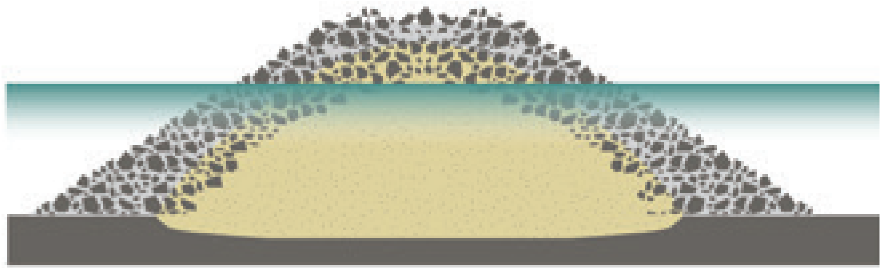


Figure 6.6: Section of the fixed centre part of the breakwater

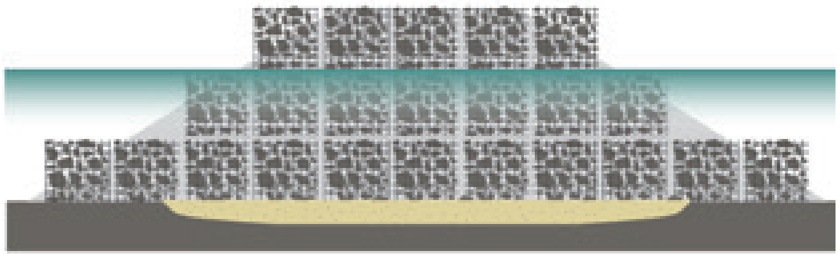


Figure 6.7: Section of the flexible outer parts of the module, consisting of gabions

One of the variables for this module are the length and orientation of the breakwaters. Different wind directions will allow suspended fine sediment to be carried around the breakwaters in different ways, causing differences in sedimentation of the suspended sludge. At the ends of the break-waters, pits in the waterbed can be dug to 'lead' the sludge there as well, allowing it to settle. The sediment that is dug out to create these pits can be used as building material for the core of the breakwaters (sand) or as the primer for the wicker dam grids (sludge).

Another variable is the slope of the sand gradient on the sheltered side of the breakwater. Different flora and fauna make use of different water zones, and a variation of the slope can create these differences. The sheltered zones also allow the wicker dam grids to be placed, being pro-tected by the breakwaters to a certain extent, but also having openings to allow suspended sediment to enter.

The other variable is differences of construction of the breakwater. In the middle, it is made with a fixed sand interior and armour rock exterior (fig. 6.6). This construction is very solid, providing strength but making it difficult to remove. The ends of the dams are therefore made from gabi-ons, or cages with armoured rocks. These gabions can be removed later, changing the context for the process-es impacting the dam (fig 6.7).

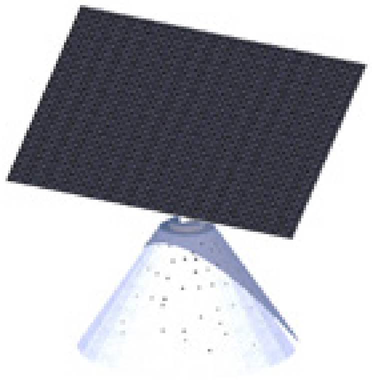


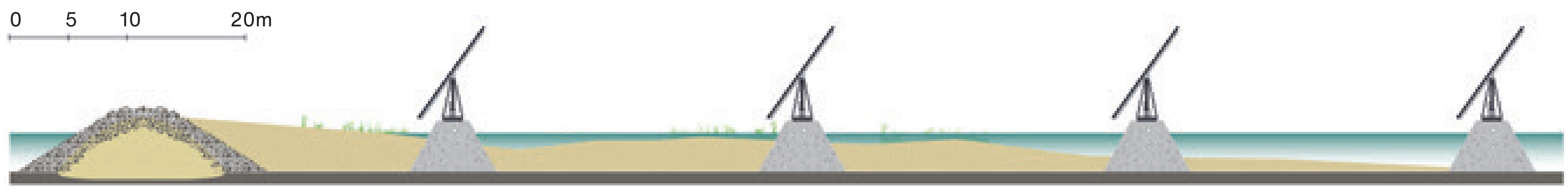
Figure 6.8: Isometric view of a solar tracker on an eco-concrete base

Both modules use the design principles of 'human agency' and 'frameworks' to provide a hybrid structure that is a precondition to its adaptation by self-organising ecosys-tem processes. The modules respond to the processes already present in the ecosystem, and hence use the design principle of 'one system'. Both modules, but especially the wicker module uses the principle of 'diversify' to create a set of variables within a basic modular idea. These variables allow for different responses of the 'disturbances' regime. By applying these principles to the basic set up of the modules themselves, several design guidelines can be extracted from these designs:

Module Guidelines

- ***The modules are frameworks for a multitude of processes.***
- ***Constants and variables within the modules are important. Let the basic principle remain the same but work with a multitude of variables to let processes play out differently.***
- ***Two modules can be combined to create mutually beneficial effects.***
- ***Module materials are preferably locally sourced, such as willow wicker and building sediment.***

Figure 6.9: Section of the breakwater in com-bination with the eco-concrete foundations of the solar along a sandy gradient



Transition

The modules above provide the framework for system processes to occur and change the modules over time. The modules create a precondition for system change to occur (fig. 6.10). Wicker grids slowly settle more sludge in their compartments over time, adding up in the grids depending on the variables of the module. At a certain point, the water can be so shallow that a hydrosere can occur, accelerated by water plants that can emerge. Where and when can depend on the variables of the wicker dam, effecting the causes and mechanics of the succession pathways. The catching of dredge depends on the size, orientation, density and primer. The growth of plants heavily depends on the water level, but also on the arrangement of the solar array since it can prevent light from reaching the watersurface turning into soil. Phased removal of the solar panel array can create diverse patterns in succession pathways. For example, when there the water in the grids is not too shallow, reeds can pop up, but when it is very shallow or when sludge is added to above the water level, pioneer species like Tephroseris palustris can appear (swamp ragwort; in Dutch: moerasandijvie). Other species that will soon appear are willows, as the propagules of these species are carried in large amounts by wind. Willows grow fast and cause certain parts of the solar array having to be removed

Figure 6.10: stages of development of the wicker module. As sedimentation and hydrosere processes take over, PV panels are phased out and partially moved to a newly constructed module

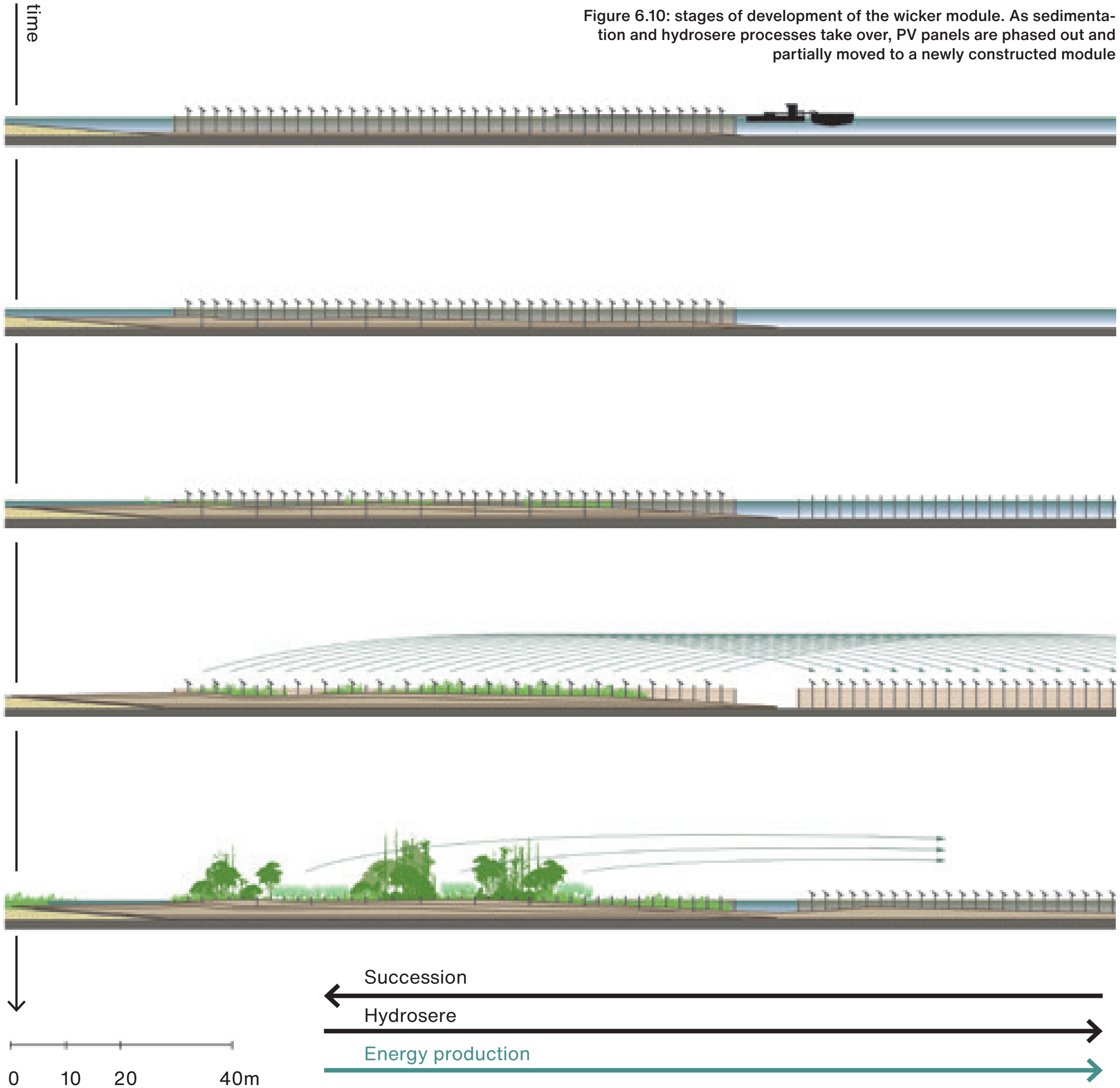
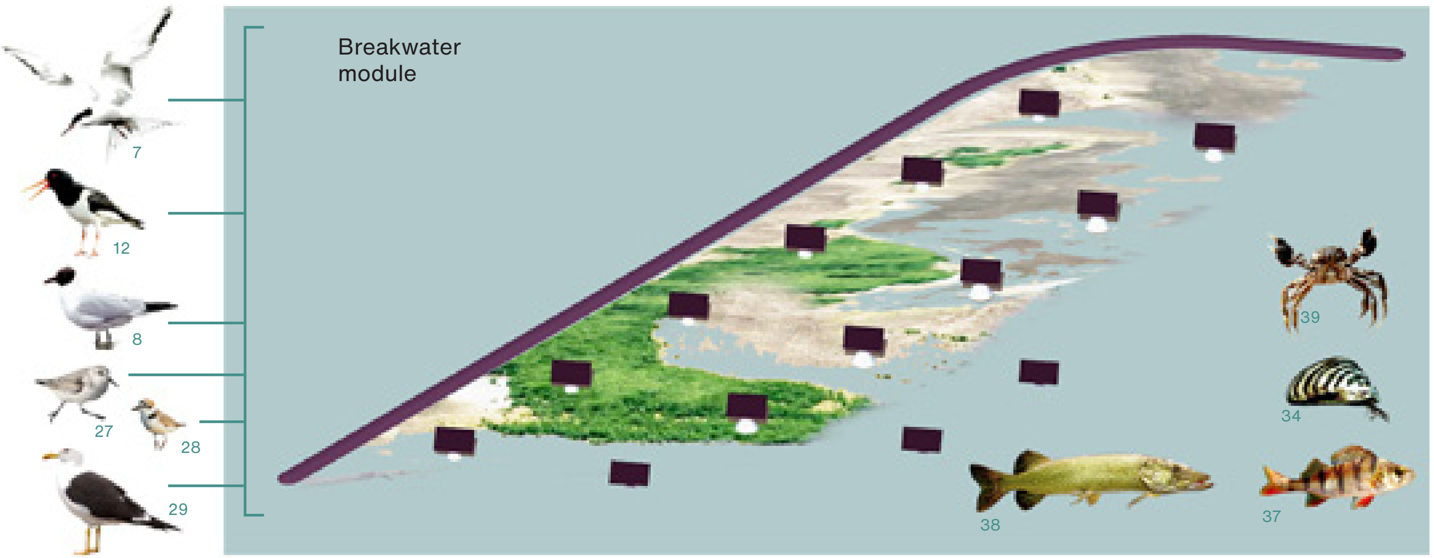


Figure 6.11: Different bird species and their habitats in different stages of the module. Because new modules are constantly when a hydrosere takes over, all habitats are continuously present (Svensson, 2005)

1. Mergus merganser
2. Aythya fuligula
3. Aythya marila
4. Aythya ferina
5. Mergellus albellus
6. Phalacrocorax carbo
7. Sterna hirundo
8. Chroicocephalus ridibundus
9. Limosa limosa
10. Charadrius dubius
11. Recurvirostra avosetta
12. Haematopus ostralegus
13. Tringa nebularia
14. Charadrius hiaticula
15. Platalea leucorodia
16. Ardea alba
17. Rallus aquaticus
18. Botaurus stellaris
19. Pandion haliaetus
20. Luscinia svecica
21. Acrocephalus schoenobaenus
22. Phylloscopus trochilus
23. Panurus biarmicus
24. Acrocephalus arundinaceus
25. Haliaeetus albicilla
26. Dendrocopos major
27. Calidris alba
28. Charadrius alexandrinus
29. Larus fuscus
30. Cobitis taenia
31. Cottus perifretum
32. Osmerus eperlanus
33. Anguilla anguilla)
34. Dreissena polymorpha
35. Abramis brama
36. Sander lucioperca
37. Perca fluviatilis
38. Esox lucius
39. Eriocheir sinensis



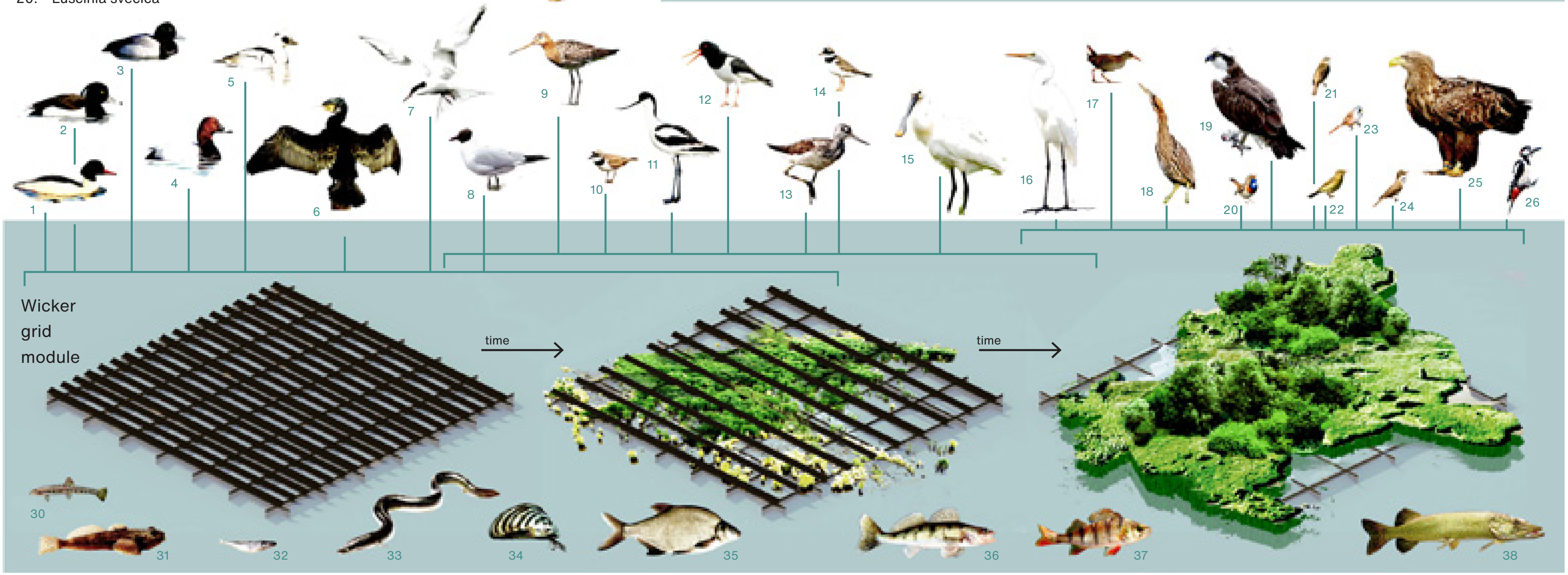
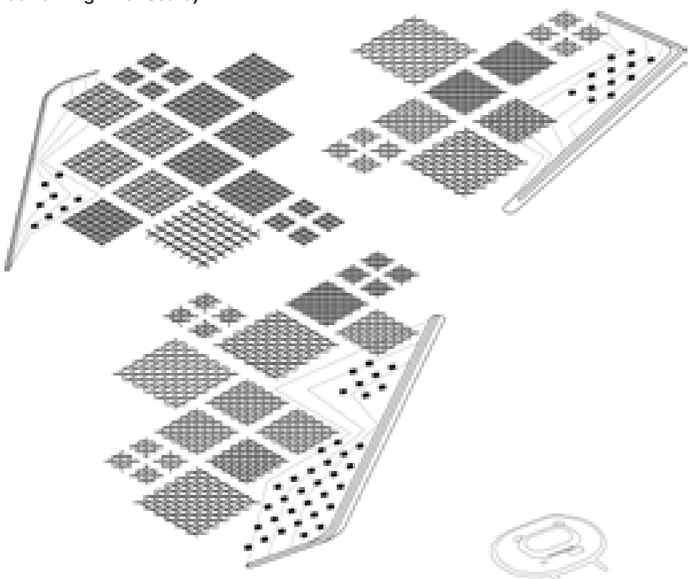


Figure 6.12: example of a small scale willow farming

Figure 6.13: Composition of the combination of modules into a semi-permeable ‘island’. Notice the variation of different wicker modules. (Pampus in the bottom right for scale)



to make way. However, this is all speculation. Monitoring the effect of the early implementation of modules is important to assess the effect of the module variables. This knowledge can be used in other places to purposely slow down succession processes, or speed it up. However, the module can act differently in other locations. In this sense, the entire project is a pilot project. Learning happens by doing, and uncertainty is part of the game.

The wicker dam grids operate in cycles in relation to the ecosystem processes; when a hydrosere is established, and the grid slowly turns into land, the solar array has to be phased out to allow plants to grow. At that point, a new wicker dam grid module is placed in some distance next to it one at a random side. The solar arrays from the previous module get partially placed on the new one, and the whole cycle begins again on the new wicker dam grid. When there is enough substrate on the previous modules, some areas can be used to for small willow plantations (fig. 6.10,6.12). These willows can provide the material for the next module construction. By these cycles, the succession process is in continuous motion. Different moments in its pathways are continuously present on different modules. This allows for a multitude of habitats. Sterna hirundo (common tern; in Dutch: visdief) can make their nests on the bare soil, Botaurus stellaris (bittern; in Dutch: roerdomp) can hide and forage in reeds and Phylloscopus trochilus (willow warbler; in Dutch: fitis) sing in the tops of grown willows (fig. 6.11).

The breakwater module and the wicker dam grids relate to one another in its aspect of development as well. The wicker dam grids need some shelter from the open water, but also a degree of openness to allow suspended sludge to be captured by the module. The first wicker dam grids are constructed just behind the sandy shallow gradient on the sheltered side of the breakwater. The other breakwaters are placed further away from the shallow zone. The sheltered side is always relatively close to a coastline, or in more open waters, another breakwater. This way, two kinds of larger structures emerge. Close to coastlines, the combination of the two modules and succession can over time develop in a foreshore. In more open waters, several breakwaters can outline an ‘island’ structure, with the wicker dam grids somewhat sheltered within them (fig. 6.13). By leaving openings in in the islands by not fully closing it by a breakwater, the island becomes ‘permeable’, allowing slowed down suspended sludge to enter the inner island and settle among the wicker. The modules in these islands become accessible as ‘land’ over time, but people can experience succession processes through several elevated pathways (fig 6.14).

The breakwaters are partly constructed by gabions which can be removed or added upon in other areas by cranes. Shifting some gabions to the other side or adding them to other breakwaters can 'finetune' the sheltering and water guiding effect of the breakwaters. When the wicker dam grids are 'filled' to a point where they can withstand harsher waves and currents, these gabions can also be removed altogether. This can also allow for some disturbance where sediment can also erode again and slightly change the state of the ecosystem.

The sustainable energy technologies are for a part reused in the cycles of new modules, but more solar panels can also be added in general. Not only the succession is conditional for the development and building of new modules, but also the outlook on the energy transition. When the energy transition needs to speed up, more modules can be constructed. However, sustainable pathways are also uncertain. When large energy projects in and outside the Netherlands are constructed, such as large wind turbine parks at sea or a well-developed European energy network, the need for energy production can decrease in the IJmeer and the succession process can supersede the need for energy, allowing the wicker dams to be fully utilised for ecological purposes.

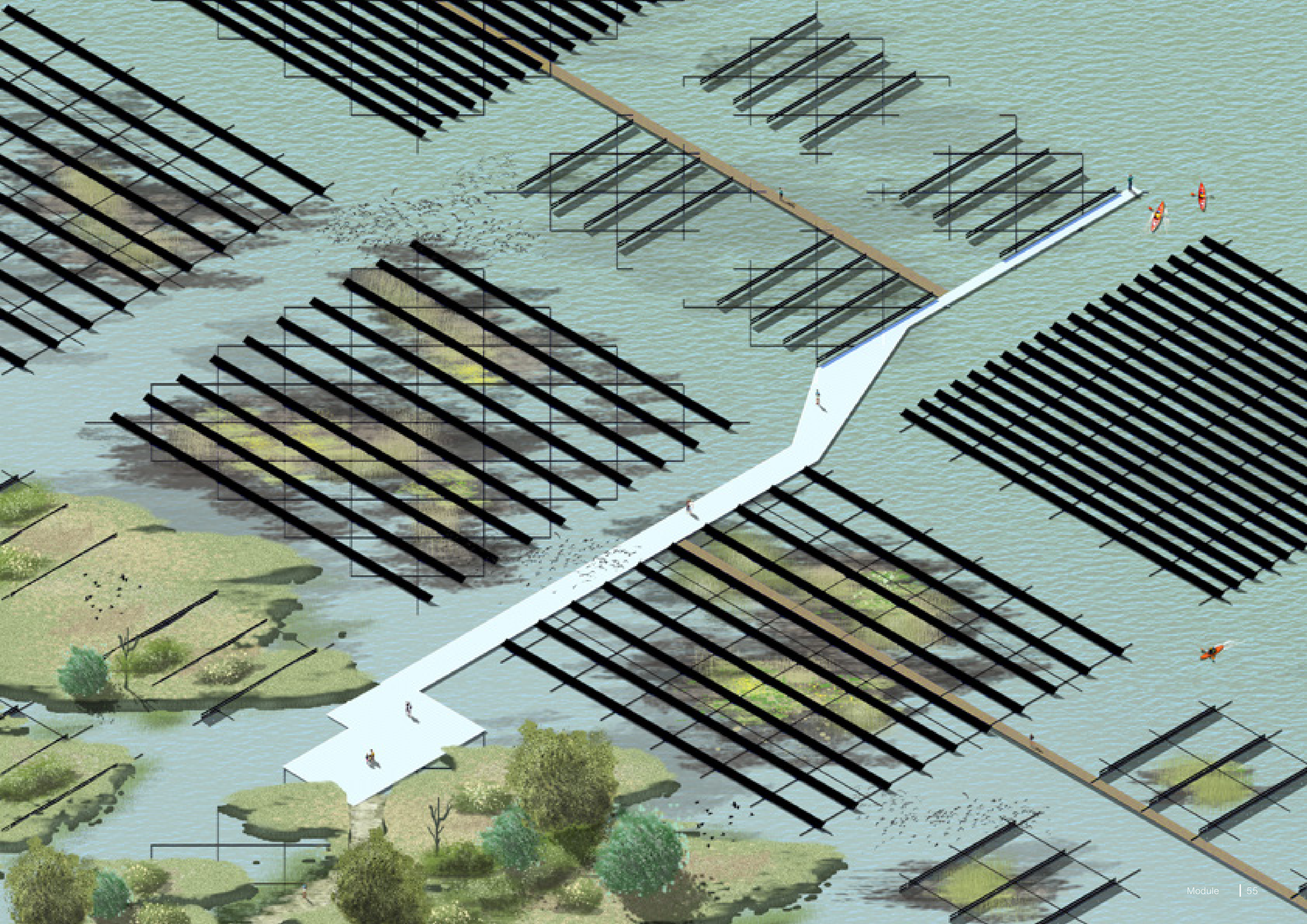
In a holistic approach to ecosystems we also accomodate human processes. Urban expansion and infrastructure must be recognised as processes as well which the framework of the modules can accommodate. The possibility of an outer-dike expansion of Almere and a metro connection across the IJmeer in combination with the modules will be discussed further in the chapter on subareas. These developments will take place somewhere over the course of thirty years; after that, the system can be altered again by a more fluctuating water level for example.

The way modules change over time cannot be exactly predicted and controlled, based on the design principle of 'indeterminacy'. The principle of 'human agency' comes into play as we do not only create the preconditions for change but can also change the modules later on by changing its system responses and by phased removal of solar panels. Here, anthropogenic influence is also present in creating 'disturbances' and the conditions of the module responding to disturbances of the self-organising system. This allows principle 'experience time and change' come into play as the modules placed in series are based on similar preconditions but are present at different stages in the process. In its relation to sustainable energy generation, it is important to consider the principle of 'designing in the Anthropocene' as not simply maximizing energy output but moving along with the emergence of habitats for flora and fauna over time. Several design guidelines can be extracted from the aspect of transition.

Figure 6.14 (next page): Isometric view of a composition of wicker modules in different stages of the hydrosere and succession. A path system makes these stages perceivable.

Transition Guidelines

- ***The modules depend both on the system processes and human intervention for their development and change.***
- ***The modules are a precondition for ecological processes to occur, but also require human involvement throughout the process as an interplay with natural processes.***
- ***Multiplication of modules in conditional, depending on the rate modules respond to ecosystem processes.***
- ***The change and development that occurs by ecosystem processes can be monitored to learn from the effects of the module variables.***
- ***The modules combine on a large scale into foreshores and islands, of which the layout can be predetermined to a certain extent by the placement of breakwater modules.***
- ***Wicker dam grids grow in number; one creates the preconditions for the next.***
- ***The breakwater module can be adapted later on by extending or reducing their length by the gabion components.***
- ***The materials for new modules are for a certain extent recycled within the development of the modules themselves.***



7

Landscape design

Figure 7.1: Sketch of the allocation process of the module placements

Region

To allocate modules in the IJmeer, various characteristics of the region must be considered. Varied non-urbanised coastal areas will be used as foreshores, such as the Waterland and Muiden coastal areas. The foreshores will partly consist of permeable islands offsetting the coastline, placed in such an angle that a variety of wind directions can funnel in suspended dredge to be 'catched' in the wicker dam grid modules. The future urban axis of the extension of IJburg and the outer dike expansion of Almere, along with the possibility of an infrastructural connection, can be supported by a series of islands. In this way, the Muiden coast, the Waterland coast and the urban axis of Amsterdam and Almere are three 'strands' of a series of islands, with the space between them expanding further away from Amsterdam (fig. 7.1). In this way, an archipelago of solar and nature islands is created (fig. 7.2).

The placement of these islands in series also outlines the energy infrastructure that connect to the substation at the Diemen power plant. The strands of islands differ in size and orientation to diversify the effect of the processes in relation to the context. Between the islands in the strands, pits to supply the resources for the modules and as sludge 'catchers' are dug. The areas between the strings of islands is kept clear mostly because of shipping lanes, sand excavation and to keep some areas more open as a habitat for certain species. The fortress island of Pampus also plays a role in this sense and maintains its character as a panopticon in the IJmeer by keeping distance between the strings of islands and the Pampus island. It should further be noted that the regional design depicted is a hypothetical situation of the characteristics described above; indeterminacy relating to the hydrosere performances of the wicker dam grids means that full 'blueprint' designs cannot be made. Instead, it fully depends on how the wicker dam grid modules multiply, in what rate and in which direction.

Regional guidelines

- Three 'strands' of islands placed in series will form an archipelago that will in part shape itself by sedimentation and hydrosere processes and provide an efficient energy infrastructure.

- The strands along the coast along Waterland and Muiden will be intended as foreshores and connective zones to the shores.

- The urban axis that can be observed by IJburg II, possible outer dike expansion of Almere towards Noorderhoek and a metro line will be supported by a central strand of islands.

- The islands develop in series towards Flevoland and the Markermeer, and inwards through sedimentation and hydrosere.

- The strands purposely avoid large shipping routes and essential characters to heritage structures like Pampus.

Four subregions can be distinguished among these strands in the regional design, all relating to one or more of the large landscape projects discussed in the analysis: the Muiden coast, the Waterland coast the Pampus causeway and Almere Outer Dike. The modules perform differently in each subregion according to the characteristics and projected developments of the area. These are not only the physical conditions, but also the cultural meaning and experience of different spaces can be reflected by the module implementations. Each subregion will have its own set of guidelines relating to the application of the module in that specific area. The different subregions are also phased in the above other (with some overlap). More knowledge is gained over the course of decades and the use of the module can become more and more complex in relation to future challenges.

To give an indication of its energy performance, we can look at the number of modules shown in the hypothetical situation of the regional design. Based on number of modules, the region provides around 100 MW-peak, and 450 TJ of energy per year. This amount of energy can cover the yearly electricity use of around 42000 households. To illustrate, the situation covers 14% of the yearly domestic electricity use of Amsterdam, or 54% of the domestic electricity use of Almere (for more details on this calculation, see appendix C).

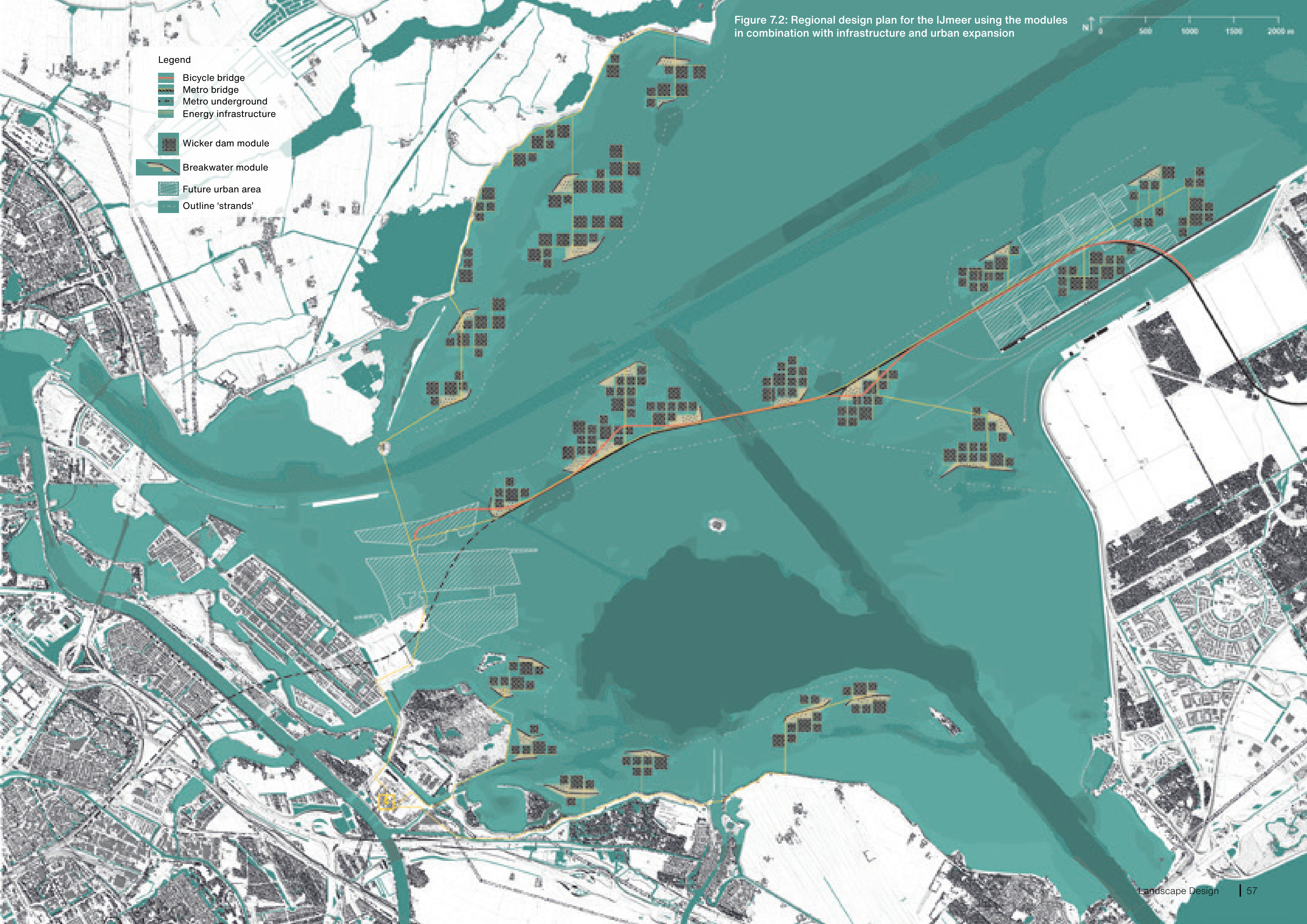
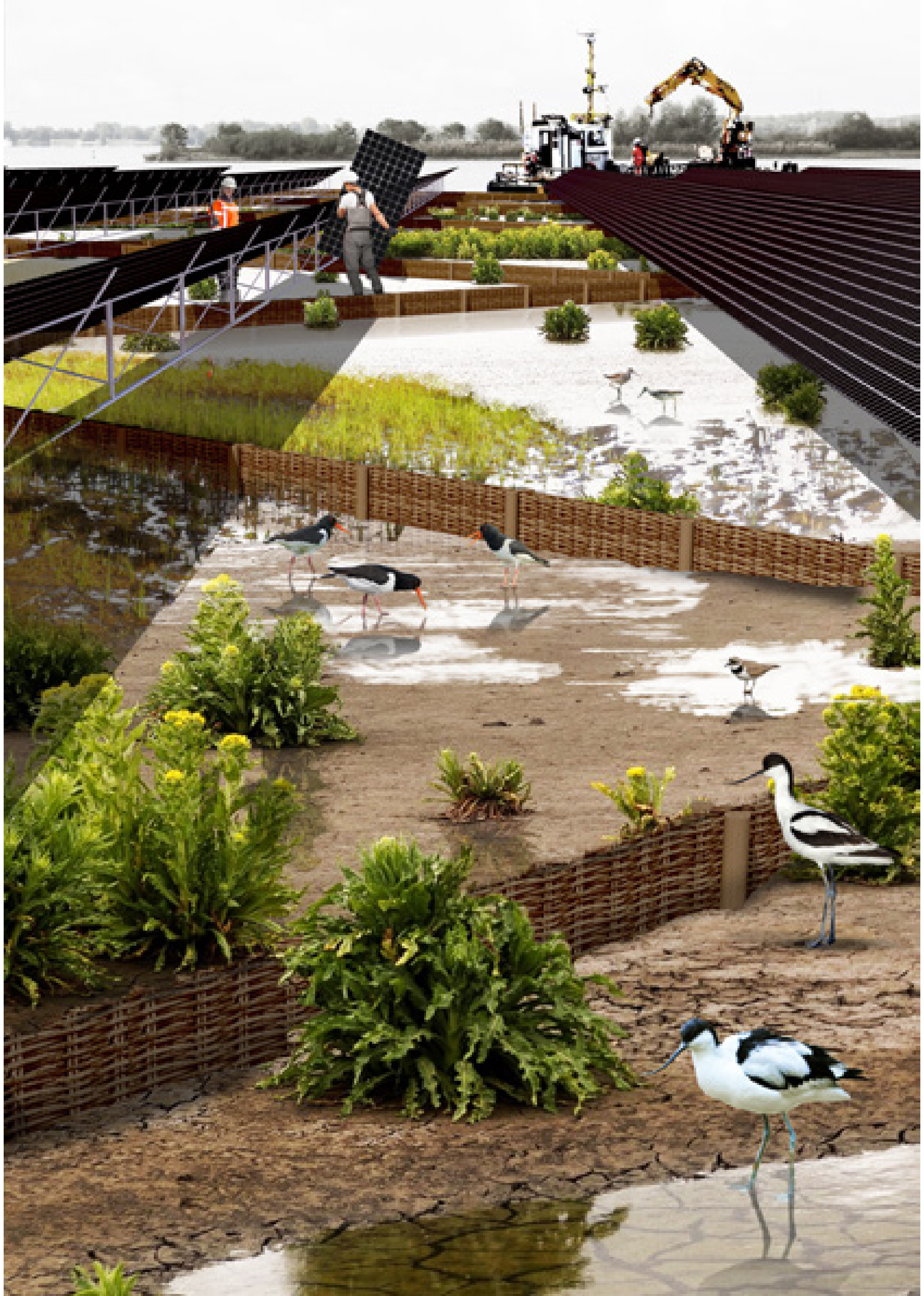


Figure 7.2: Regional design plan for the IJmeer using the modules in combination with infrastructure and urban expansion

Muiden coast

The first string of islands to be developed is along the coast of Diemen and Muiden. This area has over the course of its history been defined by the development of the Vecht region, the creation of the Stelling van Amsterdam. In modern times, major changes have occurred by the creation of large infrastructures, energy production and the necessary nature conservation measures, all squeezed within a green wedge of Amsterdam. The large variety in its coastline allows for a proper site to experiment with the wicker dam grids and the dam modules; making this subregion a place for testing how the modules perform and what effects its variables have. Existing breakwaters and islands are incorporated in the creation of foreshores and islands (fig. 7.3). The northern orientation of its coast means that the modules will heavily rely on winds coming from the north-northeast.

Figure 7.3: Plan of a situation of the Muiden coast area, later in the implementation and succession process. A string of islands and foreshores is combined with its already existing islands



The islands and foreshores are partly formed by already making use of the already existing islands, breakwaters and other nature conservation measures. A variety of different modules provides a set of variables to monitor in how they perform, both for energy production, hydrosere and biodiversity (fig. 7.4). The results of this monitoring with a conclusion to its effect can be used to have a little more control over creating a diversity in habitats for species in relation to optimal use of the solar arrays. When an advanced hydrosere is reached in the wicker dam grid modules, the modules can be used as small willow plantations to grow the resources for modules in other subareas.

Specific guidelines for Muiden coast:

- Use a diverse area for testing and monitoring processes of variables of the module to gain knowledge for future implementations.
- Start with module building in the southwestern part of the IJmeer as obstructions to the northeast for sludge catching are not yet in place.

Figure 7.4: A recently exposed mudflats bound in a wickier module calls for partial outphasing of the PV array. Meanwhile, many birds use the module for foraging

Waterland coast

The Waterland coast is characterised by its ruggedness, the capes and bays which have formed over time because of continuous adaptation of the Waterlandse Zeedijk. Waterland is a historically significant and well-preserved polder area, with far reaching views across meadows, canals and small lakes. The Waterland foreshore is defined by a strand of multiple islands offsetting the outline of the shore, maintaining the experience of bays and quays from the dike. The islands partially protect a foreshore along the coast (fig. 7.5). The bays will be more sheltered and have more diversity, while the capes provide open views toward the Markermeer. The general size of modules will be bigger and be filled with less primer meant to slow down hydrosere processes and allowing a large area of shallow reed lands to develop over time. Together with greater distances between wicker modules, this can cause succession to occur in a different rate than elsewhere, maintaining a sense of preservation of the openness of this historic area while still increasing its variety.

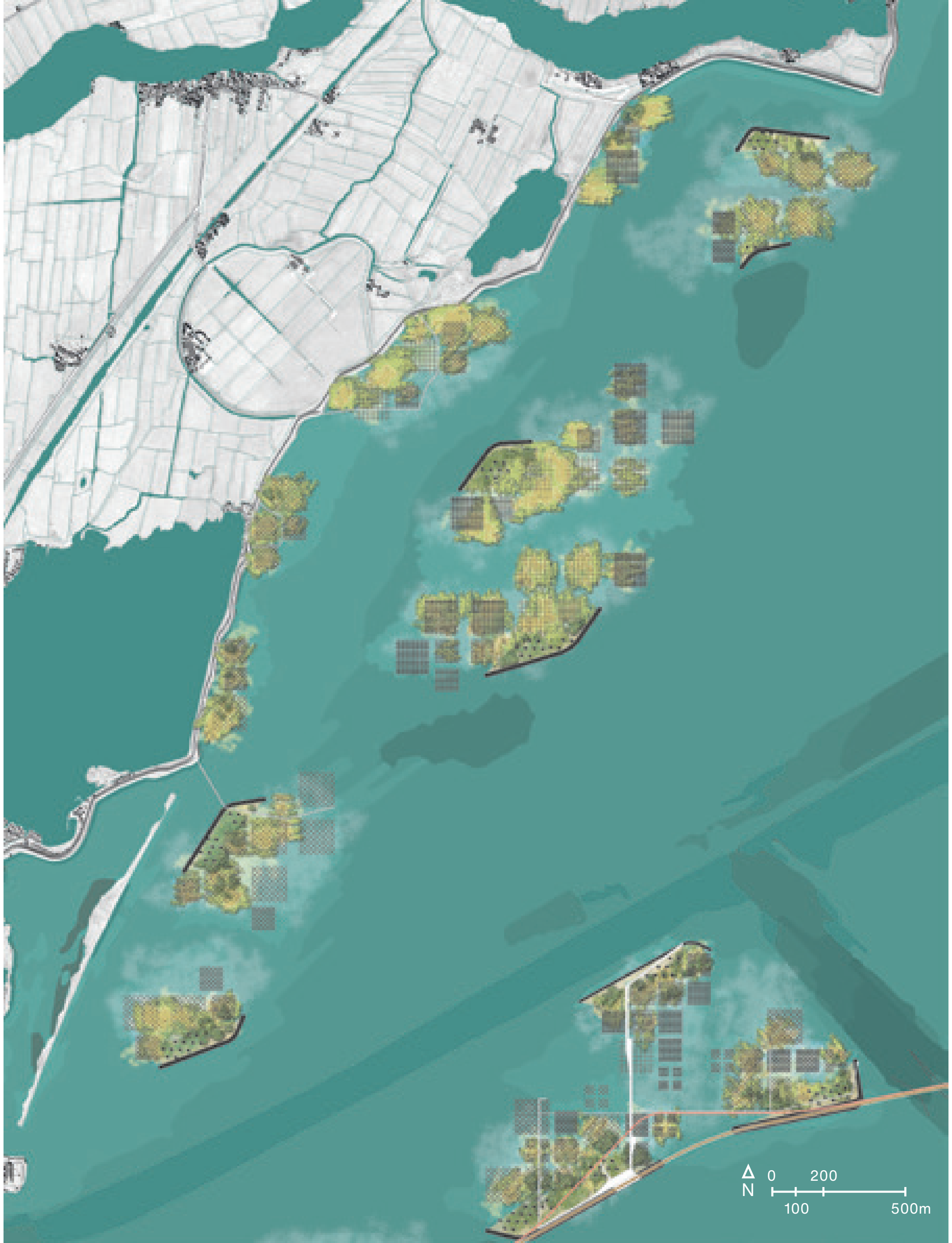


Figure 7.5: Plan of a situation of the Waterland coast, later in the implementation and succession process. A string of permeable islands is partially protecting a foreshore. The grid modules are larger in this area and placed further apart

Small floating walkways from the capes can allow visitors to explore the reed lands and its biodiversity, as well as creating the opportunity for small scale boating recreation. The preconditions of the modules, including its variables and initial energy production, are imprinted on steel elements present by some of the islands. These elements, inspired by totem poles, provide a monument to the preconditions over time, listing the variables and initial energy generation of the islands. The form language and colours are inspired by colourful buoys and signs along the water. After the solar panels have been removed and the modules have 'wildernised', the element remains as a witness to its original state (fig. 7.6).

Specific guidelines for Waterland coast:

- Respect the characteristic of openness of historic polder areas and purposely slow down hydrosere processes, creating marshes.

- Consider the characteristics of the ruggedness of the coastline of old dikes; let the experience of bays and capes echo in the implementation of module

Figure 7.6: Wicker modules are placed further apart to purposely create large marshes over time. Steel elements contain a 'biography' of energy production after the PV array has been phased out

Pampus causeway

The string of islands in the middle of the IJmeer is not part of a foreshore. It follows the direction of an implied urban connection by being centred around an extension of several reinforced breakwaters that are broader and higher than usual. These breakwaters double act as a causeway for a new above ground metro line and bicycle highway (fig. 7.7). This metro line extends from the metro station Diemen-Zuid, underneath the Amsterdam Rijnkanaal and IJburg, coming above ground just east of the Buiten-eiland, a part of the urban extension of IJburg II. The metro line follows a bridge from there that is partially supported by the foundation of the breakwaters. The bridge slopes down slightly at these islands and rises to around 14 meters to cross the shipping lane to the Randmeren. At the Pampushaven of the Flevopolder, the elevated metro line turns south onto land and connects to the rail network in the centre of Almere

Figure 7.7: Plan of a situation of the Pampus causeway, later in the implementation and succession process. The breakwaters provide a foundation for a railway and bicycle bridge

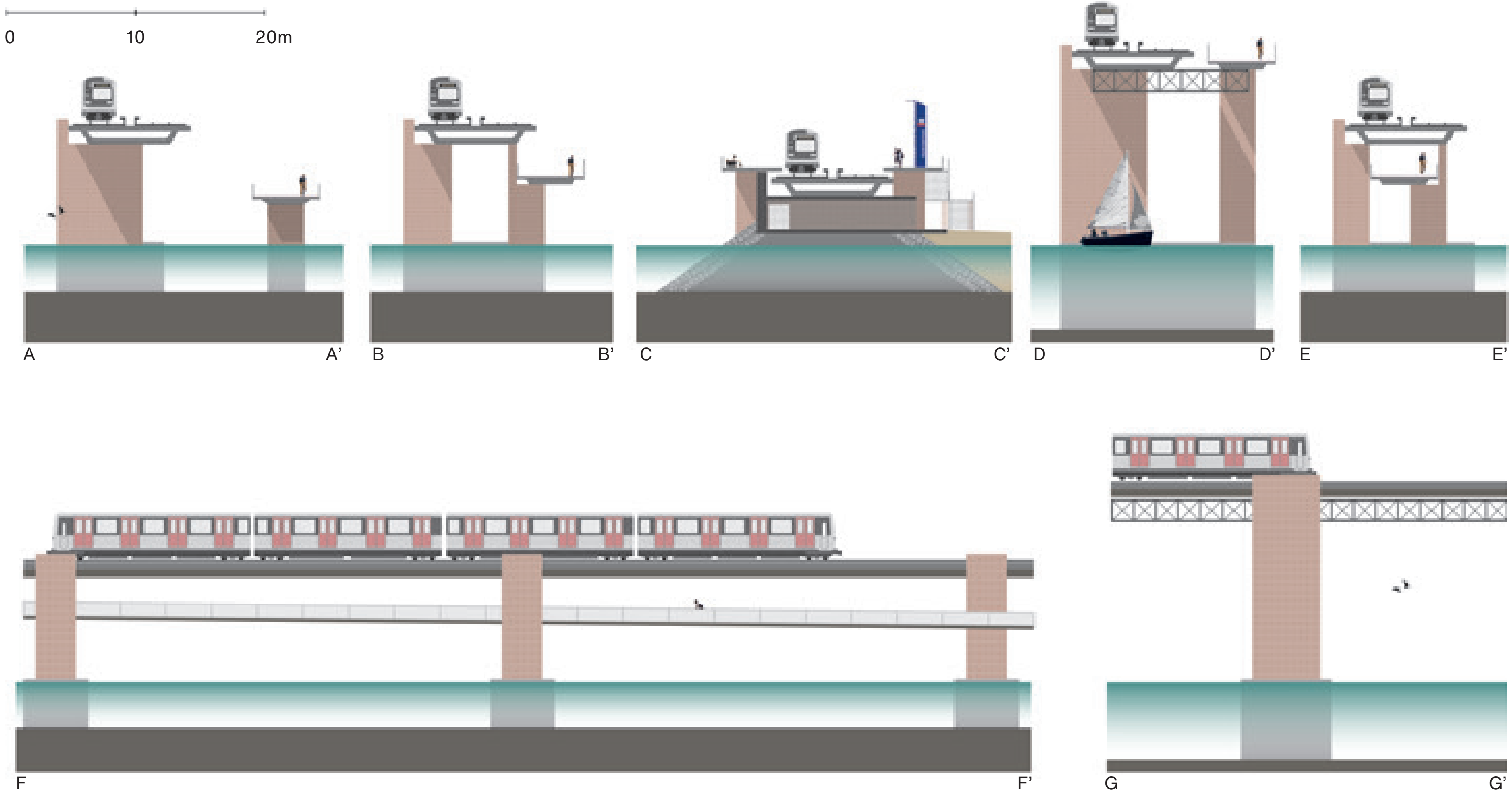


Figure 7.8: Different sections (A,B,C,D,E) and elevation profiles (F,G) of the metro and bike connection across the IJmeer. Locations can be found in figure 7.7. The bicycle bridge twists and turns around the metro bridge, allowing cyclist to have a more interesting cycle experience on their commute or leisure bicycle ride. Cyclists are also provided occassional cover from wind and rain.

The metro connection with Almere can fulfil the cities promise as a proper suburb of Amsterdam, allowing affordable housing for commuters. The elevated metro line is combined with a fast cycling path, so that commuters can cross the IJmeer by bike as well. This cycling path diverts from the elevated metro track multiple times to also offer a more diverse and interesting route along the string of islands. In other places the path converges with the elevated metro, making use of the same foundations of the viaduct and protecting cyclists from wind on the sheltered side of the metro (fig 7.8).

Figure 7.9: A ride on the metro provides stunning view across the IJmeer and its islands along the causeway

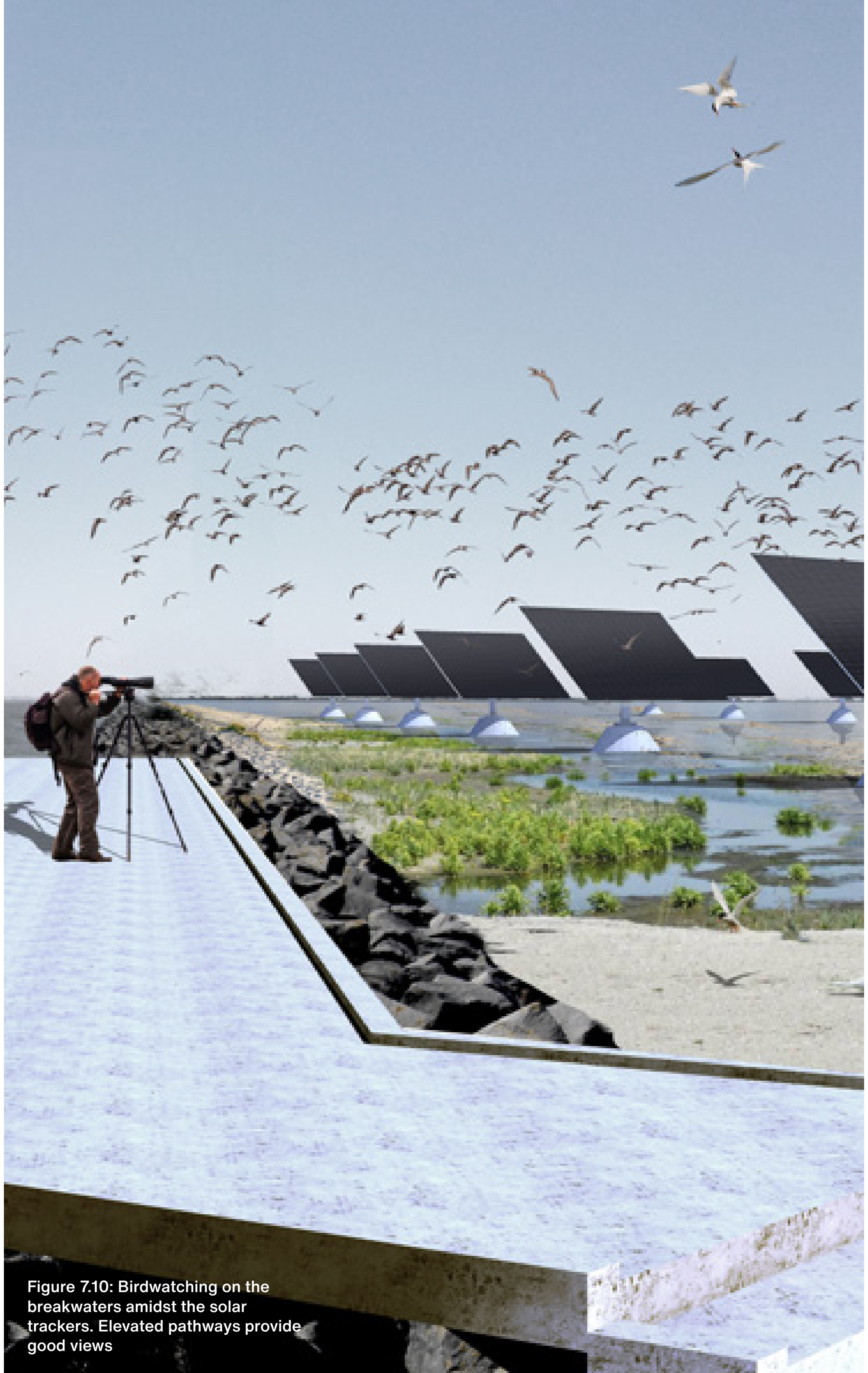


Figure 7.10: Birdwatching on the breakwaters amidst the solar trackers. Elevated pathways provide good views

The islands that this causeway is partially based on differ in size and orientation, with a notably large island in the middle (fig. 7.11). This island is accessible for visitors not only by bike, but also by metro. A metro station that is used outside of commuter peak hours, such as in weekends, can efficiently allow Amsterdam residents to get outside of the city within a couple of minutes (fig. 8,10).

The central island features the bicycle lane, as well as a hierarchy of modular elevated footpaths that allow people to explore the modules on the islands. The footpaths partially rest on the same foundations as the wicker grids, letting the visitors to walk across, alongside and besides them.

Figure 7.11: Plan of the 'central island'. A hierarchy of paths alirgned with the grids allows for exploration for visitors arriving by bicycle or metro

Figure 7.12: Section of the crossing of pedestrian paths and the bicycle highway through the central island. A bridge provides safe passage and a viewpoint.

When a somewhat sturdy ground has formed after sludge thickens the soil layer, the footpath can be placed on a newly built module further down the path. In time, the path system grows. By walking along the path system, visitors experience the transition of the ecological system and the energy system that takes place in the modules (fig. 7.12). The paths end at the breakwaters that partially outline the island, offering wide views towards the Markermeer. The centre island also allows for small scaled recreation such as swimming and canoeing between the modules (fig. 7.13,7.14).

Figure 7.13: Elevated pathways also offer the opportunity to swim in the sheltered areas inbetween the module, especially when a full hydrosere has not been yet been achieved. Visitors make use of the pathways while PV arrays and wildlife can be found in the modules.

Specific guidelines for Pampus causeway:

- Modules can double act as a foundation for various types of infrastructure, such as rail, bicycle or metro. Map out possible regional and local connections.

- Modules can provide the base for recreation and education in nature for urban dwellers. Provide accessible connections and create a diversity of experience.

Figure 7.14: Willow forests will emerge in later stages of the development of the modules. These forests can be combined with small scale willow farming to provide the materials for new modules. Not only do the pathways provide a possibility to expierence the island, there are possibilities by boat as well.

Almere Outer Dike

To the east of the centre islands and the shipping lane to the Randmeren, the elevated metro line continuous along the corner of Flevoland before connecting to it. This area is projected to be a possible zone for outer dike expansion of the city of Almere, which will in this project be called 'Almere Outer Dike'. The new metro connects this area to Amsterdam and the centre of Almere, making it very suitable for a mixed residential area with a medium to high densities amidst the waters of the Markermeer (fig 7.15).

The breakwater dam that is currently present at the Pampushaven can function as the base of this urban expansion towards the northwest. To provide this urban expansion with green areas, wicker modules will be placed alongside the existing breakwater. The locations of these modules lie in the extension of the Almere green structure and ecological connection on land. The modules will multiply outward onto the Markermeer to the Northwest. The conditional multiplication of the wicker modules, which extends somewhat randomly, can form the green framework of the new urban area, providing a large, porous green wedge in this urban extension that can dual act as an urban park and a nature area (fig. 7.16). When this structure has roughly developed, it lays out the structure of the urban areas as well, together

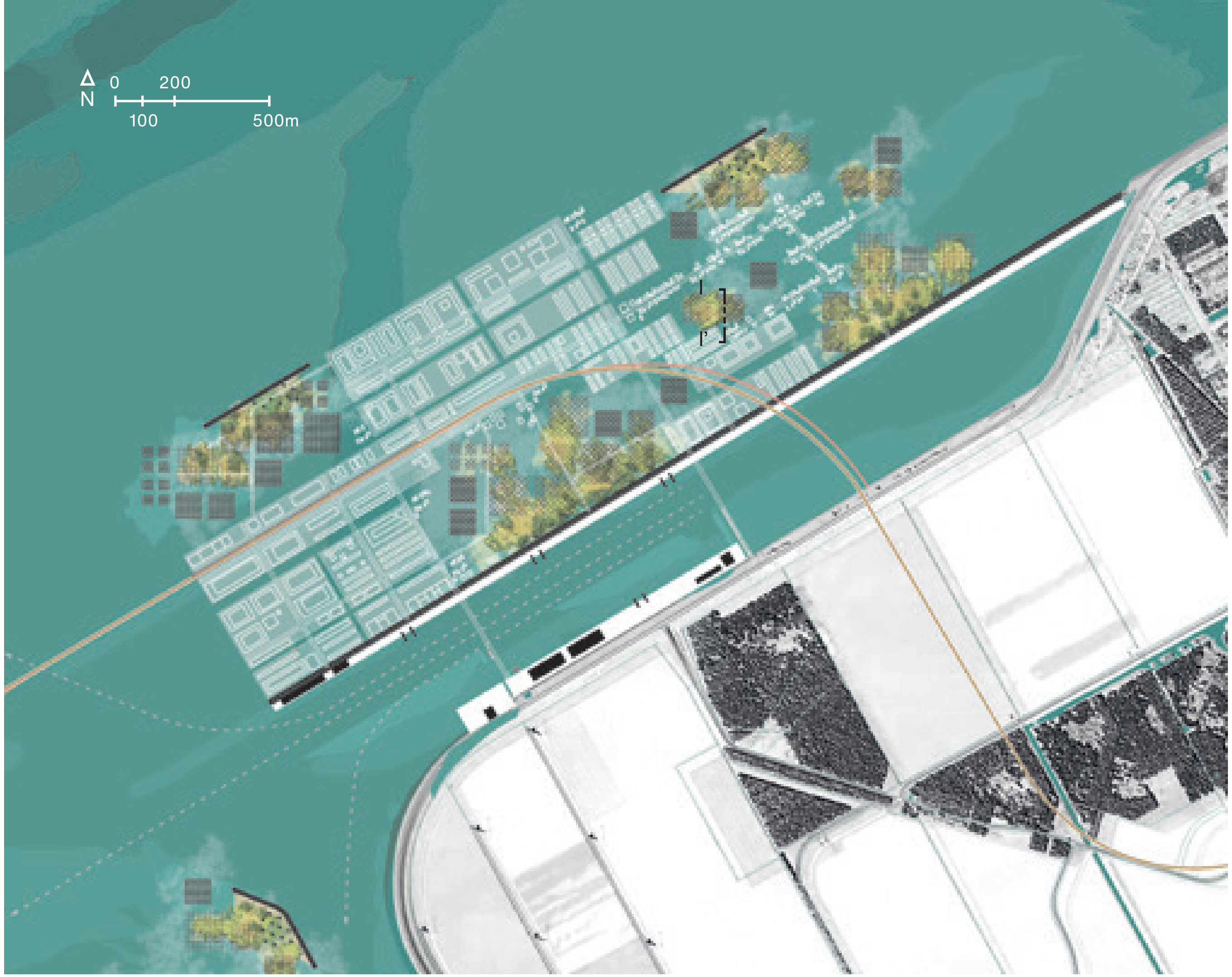


Figure 7.15: Plan of a situation of the Almere Outer Dike expansion, later in the implementation and succession process. The possible urban composition of the new urban expansion is already determined by the 'spine' of the metro and the green structure of wicker modules. The urban expansion follows the grid of the Flevopolder, but is combined with the south facing grid modules. The Pampushaven in the sheltered zone of the breakwater is transformed into a 'base of operations for construction and implementation of the modules.

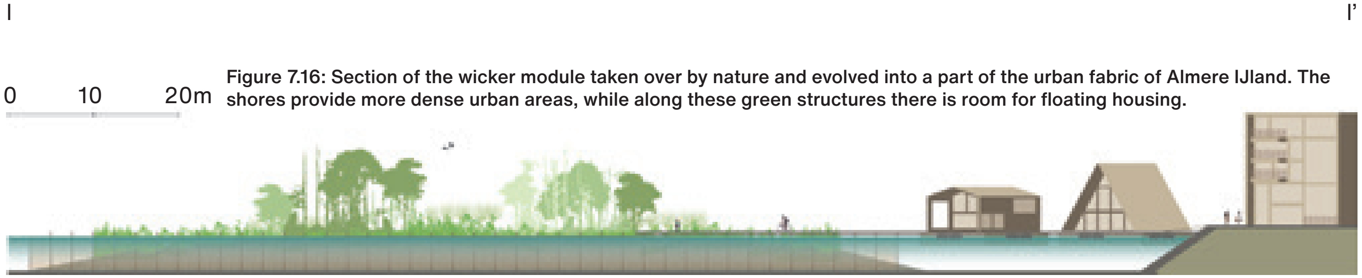


Figure 7.16: Section of the wicker module taken over by nature and evolved into a part of the urban fabric of Almere IJland. The shores provide more dense urban areas, while along these green structures there is room for floating housing.

with the ‘spine’ of the metro connection in the centre of this development. When Almere Outer Dike is constructed, the sludge that has to be dug out to create stability for the sand base can be used to fill modules elsewhere. Gabions removed from breakwaters elsewhere in the IJmeer can in turn be used for the edge of Almere Outer Dike. The character of Almere Outer Dike will be highly mixed, with wood-constructed high density housing along the spine and waterfronts, and lower density housing boats and smaller structures on the edges of the newly created green structure.

The Pampushaven, just south of the breakwater in the corner, is currently not in use as a harbour. However, to supply the materials for all the modules, organise construction of the grids and the equipment to place them, a specialised harbour is needed for the entire IJmeer. In the Pampushaven, dredging barges can move in and out of the area and solar panels, willow branches and armour rock can be stored in these areas. The Pampushaven is perfectly situated as a ‘base of operations’, with good access to the IJmeer by boat and access to regional infrastructure by land. When the production of modules slows down, or when no space in the IJmeer for new modules can be found, the layout of the harbour can be used as a commercial and cultural centre for the urban expansions of Almere, providing a waterfront as a bonus (fig. 7.17).

Specific guidelines for Almere Outer Dike:

- A multitude of modules can create the green structure for urban development to occur. The conditional growth of the model count and direction lays out the composition for the future urban area.

- The large-scale construction and implementation of modules need a base of operation. Consider a future purpose for this base of operation for when there is no longer a need for these modules.

Figure 7.17: The Pampushaven turns into a bustling area full of construction projects both for wicker modules as for the outer dike urban expansion of Almere

⑧
Discussion & Conclusion

Discussion

The points for research quality by Deming & Swaffield (2011) discussed in the final part of the methodological framework are to be assessed in retrospect as well. Considering truth value, it must be acknowledged that prominent recurring themes of design principles include indeterminacy, being open for unexpected system responses and allowing for disturbance. These themes have proven difficult to work with. Design for a landscape architect can be perceived as an exercise of controlling, guiding and shaping the landscape and its processes. This research was more concerned with the guiding of processes, but also purposely leaving blind spots in the guiding of these processes. Rationalising this design proposal as an effective measure was therefore not easy. If, and how well the systems proposed in the design work according to the objectives is therefore very uncertain. The technologies and measures used are heavily based on pilot studies and until now quite limited research of the ecological effects on sustainable energy systems. The design 'ingredients' chosen for the design, along with other design choices made both explicit and implicit, also reduce several other research qualities. Many of these design choices were not recorded, nor can they be fully rationally justified, reducing the transparency in the research methods. Many different design choices could be taken along the lines of the design principles.

This project could in this sense use more detailed methods of 'research on design' as mentioned in the methodological framework. This project has in its attempt to be concise rarely shown an in-depth procedure of designing itself. More insight into design processes could have been provided, possibly in the appendix. Although design processes are always inherently complex, chaotic and nonlinear, some general methods and strategies could possibly be extracted from the design process in retrospect. Logbooks or sketches of 'train of thought' are possibilities to include in the appendix. In this way, the reader can have a better understanding of the design process and provides more validity to the 'research through design' process. However, many design decisions are not 'recorded', partly because these are difficult to visualise without being part of the design result, especially in retrospect. These comments on the design phase must be somewhat mitigated by the fact that all creative design processes are inherently artistic, personal, and hard to grasp. The consistency of this research can further be questioned by the many and varied methods used in this report. However, considering the holistic and multi-faceted context a landscape operates in, it is necessary to analyse the landscape from many different perspectives, especially when using an ecological mindset.

Ecological thinking, the overwhelming thought that everything relates to everything, has been topic of this research but also a major obstacle. A flaw of this research could be that it somewhat fails to distinguish main points and side points to an extent. There is a tendency to explore every link and explain every process. However, a large part of designing is 'bounding off' the field of design, contextually and thematically. The use of ecological knowledge in design has been very prominent in the context of the IJmeer and its analysis. This research has shown that landscape architects should be aware of fundamental concepts in ecology and consider the applications of their use for design. However, designers can still come up short in this sense. Intensive collaboration between landscape architects and ecologists is therefore needed in both education and practice. This is especially useful for the design context.

Considering the use of theory on renewable energy, this research has over its course shifted its balance more towards ecological theory rather than theory on renewable energy. Even though an energy transition has been the jumping-off point for this research when looking at the objective, the term has not come back very often after the methodological framework. This has primarily to do with the shift of focus to the change of ecosystems, and the way that they change. Instead of timeframes and thresholds, the design is dominated by open-endedness and uncertainty. The conditional replication of modules means that creating a timeline and detailed phasing of an energy transition in the region very difficult. Whether this research really answers the objective of desiging an energy transition is debatable.

Although PV systems are included in the design, these have become more of a vehicle for the objective of ecosystem change, rather than an objective of energy transition. In this way, the entire research objective has shifted. This also shows the difficulty in making sustainable energy technologies compatible with ecosystems under pressure. This research has, considering its objectives, put more emphasis on improving the biodiversity and population health of flora and fauna rather than the goals for energy transition. Even though this is partly due to the prominent use of open-endedness in the design, and the conditional way the design develops over time, more emphasis on a pathway and energy goals could have given this project a more completion on this aspect. The use of the design approach used in this research does not directly address sustainable energy technologies, as the holistic notions have reduced it to just one part in a larger whole. This research could have placed more emphasis on renewable energy.

This research uses a modular approach, with the modules being designed by analysing the solutions to the specific problems of the context. A modular approach means mediating between generic objects that are not place specific, and place specific design and implementation according to the site. The latter is usually the preferred working field of the landscape architect. However, a modular approach does provide the possibility for large scale and phased implementation according to demand.

This research has used ecological technologies and measures for its modules, but at the same time has somewhat rejected its use in guidelines and principles. It rather perceives them as design ingredients. The guidelines can however deal with the specific implementation or combination of modules in the landscapes. Furthermore, the measures and their mechanics that can be described as ‘building with nature’ are not individual machines; they are part of self-organising, complex and changing ecosystems. Understanding the context that they place the measures in should not be underestimated. Landscape architects should view ecology not only in a technical perspective. Landscape architecture is a discipline that combines science and arts, the natural world and the human experience. Ecological thinking in landscape architecture have largely resulted in technofix approaches that viewed ecosystems as machinic, putting a lot of emphasis on maximising its thermodynamic properties. In design, this means a large focus on efficiency and optimal use of landscapes as a goal to sustain the status quo of our current lifestyle. This contradicts the need for a system transition where we move to a more ecologically sustainable and just society.

Considering the efficiency and organisation of this research, it must be noted that this research was very explorative in nature and did not have the same objective and research questions from the start. The subject matter and study area of this thesis evolved over time due to new findings in the analysis and design phase, but also in forming a theoretical context. To illustrate, the concept of succession was first applied in an analogous way; this made the application of the concept somewhat questionable. Further research into the concept caused the situation to change to an application truer to its original ecological meaning. Even though many major choices on the focus of this research came to be being doing research and design, the timespan of this research could have been shorter.

This research can also be split into general and place-specific knowledge. Both can have a significance for other researchers. As for general knowledge, the use of the concepts of succession and ecosystem change have been applied in past landscape architecture studies and projects explicitly and implicitly. This research consists of a direct approach in combining both the ecological concept of succession as well as applying notions of non-linearity, indeterminacy and complexity. This approach in combination with renewable energy systems can prove useful to expand on the design of energy landscapes elsewhere. As for place specific knowledge, the case study and the use of a module designed for specific ecosystem functions of the IJmeer makes its applicability for other regions is somewhat limited. However, there are multiple metropolitan regions in the world situated in a water-rich area with dynamic sludge. Somewhat similar areas in the Netherlands can include saltwater systems as well, such as the Eem estuary, the Schelde estuary or the Frisian Wadden coast. Here the modules can support other species and function as coastal protection as well. The IJmeer could in this sense act as ‘pilot’ for other regions of this technology, as more knowledge about the effectiveness of the module is needed.

Conclusion

The objective of this research is to design an energy transition for the IJmeer that aligns with the change in ecosystems and while applying ecological concepts. This conclusion will address all the sub research questions before evaluating the design questions. A summary of all princinples and guidelines can be seen in figure 8.1.

SRQ 1: What are the principles for landscape analysis and design related to succession and ecosystem change? (Chapter 3)

Several things can be concluded considering the synthesis of design principles. The principles rely heavily on the holisticness of ecosystems and the position of anthropogenic influence on it. This is especially true for the principles of 'human agency' and 'one system'. This can also be seen as the bigger question of how human and nature relate to each other. When making a design for a specific region, these principles are more of a contextual backdrop for landscape architecture in general than a directly applicable principle. This is not necessarily negative; all landscape architecture is concerned with human-nature relationships, and landscape architects who are very self-aware of their position on this relationship could benefit from this when designing. The principle of human agency questions the role of the designer inherently as well. It is however debatable whether the principles are not too general. Especially the principles of 'human agency' and 'one system' principles may not actually be principles, as they may be better seen as 'world views'. The theoretical framework has not directly addressed many points for sustainable energy transition, due to an attempt to be concise and limit itself to the concepts of the research question.

SRQ 2: What are the characteristics, constraints and problems in the current ecosystem state of the IJmeer and how did they develop? (Chapter 4)

The analysis principles synthesised in the theoretical framework have resulted in a dual approach to distinguish human interventions and 'traditional' ecological analysis. This has been very effective in categorising the analysis and reducing the complexity. Even though this contradicts principles of humans and their influence on the landscape also being part of an ecosystem, we do have to acknowledge that humans have a unique position in the ecosystem in carrying out large landscape projects. The analysis has shown that although large landscape projects were very common in the past, more recent adaptations to the landscape have a much finer grain size and are rarely bound by visions on a large scale. The design part of this research is also a call to go back to these large plans, especially now that urgent action must be taken for an energy transition and mitigation of biodiversity loss. The ecosystem analysis has shown that heavily impacted ecosystems are constrained in their ability of diversifying through succession processes. Human intervention can be also be directed towards this effort however.

SRQ 3: What technologies and measures can lift the constraints of the IJmeer ecosystem and provide solutions for sustainable energy implementation? (Chapter 5)

This research question is twofold; it asks both for measures to improve ecological quality and sustainable energy technologies suitable for the design. This research question has treated the outcome as 'ingredients' for design rather than guidelines or principles. This is on purpose, considering the critique of viewing ecological approaches in landscape architecture being solely instrumental. The outcome of this sub research question has become an inventory of possible measures to use in order to 'pick and mix' to create hybrid structures, but also to assess which measures and technologies are capable of changing its state or flexible in their implementation and removal.

Main research question: What are the principles and guidelines for designing an energy transition the metropolitan ecosystem of the IJmeer through the concepts of succession and ecosystem change?

Considering the objective of this research, renewable energy transition has been the jumping off point into looking for ways Thinking in the 'frameworks' for natural processes has revealed to be especially useful in this sense. Rather than trying to control each aspect that occur in landscapes, a solid and simple set of working principles can mean a more meaningful design. Designers also do not only have to design the preconditions for processes to catch on; they should design anthropogenic interventions in later stages of the process as well. Adaptations to the design by humans is one of the few aspects that designers can exert control over.

In synthesizing the design principles, taking analogous approaches to ecological concepts can result into misconceptions, especially when this analogy is the base for a landscape design. Considering a concept of succession in its original, scientific sense as an inherent process of ecosystems and not as an analogy makes it more useful and accurate to use it accordingly when designing. Principles like uncertainty and complexity however operate on larger scales and are also broader terms in general. This should

Module guidelines

- The modules are frameworks for a multitude of processes.
- Constants and variables within the modules are important. Let the basic principle remain the same but work with a multitude of variables to let processes play out differently.
- Two modules can be combined to create mutually beneficial effects.
- Module materials are preferably locally sourced, such as willow wicker and building sediment.

Transition guidelines

- The modules depend both on the system processes and human intervention for their development and change.
- The modules are a precondition for ecological processes to occur, but also require human involvement throughout the process as an interplay with natural processes.
- Multiplication of modules in conditional, depending on the rate modules respond to ecosystem processes.
- The change and development that occurs by ecosystem processes can be monitored to learn from the effects of the module variables.
- The modules combine on a large scale into foreshores and islands, of which the layout can be predetermined to a certain extent by the placement of breakwater modules.
- Wicker dam grids grow in number; one creates the preconditions for the next.
- The breakwater module can be adapted later on by extending or reducing their length by the gabion components.
- The materials for new modules are for a certain extent recycled within the development of the modules themselves.

Modular guidelines

Analysis principles

- History matters for the abiotic foundations
- Identify human systems by large landscape interventions over the past
- Analyse ecosystem conditions independently from human systems and identify its constraints

Design principles

- Human agency
- One system
- Frameworks
- Indeterminacy
- Disturbances
- Diversify
- Experience time and change
- Design for the Anthropocene

Regional guidelines

- Three 'strands' of islands placed in series will form an archipelago that will in part shape itself by sedimentation and hydrosere processes and provide an efficient energy infrastructure.
- The strands along the coast along Waterland and Muiden will be intended as foreshores and connective zones to the shores.
- The urban axis that can be observed by IJburg II, possible outer dike expansion of Almere towards Noorderhoek and a metro line will be supported by a central strand of islands.
- The islands develop in series towards Flevoland and the Markermeer, and inwards through sedimentation and hydrosere.
- The strands purposely avoid large shipping routes and essential characters to heritage structures like Pampus.

Sub regional guidelines

Specific guidelines for Muiden coast:

- Use a diverse area for testing and monitoring processes of variables of the module to gain knowledge for future implementations.
- Start with module building in the southwestern part of the IJmeer as obstructions to the northeast for sludge catching are not yet in place.

Specific guidelines for Waterland coast:

- Respect the characteristic of openness of historic polder areas and purposely slow down hydrosere processes, creating marshes.
- Consider the characteristics of the ruggedness of the coastline of old dikes; let the experience of bays and capes echo in the implementation of module

Specific guidelines for Pampus causeway:

- Modules can double act as a foundation for various types of infrastructure, such as rail, bicycle or metro. Map out possible regional and local connections.
- Modules can provide the base for recreation and education in nature for urban dwellers. Provide accessible connections and create a diversity of experience.

Specific guidelines for Almere Outer Dike:

- A multitude of modules can create the green structure for urban development to occur. The conditional growth of the model count and direction lays out the composition for the future urban area.
- The large-scale construction and implementation of modules need a base of operation. Consider a future purpose for this base of operation for when there is no longer a need for these modules.

Place-specific guidelines

Figure 8.1: Summary of principles and guidelines

be considered when using ecological concepts for landscape architecture. Landscape architects should also take note of ecological knowledge in landscapes that are highly dominated by anthropogenic processes. Humans have been the cause of the reduction of biodiversity and diminishing of populations of many flora and fauna. In the Anthropocene landscape architects must acknowledge that the way in which ecosystems function is heavily impacted by human influences. Rather than moving to 'nature compensation', landscape interventions should include aspects of hybridisations for ecological processes that benefit flora and fauna.

The use of the design principles in the design for the IJmeer has made clear that its use is highly tied to the design of the modules. This makes sense as neither of them are entirely place specific. However, the modules are based on the technologies and measures analysed in SRQ 3. The use of the principles is heavily tied to the availability of the mechanics of the measures used. The measures chosen must be able to change in some way, allow for modification over time and different and unexpected responses to ecosystem processes. The focus on processes in the design principles is clearly reflected in the choice of the module mechanics. Partly because of this, a modular approach for the design question has shown to be effective, especially for a regional scale. Generic design measures for designing with uncertainty and complexity may seem contradictory. However, modules can be designed on a small set of constant working principles and include variables in their performance alongside it. Even if these working principles and the effect of variables are still uncertain, including an aspect of monitoring and adapting accordingly can increase the performance of the design in relation to biodiversity. The way modules change or transition should not be underestimated when designing for an energy transition and an ecosystem change. The application of the module into the context of the IJmeer required an analysis of the characteristics of different landscapes. Designing with somewhat generic modules in a landscape with a lot of variation meant special emphasis on the speculation of module variables. The context of the IJmeer also proved that a metropolitan context with future urbanisation and infrastructure should be considered as well.

The guidelines were categorised along four categories: modular, transitional, regional and subregional. The first two categories specifically relate to the use of the design module and how they are composed and operate. These guidelines also have the closest relation to the design principles as described in the chapters. When using a modular approach, a hierarchy of the cascading of themes from the design principles could be perceived, as the place-specific guidelines relate more directly to the modules rather than the principles. Direct links are however hard to make between principles and guidelines, as there are so many, often contextual considerations that come into play when designing as well. The guidelines are in this research also framed as a result of the design, a distilled set of considerations that have emerged over a long and chaotic design process. In hindsight, it has not been possible to provide guidelines prior to designing- only through thorough design experiments, guidelines could be created. In this sense, the guidelines could also be a summary of its design reducing its complexity in the choices made. The guidelines are however still somewhat general and can be used for further research in modular approached of hybrid structures, or interventions in the IJmeer in general considering the place-specific guidelines.

As discussed earlier, the objective of designing an energy transition has changed somewhat after notions of open-endedness and purposeful reduced control over ecosystem processes. An energy transition must, as this thesis shows, be absorbed into other processes that are happening in the landscape. These processes are partly self-organising, but urbanisation and building infrastructures in these dense environments are important as well. Whether the goals of Amsterdam and Almere for 2040 considering energy and urbanisation can be reached by this approach is highly uncertain. However, the key lesson for an energy transition in this region is to use a modular approach and a vision for large scale implementation, while staying flexible and open for changes in its implementation. Designers being the node of other areas of expertise is key here. Designing, a unique research practice, can as test, evaluate and play with many different features of other sciences such as ecology. This research proved that the discipline of ecology is very important for landscape architecture. Landscape architecture should first not only concern itself with engineering approaches to ecological problems. As in all ecological systems, this design is just a small part of a larger whole. To determine our place in the world that has already been highly influenced by our presence, moving with the pulse of ecosystems in landscape design is a necessity.

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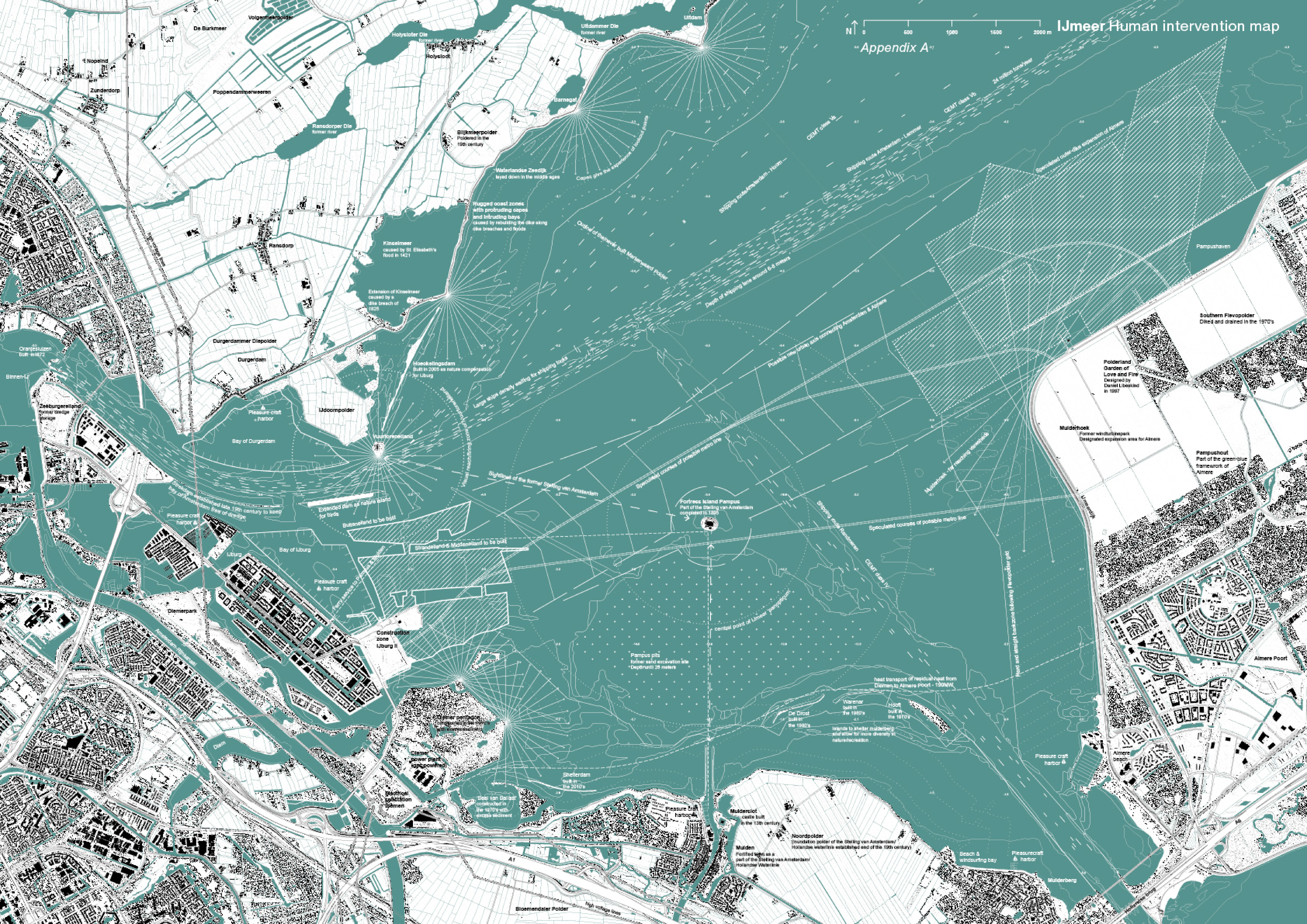
6.1	Image by the author
6.2	https://www.rgbstock.com/photo/mfjPXae/willow+wickerwork+texture
6.3-6.11	Image by the author
6.12	https://commons.wikimedia.org/wiki/File:Carnisse_grienden_1.jpg
6.13-6.14	Image by the author
7.1-7.17	Image by the author
8.1	Image by the author


IJmeer Human intervention map
Appendix A
N
0 500 1000 1500 2000 m
Volgermeerpolder
De Burkmeer
Holysloter Die
former river
Uitdammer Die
former river
Uitdam
Holysloot
't Nopeind
Zunderdorp
Poppendammerweeren
Ransdorper Die
former river
Barnegat
Blijkmeerpolder
Poldered in the
19th century
Waterlandse Zeedijk
layed down in the middle ages
Capes give the experience of lookout points
Rugged coast zones
with protruding capes
and intruding bays
caused by rebuilding the dike along
dike breaches and floods
Ransdorp
Kinselmeer
caused by St. Elisabeth's
flood in 1421
Outline of the never built Markerwaard polder
Extension of Kinselmeer
caused by a
dike breach of
1825
Durgerdammer Diepolder
Durgerdam
Oranjesluizen
built in 1672
Binnen-IJ
Hoeckelingsdam
Built in 2005 as nature compensation
for IJburg
Large ships densely waiting for shipping locks
Zeeburgereiland
former dredge
storage
Pleasure craft
harbor
IJdoornpolder
Bay of Durgerdam
Vuurtoreneiland
Sightlines of the former Stelling van Amsterdam
Extended dam as nature island
for birds
Buiteneiland to be built
Strandeiland & Middeneiland to be built
Pleasure craft
harbor
Bay of IJburg
IJburg
Pleasure craft
harbor
Diemerpark
Construction
zone
IJburg II
Pampus pits
former sand excavation site
Depth until 25 meters
Diemen
Diemer
power plant
Shelterdam
built in
the 2010's
Electrical
substation
Diemen
A1
Bloemendaler Polder
high voltage lines
CEMT class Va
CEMT class Vb
24 million tons/year
Shipping route Amsterdam - Lemmer
Shipping route Amsterdam - Hoorn
Speculated outer-dike expansion of Almere
Depth of shipping lane around 6-8 meters
Possible new urban axis connecting Amsterdam & Almere
Pampushaven
Southern Flevopolder
Diked and drained in the 1970's
Polderland
Garden of
Love and Fire
Designed by
Daniel Libeskind
in 1997
Mulderhoek
Former windturbinepark
Designated expansion area for Almere
Pampushout
Part of the green-blue
framework of
Almere
Speculated courses of possible metro line
Fortress Island Pampus
Part of the Stelling van Amsterdam
completed in 1895
Speculated courses of possible metro line
CEMT class IV
central point of IJmeer 'panopticum'
Hard and straight bankzone following Flevopolder grid
Almere Poort
heat transport of residual heat from
Diemen to Almere Poort - 190MW
Warener
built in
the 1980's
Hooft
built in
the 1970's
De Drost
built in
the 1980's
Islands to shelter mulderberg
and allow for more diversity in
nature/recreation
Pleasure craft
harbor
Almere
beach
Pleasure craft
harbor
Muiderslot
castle built
in the 13th century
Noordpolder
(inundation polder of the Stelling van Amsterdam/
Hollandse waterlinie established end of the 19th century)
Muiden
Fortified town as a
part of the Stelling van Amsterdam/
Hollandse Waterlinie
Beach &
windsurfing bay
Pleasurecraft
harbor
Muiderberg
A6

IJmeer Ecosystem map
Appendix B
N
0
500
1000
1500
2000 m
-X Depth of pleistocene layer below N.A.P.
Density of water plant presence
Relief lines and depth of waterbed
Waterland is a very important habitat for meadow birds
Lakes and canals surrounded by reeds are important resting and hiding areas for waterbirds
Kinselmeer
Open waters kan be fouraging grounds for birds like sterns and cormorants
Shipping lanes are often avoided by wildlife
Water level bandwidth
Summer: -0,30/-0,10 N.A.P.
Winter: > -0,40 N.A.P.
Hoeckelingsdam intended as a shelter for the reedlands on the coast and fouraging and nesting ground for birds
New spawning areas for fish made in polder canals
Natura 2000
Birds directive
Large problem for birds in the area is a lack of food due to limited presence of fish and waterbed fauna
Posts in the water are important lookout and resting areas for waterbirds
Ecological infrastructure Almere connecting Lepelaarsplassen & Weerwater
Smooth and straight Lijnsedijk causes little gradients and variation
Diving ducks prefer calmer areas near coasts
Deep waters allow for cooling and habitats for certain fish species
deepest point around 20 meters
Natura 2000
Birds & habitat directive
N
E
S
W

Appendix C

								ratio		
	single panel size	Wp	Kwh per year			boost cooling	10%	0,1		SUM
	1*2	360	300			boost reflection	10%	0,1		1,2
						boost bifacial	30%	0,3		
Normal array types			no of modules							
	no solar panels				Wp	kWh/year	boost		**TOTAL**	
grid	1824		21		13789440	11491200	17236800			
grid half coverage	960		23		7948800	6624000	9936000			
grid porous	1216		6		2626560	2188800	3283200			
grid porous hc	608		0		0	0	0			
grid L	3944		14		19877760	16564800	24847200			
diagonal	1824		22		14446080	12038400	18057600			
diagonal hc	960		37		12787200	10656000	15984000			
diagonal porous	1216		4		1751040	1459200	2188800			
diagonal porous hc	608		4		875520	729600	1094400			
diagonal L	1752		12		7568640	6307200	9460800			
				SUM	**81671040**	**68059200**	**102088800**		**367,52**	
	single panel	Wp	kWh/year							
	1*1.65	140	182,186809							
Vertical array types										
	Vertical bf		no of modules		Wp	kWh/ year	boost			
grid V	630		11		970200	1262554,583	1515065,5			
grid porous V	420		1		58800	76518,45957	91822,1515			
grid L V	980		17		2332400	3035232,23	3642278,68			
	Vertical bf									
diagonal V	900		16		2016000	2623490,043	3148188,05			
diagonal porous V	480		2		134400	174899,3362	209879,203			
diagonal L V	1644		22		5063520	6589332,49	7907198,99			
				SUM	**10575320**	**13762027,14**	**16514432,6**		**59,452**	
	no.	Wp	kWh/year							
solar trackers	243	18000	15500							
				SUM	**3645000**	**3766500**	**5084775**		**18,305**	

				95891360	W
ABSOLUTE TOTAL		**445,28**	**TJ**	**95,89136**	**MW**

			Covered by Solarchipelago	
	yearly use		factor	%
Amsterdam	Electricity total	16458	0,0271	3%
	Electricity houses	3102	0,1435	14%
Almere	Electricity total	2544	0,175	18%
	Electricity houses	831	0,5358	54%

Avarage houshold electictricity use	3000	Kwh
	0,0108	TJ
No. Of households		
Covered by Solarchipelago	41229	

Reference bifacial Winterthur -²		
total lenght set up	188	m
Nominal output	9,09	KWp
Yearly	942	KWh/kWP
Yearly amount	8562,8	
kWh yearly per m s	45,547	
quadrupel height	182,19	
Boosted albedo	227,73	

Calculation sources

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