Building with Nature perspectives
Cross-disciplinary BwN approaches in coastal regions

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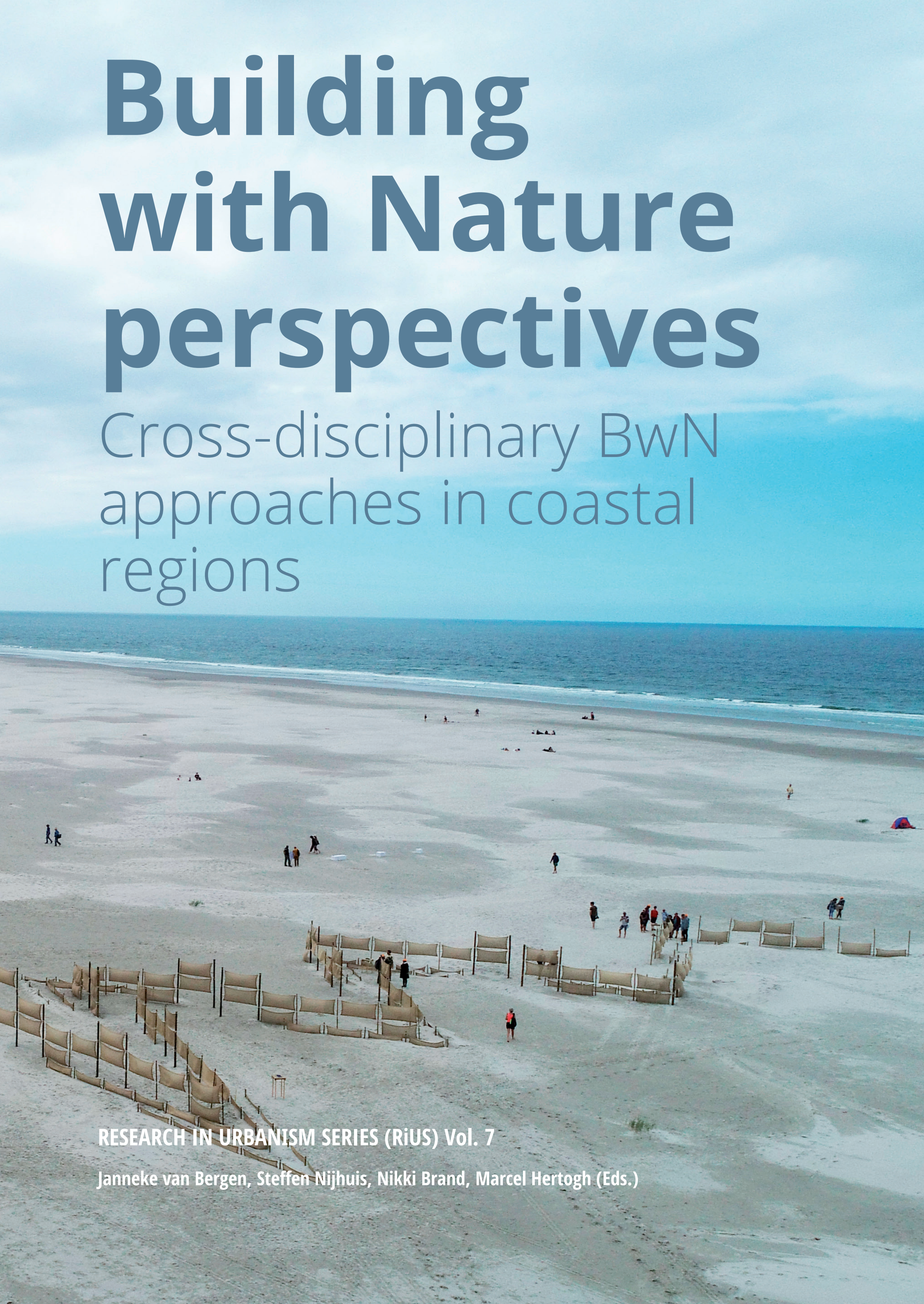

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Building with Nature perspectives:

Cross-disciplinary BwN approaches in coastal regions

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Cross-disciplinary BwN approaches in coastal regions

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Editorial

Building with Nature perspectives

This publication offers an overview of the latest cross-disciplinary developments in the field of Building with Nature (BwN) for the protection of coastal regions. The key philosophy of BwN is the employment of natural processes to serve societal goals, such as flood safety. The starting point is a systems-based approach, making interventions that employ the shaping forces of the natural system to perform measures by self-regulation. Initial pilots of this innovative approach originate from coastal engineering, with the Sand Motor along the coast of South Holland as one of the prime examples. From here, the BwN approach has evolved into a new generation of nature-based hydraulic solutions, such as mangrove forests, coastal reefs, and green dikes.

As exemplified by the body of knowledge expressed by academic literature (see graph below), the first generation of BwN pilots created valuable links between coastal engineering and ecological development. However, a link with the spatial domain of urban and landscape design remains underdeveloped. This publication aims to contribute to filling this gap. Now that BwN has proven itself as a new flood protection strategy, the time has come to investigate the new boundaries between BwN-based hydraulic solutions, ecological, urban and, landscape design to develop a new series of dynamic coastal landscapes, connecting the different disciplines. Ecosystem services and nature-based solutions already express this integral potential of BwN, showing that the reinforcement of supporting services (BwN management of f.e. soil and ecology), not only safeguards regulating services (such as flood protection) but also feeds provisioning (f.e. harvest, wildlife) and cultural services, such as recreation and landscape scenery. Another characteristic is the time aspect of

BwN. The employment of natural forces introduces a longer timeframe and certain dynamics to the planning process, creating room for adaptation. This adaptive quality of BwN is overlooked the most in the current debate about sea level rise: doom scenarios only demonstrate the failure of, or the transition to another ecosystem. They deny the resilience of the current system, that can be empowered by BwN to adapt and offer precious time for the development of transitional landscapes.

These two characteristics, multiplicity and adaptivity, make BwN a valuable strategy in times of climate change, sea level rise and urbanization; creating new solutions for resistance, response and resilience in urban deltas.

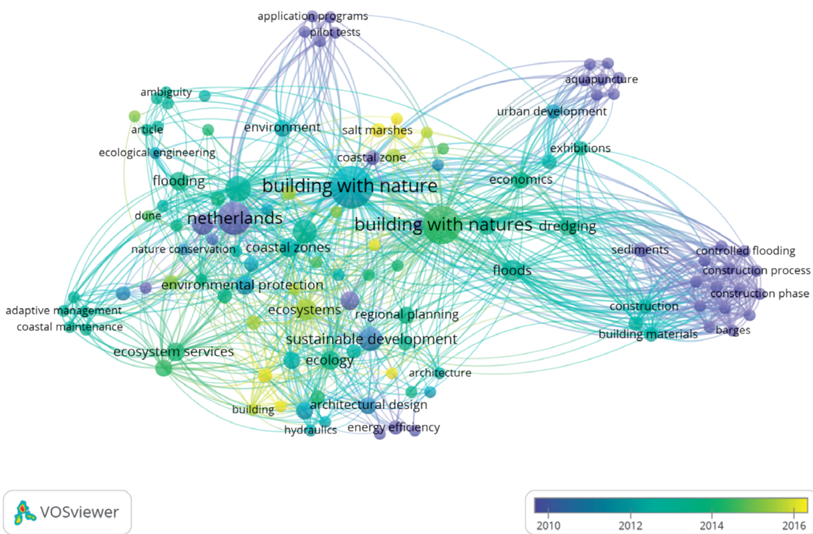

Figure 1. Thematic mapping of Building with Nature based on academic output from 2010-2016 (Vosviewer image: J. van Bergen & J. Essen). The mapping clearly shows the origins of BwN, starting from a civil engineering perspective, rooted in the Netherlands (dark blue). From here, a second generation evolved, including ecology, salt marshes and ecosystem services expressing the multiple benefits of BwN. However, spatial design is on the margins and needs repositioning.

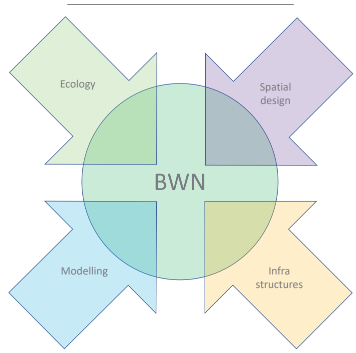

Figure 2. Projects and research, divided in four perspectives

This publication aims to explore Building with Nature as new dynamic, spatial strategy for coastal regions. It illustrates the main drivers for the next generation of BwN to evolve as well as key factors for its embedding in its physical and societal context; integrating multidisciplinary perspectives to offer more than the sum of its separate solutions. This new way of cross-disciplinary thinking and designing is illustrated by a series of projects and research, divided in four perspectives (figure 2).

Infrastructures discusses the altered perspective of large-scale infrastructural interventions in the Delta, based on the new Building with Nature approach. These artefacts incorporate forces of nature to deliver ecosystem services for coastal safety or energy, whilst incorporating other services such as nature or recreation. This asks for an interdisciplinary approach, and this chapter discusses various methods to achieve it. With dynamics as a driving force, BwN starts with understanding the system, that reaches from a local to regional (De Vries et al) and from a multi-layered to integrated design (Brand et al). Within this context, the definition of multifaceted design objectives, as well as design roles (Klaassen et al) are necessities for addressing the complexity of the BwN systems approach.

Building with nature creates new dynamic, adaptive landscapes based on a synthetic, engineered and modelled nature. This challenges **spatial design** to translate and incorporate these landscapes into their socio-economic reality, not just by addressing safety and ecology, but transforming it into a cultural landscape, offering new living environments that mediate between floods and waterfronts. This asks for *transitional design*, transferring nature-based principles to support new adaptive waterfronts, as illustrated in 'Urban dunes' by Van Bergen et al.. Van de Velde et al. address the link between BwN and landscape architecture. Landscape methodologies can support the next generation of BwN projects in the way interpretation or *mappings* of nature are made; functions are integrated by *layering* in various spatial, cultural and temporal scales; and *narratives* can stimulate the social acceptance of BwN. Heerema concludes with the role of art in the social embedding of BwN; her 'Satellite' program offers a cultural community of practice to critically investigate the Sand Motor; not only for the landscape to become part of the collective memory, but also as a reflective practice towards the artefact and technology itself.

The **Ecology** chapter discusses the correlation between BwN, ecological and anthropological regeneration. BwN not only offers engineering solutions, but also reintroduces natural processes back into the delta, creating buffer zones that restore the valuable ecosystems between water and land. This gives potential to redevelop a powerful estuary landscape with flexible transition zones between land and water for multifunctional flood protection, for nature and humans, generating new forms of amphibious living and an alternative agriculture. Cook discusses the fundaments of the ecological approach by the work of E. Odum. It stresses the importance of understanding the 'nature' of the system before intervention; including the anthropological perspective. Van Stiphout illustrates how nature is employed for biodiversity in inhabited landscapes, adding multiple values, beauty and stewardship.

Modelling discusses the representation of Building with Nature processes by computer and governmental science. These processes can be represented as algorithms and interactive data in programs and decision models. They have great meaning in the design, prediction and incorporation of BwN solutions. Luijendijk discusses how virtual morphodynamic forecasting, crucial for the application of BwN, has benefitted from the real-time and interdisciplinary findings of the Sand Motor pilot project. The development of process-based landscaping tools can stimulate the further integration of BwN related disciplines. By virtual modelling, spatial & temporal conditions can be simulated, prescribing natural and urban processes for the landscape to evolve. These digital simulations are important for design processes, but still need their physical counterparts to calibrate and bridge the knowledge gaps, as described by Wijnberg et. al.. Ruijgrok concludes with cost-benefit models for documenting the ecosystem benefits of BwN compared to traditional measures, an important tool for integrated decision making.

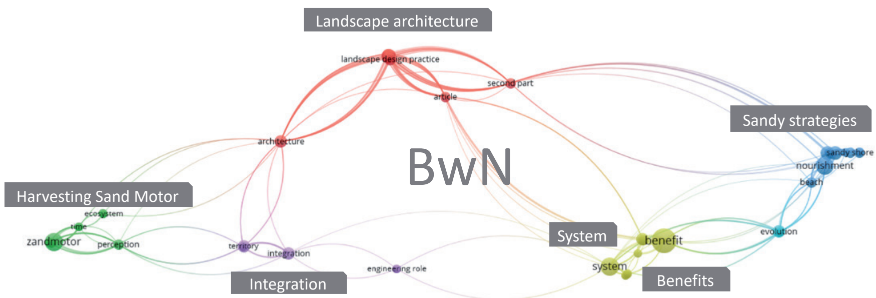

Figure 3. Mapping of Building with Nature themes added to the academic landscape based on the scientific contributions from this publication (Vosviewer image: J.v.Bergen & D.J. Ligtenbelt). The mapping shows the clusters of interest, including: continuation of sandy strategies (right); the harvesting of the Sand Motor (left); the introduction of landscape architecture (top) and shared ambitions for integration and benefits. Although connected, the future challenge will be to bring these clusters closer together.

Altering the BwN perspective

This next generation of BwN research has created a body of knowledge for the application and integration of BwN techniques. They not only show the range in which BwN solutions develop, but also introduces a new integrated scope for BwN in the spatial domain, as shown by Vosviewer-analysis (figure 3). They confirm that sandy BwN solutions will remain one of the major strategies in response to sea level rise. Now with the first pilots, like Sand Motor, operating for almost 10 years, these projects produce vital sets of data to create better understanding of the coastal dynamics involved. Furthermore, they show that the gap between BwN and landscape architecture is dissolving. A natural bond, since landscape architecture is based on the understanding and manipulation of natural systems, and offers design tools to embed BwN artifacts in their physical, cultural and societal landscape. With the emancipation of landscape architecture and art as contextual and reflective disciplines for BwN, greater integration can be achieved, raising the benefits and social acceptance of any BwN solution.

The publication was concluded with the symposium BwN Next (February 2020), collecting, disclosing and evaluating lessons learned from BwN from an interdisciplinary and international perspective to a broader audience and setting a framework for the application of BwN as a spatial strategy for urban delta landscapes. It discussed an outline of the agenda to work on: towards a deeper understanding of the systems involved; from amalgam towards a clear definition of BwN; and the set up of BwN as a learning community for generations to come.

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INFRASTRUCTURE

Building with Nature as integrated design of infrastructures

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Abstract

Many people associate Building with Nature with its flagship project, the Sand Motor. This mega-nourishment redefined the role of natural processes in civil engineering projects, demonstrating that instead of 'do no harm' as the highest possible supporting goal of coastal infrastructure, the design could incorporate natural processes to attain societal and ecological goals. As such, the Sand Motor represents a key example of the integrated design of civil infrastructures. In this contribution, we pursue an improved understanding of the integrated design of civil infrastructures, by comparing the illustrative example of the Sand Motor against a framework based on transport infrastructures and the occasional flood defence. It turns out that application of a framework from one domain to another - a conscious act of interdisciplinary learning - results in a modification of that framework. Although the domain of Building with Nature fits well with many existing attributes of integrated design for civil infrastructures (the life cycle approach, adaptive design and adding functionalities), its key attribute (dynamics) adds a unique box to the integrality index. This intellectual effort raises two issues. It demonstrates that our understanding of integrated design is rather specific for different infrastructure-domains. Second, it is likely that the bandwidth of uncertainty that is key to the incorporation of natural processes in infrastructure design, and the changing behaviour of the structure itself in the maintenance phase, has implications for the governance regime of such infrastructures.

KEYWORDS

Building with Nature, Sand Motor, life cycle approach, adaptive design, infrastructures

1. Introduction

Despite ubiquitous calls for interdisciplinary research, the conscious, strategic pursuit of such learning is often an exception to the rule (INTREPID, 2019). Multidisciplinary research packages remain the trend, and measures to integrate learning throughout the research process are established 'on the go' (DIMI, forthcoming). While on the one hand, multidisciplinary research is often sold as far more ambitious than interdisciplinary research, we suspect it is quite common that many scholars pursue interdisciplinary learning unknowingly. Scholars can also make interdisciplinary cognitive connections on an intrapersonal level (Pfirman & Martin, 2017). Interpersonal, collegial connections in team-collaboration within a university department are also systemic, especially among disciplines that are closely related to one another such as urban planning and urban design. Such curiosity-driven interactions occur daily and are likely the engine behind the creation of new academic disciplines (Lyall, 2008; Gibbons et al., 2010), although, as a rule of thumb, integrative learning is not done explicitly (Tress et al., 2005). It is possible that interdepartmental, cross-field connections on topics that sit at the intersection of multiple disciplines may be the most challenging type and this is where awareness about the methodology of interdisciplinary learning could facilitate integrative learning. This is especially the case when such problem-oriented research engages multiple stakeholders outside of academia, and a full inter- and transdisciplinary research project develops (Pfirman & Martin, 2017; Rhoten & Pfirman 2007; Tress et al., 2005). This chapter therefore aims to explicitly pursue interdisciplinary thinking, with a twofold aim.

1. First, we ask how the application of an integrated design methodology from the domain of civil infrastructure to the concept of building with nature *changes the understanding of integrated design*.
2. Second, by consciously selecting the why and how of an interdisciplinary learning strategy, we reflect on the presumed benefits of such integrative reasoning.

The chapter is structured as follows. In the first section, we outline key notions of interdisciplinary research and its presumed contribution to learning. Second, we explain integrated design methodology as derived from the topic of transportation infrastructures and the occasional flood defence. In the third section, building with nature's flagship example of the Sand Motor will be contrasted with features of different forms of integrated design in the civil infrastructure domain. How does the Sand Motor fit into our current understanding of integrated design of civil infrastructures and should that understanding be adapted? After a discussion of results, we conclude with the implications of this study, including a reflection on interdisciplinary learning.

2. Interdisciplinarity as a means for research

Interdisciplinary research – which we define as the act of interdependent learning strategies of different academic disciplines – is considered as the key vehicle to pursue knowledge and contributes to the solution of complex (socio-scientific) problems, where one discipline on its own cannot provide an answer (Lyall, 2008). Despite the increase in availability of scientific knowledge, decisive action regarding persistent, complex problems including climate change, biodiversity loss and related issues such as poverty, security and governance has been very slow (Hirsh Hadorn et al., 2008). While transdisciplinary research – learning that involves stakeholders – is considered as a means to overcome the mismatch between knowledge production in academia and knowledge requests for solving societal problems (Hoffman-Riem et al., 2008), interdisciplinary learning targets the knowledge fragmentation that undermines the capacity of society to address its complex problems. The promise of interdisciplinary research is therefore in delivering what has been called 'systems knowledge' (ProClim, 1997; COST, 2014). However, despite the urgent call for interdisciplinary learning, the organisational barriers for such work within the university's structures are large (Pfirman & Martin, 2017), the rate of progress has been slow (National Academy of Sciences et al., 2005; Krull, 2000) and confusion about the state of the art abounds (Tress et al., 2005), resulting in the term being used as window-dressing for what, in fact, is multidisciplinary research (COST, 2019). Lyall (2008) identified at least seven motivations to pursue interdisciplinary learning, as summed up below:

Table 1. Examples of motivations for undertaking interdisciplinary, policy- or practice-oriented research according to Lyall (2008)

1	The nature of the object of research is interdisciplinary (e.g. transport, environment)
2	Researchers are engaged in transferring knowledge from the laboratory to real world applications
3	The research seeks to break down barriers between science and society and encourage social acceptance of technology
4	The research is 'user-driven': either encouraging innovation by connecting technology-based businesses to market demand or involving a practice community, although not necessarily commercially oriented
5	the research may be particularly relevant to policy: many strategic issues can only be effectively addressed by interdisciplinary approaches
6	single discipline research may have encountered a bottle-neck and more than one discipline may be needed to make a breakthrough
7	or, in academically-oriented (mode 1) interdisciplinary research, for more intellectual reasons in order to promote the emergence of new disciplines and modes of thinking.

To summarize, interdisciplinarity can therefore be a means of research in four main cases: for (1) *particular objects or domains*, (2) *knowledge transfer to real-life applications*, (3) is user- or stakeholder-driven (*transdisciplinary*) work or (4) for *overcoming academic obstacles*.

The objective of this paper fits with the first and the last of these cases. First, the Sand Motor can be considered as an interdisciplinary research object, that can be addressed by a multitude of disciplines like coastal engineering, ecology, landscape architecture and civil infrastructure design. Second, our goal to consider Building with Nature from the perspective of civil infrastructure design purely for the sake of intellectual reasoning – a better understanding of integrated design of civil infrastructures – is purely academically-oriented. Having clarified why the objective of this chapter is interdisciplinary, we can consciously select a learning strategy, again following Lyall (2008).

Table 2. Examples of interdisciplinary research, according to Lyall (2008)

1	Developing conceptual links using a perspective in one discipline to modify a perspective in another
2	Using research techniques developed in one discipline to elaborate a theoretical model in another
3	Modifying and extending a theoretical framework from one domain to apply in another
4	Developing a new theoretical framework that may reconceptualise research in separate domains as it attempts to integrate them

From the four options outlined above, this chapter *modifies and extends the theoretical framework from one domain – integrated design of civil infrastructures – to the emerging domain of Building with Nature*, with the Sand Motor as an 'interdisciplinary object' or case-study. We can therefore expect the theoretical framework of integrated design to be revalued and perhaps altered, based on its application to the interdisciplinary building with nature-domain; in other words, stimulating 'new modes of thinking'.

3. Integrated design of civil infrastructures

In the larger domain of integrated design, many different understandings of the concept exist (Hertogh et al., 2018; Visser, 2020). In this contribution, we depart from examples of integrated design that were studied in our section – Integrated Design and Management – and were published in a previous publication (Hertogh et al., 2018). It is key to note that all of these case-studies are *civil infrastructures*, and that our perspective is likely influenced by the origins of civil engineering. Below, these 6 different forms of integrated design are listed. Key to understanding the different notions of integration is the rejection of the notion that infrastructure design in particular can be reduced to a single, sectoral objective with a mono-functional solution for a simplified design problem. To give a better impression of the different notions and their implications, we have included an example project for each form of integrated design and their key attributes.

	Different forms of integrated design		
	Type	**Key attribute(s)**	**Example project**
1	Fit to different scales of design	Adding design requirements	North-South subway, Amsterdam
2	Decomposition of the design (systems-engineering)	Effective breakdown of work packages in a mega-engineering project, with individual (design) requirements disciplinary, sometimes geographically	High Speed Line, railway Amsterdam-Antwerp (Hertogh et al., 2008)
3	Three-layer model	Interaction between layers and their timescale adds design requirements:	Long-term decision-making in spatial planning; Sophia Rail Tunnel with enlarged diameter (Stive, 1999)
4	Life cycle model	Incentivises contractor to pursue designs that are costlier to build, but cheaper to maintain	Design-build-finance-maintenance (DBfM contracts)
5	Adaptive design	No-regret as a key design requirement	Section ring road Antwerp
6	Multifunctional design (Visser, 2020)	Adding design requirements for different functions	Katwijk flood defense

Table 3. Six different forms of integrated design according to Hertogh et al., 2018. All forms of integrated design add design requirements to the design objective, while others seek efficiency in an effective break down of work packages.

Our working hypothesis is that different understandings of integrated design from the narrow domain of civil infrastructures can be explained, first, from paradigm shifts in design management: most notably the shift from a deterministic perspective to a complexity perspective (Hertogh & Westerveld, 2010). This paradigm shift puts more emphasis on interrelatedness of design variables, openness, and an acknowledgement that reality is knowable and controllable by a reductionist approach to problem-solving. A second factor that likely determines the differences between notions of integrated design is the design problem that they aim to tackle. Do note that with the exception of the three-layer model, all forms target large-scale (public) transportation or flood defences as examples of civil infrastructures. The three-layer model is applied in *spatial decision-making processes*, where the competition for space between different land uses is mitigated (ESPON, 2015). Rather than delivering a design itself, the layer-model is used to guide policy that informs the design of future infrastructures and land-use development. Third, it is key to note here that the three-layer model originates from the discipline of landscape architecture (De Hoog et al.,1998), and multifunctional design (of flood defences) is a hybrid between hydraulic engineering and spatial design (Voorendt, 2017). Interdisciplinary synthesis of knowledge in this domain has thus previously resulted in a different understanding of the integrated design of civil infrastructures.

4. The Sand Motor and the integrality index

A key follow-up question is therefore what the theoretical framework for integrated design of civil infrastructures currently looks like. In the previous section, we noted that there is no consensus about what integrated design of civil infrastructures actually is – rather about what it is not – and that the current understanding is that it appears in different forms, representing different *attributes* of integration within the design. To move forward, we chose a practical solution: we listed the key attributes that distinguish the different forms of such integrated design and presented them as an index, on which the example-case for Building with Nature – the Sand Motor – can be 'scored'. This flagship project of Building with Nature is a *pilot project* in the form of a large sandy peninsula: 21.5 million m^3 sand deposited in front of the coastline near The Hague in 2011 (van Oudenhoven et al., 2019). The pilot monitors the state and the functioning of the coastal ecosystem, after sand nourishment has been implemented as a solution to prevent coastline erosion. While sand nourishment as public flood safety infrastructure has been standard practice in the Netherlands since the early 1990s, the Sand Motor is *"…unique due to its size, the design philosophy behind it, and its multifunctionality"* (Van Oudenhoven et al., 2019). Five times the size of an average nourishment, the Sand Motor is expected to disperse along the adjacent coastline using the natural forces of tides, waves and wind. The design philosophy is one of Building with Nature, an *"integrated approach that harmonizes coastal management solutions with the requirements of ecosystems"* (Ibidem). Multifunctionality is sought in the combination of the primary function of coastal protection (or flood safety) with leisure opportunities in the form of a new natural landscape. The Sand Motor can therefore be seen as a new example of integrated design of civil (flood safety) infrastructure. We can analyse the integrality of the Sand Motor's design according to the attributes derived from the existing framework listed below:

	Table 4. Six key attributes of integrated design: integrality index for infrastructures	Sand Motor
1	Requires different scales for design	No, not in terms of higher and lower-scale working packages
2	Requires a geographical or disciplinary break down for design	x
3	Requires scale and speed of change to be involved in consideration of higher-tier layers or functionalities	No, not in the sense of over-dimensioning to compensate for inertia in affected tier and to accommodate change in higher tiers
4	Considers the maintenance phase explicitly	x
5	No-regret as key	x
6	Functional dominance?	x

The first attribute, different scales of design, can be discarded after some deliberation. The Sand Motor obviously consists of an enormous number of grains of sand, but different components of the nourishment cannot be designed (or controlled) at different scales. Obviously, the Sand Motor can be broken down in several components (see for example Hoonhout, 2019, who noted sand, fine silt and clay fractions, and coarse elements) in its constitution. It can also be broken down geographically, like the intertidal beach, the lower dry beach and the upper dry beach. When the project is compared however to the North-South Line example project – where everything is designed from handrail to tunnel – it turns out that the key difference is that the Sand Motor is not required to meet the design requirements immediately. As Wijnberg (2019, 105) stated: *"Contrary to hard engineering measures, the Sand Motor is not a static intervention that needs to meet all its goals upon completion when the contractors have finished their work. The Sand Motor is a dynamic intervention where nature is actually the master builder that should ensure that all goals are met over time."* The project does contain the second attribute – disciplinary break down for design: modelling the behaviour of below-water development, and the above-water development based upon Aeolian transport. According to Wijnberg (2019), the second was based on past dune growth rates as numerical models predicting above-water development with computer simulations were lacking. Third, although the Sand Motor obviously has a long-term planning horizon (as all engineering measures are designed with a certain life-time in mind) it is not an integrated design in the sense of the three-layer model. The Sophia Rail-tunnel, for example, was deliberately oversized because of its location in two layers with the lowest pace of transformation in the three-layer model: the substratum and networks (Stive, 1999). Acknowledging the higher speed of change in the highest-tier layer (occupation) and the relative inertia of the second layer (networks), the tunnel was designed with a larger diameter. This will accommodate stacked transport if the demand arises in the future. The Sand Motor, when compared with the Sophia-tunnel example, is part of the substratum-layer but was not over-dimensioned to accommodate future changes in the first occupation-layer. Moreover, the design-life of the Sand Motor is a mere twenty years, which is shorter than the speed associated with the third, subsurface layer. Fourth, the Sand Motor does match the type of integrality that we associate with the life-cycle model and the example of Design-Build-Finance-Maintain (DBfM) contracts used in the construction industry. The key issue of DBM is that they incentivize contractors to pursue designs that are costlier to build, but cheaper to maintain. This is also key for the Sand Motor, which acknowledges the maintenance-phase explicitly. The project is oversized compared to the traditional coastal nourishment projects (that occur more often), dispersing the sediment along a larger stretch of coastline using the natural forces of tide, waves and wind. Nourishment therefore has to occur less often. It should be noted however that the Sand Motor's design is not so much driven by the optimisation of maintenance costs, but by harmonisation with the ecosystem and the delivery of ecosystem services (Van Zanten, 2016). Fewer nourishments cause fewer disturbances in the ecosystem. Fifth, this flagship Building with Nature project is a no-regret design. Due to its soft-engineering nature, it does not prematurely close off future pathways to other coastal solutions in case of sea level rise or other key factors in flood safety. Sixth and last, the Sand Motor definitely does check the integrality-box for multifunctional design, incorporating flood safety, ecosystem balance and recreation in one design. In its multifunctionality, the Sand Motor is comparable to Katwijk's flood defence, in that it combines flood safety with underground parking and a more attractive, natural-looking coastline. It needs to be noted here that Katwijk also attracts direct financial benefits (parking fees) whereas the economic benefits of the Sand Motor's recreational function are indirect.

5. Results

From the perspective of integrated design, the Sand Motor, as an example of Building with Nature, ticks many boxes of the integrality-index. Four out of six attributes associated with different forms of our current understanding of integrated design fit with Building with Nature's flagship project. The rather dynamic nature of the engineering project, and the fact that the mega-nourishment cannot be broken down in smaller components that can be designed and controlled upon completion of the project, is the attribute that sets this Building with Nature project apart from the current collection of integrated projects. Strikingly, the reason why two boxes in the index are not checked can be found in the new form of integrality that is presented by Building with Nature: its dynamic nature that changes within a bandwidth provided by natural forces that cannot be forecasted precisely. This does not allow for a breakdown according to scale. The three-layer model's application to Building with Nature is somewhat problematic here. In this case, the engineering intervention affects the lowest and, theoretically slowest, layer, the underground, while its lifecycle is so short as not to facilitate permanent settlement patterns. Possibly, this would not be the case for Building with Nature-projects that target another layer, for example tsunami forests that target the highest layer. What unites examples of Building with Nature (sediment nourishment, oyster reefs and tsunami-forests) is that they often partner with dynamic, natural forces. This raises the question if the notion of scalar breakdown is not incompatible with Building with Nature-type integrality.

Overall, we can conclude that Building with Nature, when viewed as a particular form of integrated design of infrastructures with the Sand Motor as an example project, it fits particularly well with the lifecycle approach, adaptive design and adding functionalities. However, we argue that Building with Nature deserves to add its own box to the integrality-index (rather than being seen as a subcategory of multifunctional design) due to its unique attribute, dynamics. Obviously, the dynamics of natural forces represents a different form of functionality than precisely engineered co-functions. When reflecting on the presumed benefit of the interdisciplinary learning strategy followed above, this outcome is not surprising. The purpose of applying an existing framework to a new domain is to evaluate it, and in this case, is adds to the scope of a framework that was initially created for infrastructure in the form of hard engineering measures.

6. Implications

This explicit interdisciplinary research effort has two implications: one about our expectations of interdisciplinary work, and the second about the management of Building with Nature projects. In 2019, Building with Nature approaches hold great appeal for research design projects with cross-disciplinary objectives, as is demonstrated by concepts that include oyster reefs and mangrove forests for flood protection. However, we need to be explicit about how and why we are performing interdisciplinary research, and how the results are different because of it. As a rule, interdisciplinary learning is often used as a window-dressing term for what is, in fact, multidisciplinary learning, undermining the credibility of actual interdisciplinary work. This risks the dismissal of interdisciplinary learning for the wrong reasons. In the above example, where curiosity-driven interdisciplinary learning has been used for intellectual reasons, it has changed the existing understanding of integrated design. Moreover, it also raises the issue of how determinative certain research domains are for the theoretical frameworks we use. In this case, our understanding of integrated design came from the domain of civil infrastructures: geared towards transport, and with an occasional multifunctional flood defence thrown in the mix. Traditionally, these are all hard engineering measures that have to meet their design requirements upon completion. The upcoming domain of Building with Nature in the flood safety sector is different in this sense. We expect that the bandwidth of uncertainty that is associated with the incorporation of natural processes in the design of civil infrastructures, and the changing behaviour of the structure itself in the maintenance phase, have implications for the governance of such infrastructures.

Completion of the construction-phase is the default moment when hard infrastructure is assessed against predetermined and rather strict design requirements. After that, the structure is expected to demonstrate limited change, which can be compensated for by a detailed maintenance regime. Such a span of control seems unlikely for Building with Nature projects. In particular, Building with Nature projects require commissioners of civil infrastructures to acknowledge and perhaps embrace adaptivity in their policy (including legislation and financial agreements), another nudge in the paradigm shift in design management from a deterministic to a complexity perspective. To conclude, it should be noted that such modes of thinking may become more natural to certain academic disciplines.

This may be related to the object of study from which the particular discipline has originated. Landscape architecture, in particular, has traditionally worked with large spatial scales, natural processes and longer planning horizons – all attributes that belong to the landscape as the main object of study. A merging of landscape and infrastructure design efforts could therefore be a promising means to successfully organize Building with Nature projects. We can then again expect a redefinition for infrastructure and an expanded scope for its understanding – as Nijhuis and Jauslin already argued in 2015, less utilitarian, but as armatures for the facilitation of functional, social and ecological interaction.

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A systematic design approach for objectifying Building with Nature solutions

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Abstract

Hydraulic engineering infrastructure is supposed to keep functioning for many years and is likely to interfere with both the natural and the social environment at various scales. Due to its long life-cycle, hydraulic infrastructure is bound to face changing environmental conditions as well as changes in societal views on acceptable solutions. This implies that sustainability and adaptability are/should be important attributes of the design, the development and operation of hydraulic engineering infrastructure. Sustainability and adaptability are central to the Building with Nature (BwN) approach. Although nature-based design philosophies, such as BwN, have found broad support, a key issue that inhibits a wider mainstream implementation is the lack of a method to objectify BwN concepts. With objectifying, we mean turning the implicit into an explicit engineerable 'object', on the one hand, and specifying clear design 'objectives', on the other. This paper proposes the "Frame of Reference" approach as a method to systematically transform BwN concepts into functionally specified engineering designs. It aids the rationalisation of BwN concepts and facilitates the transfer of crucial information between project development phases, which benefits the uptake, acceptance and eventually the successful realisation of BwN solutions. It includes an iterative approach that is well suited for assessing status changes of naturally dynamic living building blocks of BwN solutions. The applicability of the approach is shown for a case that has been realised in the Netherlands. Although the example is Dutch, the method, as such, is generically applicable.

KEYWORDS

Building with Nature, ecosystem services, frame of reference, objectification, design, solutions

1. Nature based design philosophies

Present-day trends in society (urbanisation, growing global trade and energy demand, stakeholder emancipation, increasing environmental concern) and in the environment (loss of biodiversity, climate change, sea level rise, subsidence, etc.) put ever higher demands on the engineering of infrastructure. Mono-functional solutions designed without due consideration of the ambient system are no longer accepted. Sustainability, multi-functionality, and stakeholder involvement are required instead.

This trend equally applies to hydraulic engineering works and the associated water management system (Adger et al., 2005; Farber et al., 2006; Kamphuis, 2006; Van Koningsveld et al., 2008; Kabat et al., 2009). It triggers awareness that projects should be developed differently, multi-functional, adaptable and in line with environmental and stakeholder interests incorporated right from the start (McHarg, 1995; Mitsch and Jorgensen, 2004; Farber et al., 2006; Hallegatte, 2009; Misdorp, 2011).

Traditional approaches tend to focus on realising the primary functionality of the project and minimising or compensating the negative impacts (cf. Linde et al., 2013). Stepping beyond these reactive approaches, Building with Nature (BwN) aims to be proactive, utilising natural processes and providing opportunities for nature as an integral part of the infrastructure development process (Waterman, 2008; Van Koningsveld et al., 2010; De Vriend and Van Koningsveld, 2012; De Vriend et al., 2014, 2015; Laboyrie et al, 2018). Similar philosophies have emerged, such as 'Working with Nature' promoted by PIANC (PIANC, 2011) and 'Engineering with Nature' promoted by the US Army Corps of Engineers (Bridges et al., 2014).

Although the basic idea that engineering infrastructure should be integrated better with the surrounding natural and/or societal system has found broad support, the lack of a method to objectify BwN solutions inhibits a wider mainstream implementation. Such a method should turn the implicit into an explicit engineerable object, on the one hand, and specify clear design objectives, on the other.

Inherent natural variability and a limited understanding of ecosystem behaviour make it difficult to engineer natural components such that a set service level is achieved. Furthermore, perceptions of the extent to which one can rely on natural components, given their dynamic nature and inherent uncertainty, may differ implicitly between actors in an infrastructure development process (Van den Hoek et al., 2014). Objectification of such aspects supports a fair comparison of alternatives, thus improving the chances of BwN-alternatives to become a mainstream solution.

In this paper we demonstrate the importance of objectification as an enabler for the design and implementation of BwN solutions, while testing the Frame of Reference (FoR) approach (Van Koningsveld and Mulder, 2004; Laboyrie et al, 2018) as a means to do so. The general principles of the BwN philosophy and the steps to come to conceptual project designs are described first, followed by a description of the FoR approach, its application to a practical BwN case and the lessons learned. Although the case is Dutch, the approach is generally applicable.

2. Building with Nature (BwN)

General principles

BwN is about meeting society's infrastructural demands by starting from the functioning of the natural and societal systems in which the infrastructure is to be realised. The aim is not just to comply with these systems, but also to make the optimum use of them and at the same time create new opportunities. Doing so requires different ways of thinking, acting, and interacting (Waterman, 2008; De Vriend and Van Koningsveld, 2012; De Vriend et al., 2014, 2015).

Thinking. Thinking does not start from a certain design concept focusing on the primary function, but rather from the natural system, its dynamics, functions, and services, and from the vested interests of stakeholders. Within this context, one seeks optimal solutions for the desired infrastructural functionality.

Acting. The project development process requires different forms of acting because it is more collaborative and extends beyond the delivery of the engineering object. The natural components embedded in the project will take time to develop afterwards and one has to make sure they function as expected. Post-delivery monitoring and projections into the future are integral parts of the project. This also creates opportunities to learn from such projects than from ones that stop at the delivery of the engineering object.

Interacting. BwN project development is a matter of co-creation between experts from different disciplines, stakeholders (cf. Temmerman et al., 2013). This requires a different attitude of all parties involved and different ways of interaction, in interdisciplinary collaborative settings rather than each actor taking up his task and executing it in relative isolation.

Steps towards conceptual BwN designs

Project development generally goes through a number of consecutive phases, often in an iterative process. One might distinguish 'Initiation', 'Planning and Design', 'Construction' and 'Operation and Maintenance', but other distinctions are equally suitable.

An important starting point for any development should be the environment in which a project is to be embedded. A key characteristic that distinguishes a BwN design from other integrated approaches is the proactive utilization and/or provision of ecosystem services (e.g. Costanza et al., 2017) as part of the engineering solution. The following five steps can be applied in each project development phase to develop BwN designs (De Vriend and Van Koningsveld, 2012; EcoShape, 2012; De Vriend et al., 2015):

1. Understand the ambient system beyond the primary objective (including ecosystem services, values and interests).
2. Proactively identify realistic alternatives that use and/or provide ecosystem services, involving experts, decision makers and other stakeholders.
3. Evaluate the qualities of each alternative, including natural and societal costs and benefits, and preselect an integral solution.
4. Fine-tune the selected solution, complying with practical restrictions and governance context.
5. Prepare the solution for implementation in the next project phase, making essential elements explicit to facilitate uptake in the next phase.

Fundamental to the above design steps is a thorough knowledge of how the natural system functions and a correct interpretation of the signals to be read from its behaviour. The latter may indicate in what direction the system is evolving, how to integrate a desired development and how to make use of the ecosystem services available. They may also provide an early warning of adverse developments or indicate an increased sensitivity to natural hazards. Investing in a better understanding of the natural system and its inherent variability does not only pay off in the realisation of the project, but also to the system's overall management (De Vries et al., 2020).

3. Objectifying conceptual BwN designs with the Frame of Reference approach

The "Frame of Reference" approach

The Frame of Reference (FoR) approach (Van Koningsveld, 2003; Van Koningsveld et al., 2003; Van Koningsveld and Mulder, 2004) was developed to match specialist knowledge with end user needs by making the essential components of a decision problem explicit. In that way, the FoR approach streamlines discussions between different actors, following an interactive process to achieve ongoing refinement. To make the approach applicable in practice, Van Koningsveld and Mulder (2004) suggest the use of a 'basic FoR template' which contains a limited set of elements that appear to be systematically present in successfully implemented policies. Fundamental to this approach is the definition of clear objectives at strategic and operational levels, reflecting key elements of the policy strategy. For the operational phase, indicators are defined to verify whether or not the objectives are met. The operational phase requires specification of the following elements:

- the Quantitative State Concept (QSC),
- a benchmarking procedure,
- an intervention procedure, and
- an evaluation procedure.

These elements interact as indicated in Figure 1.

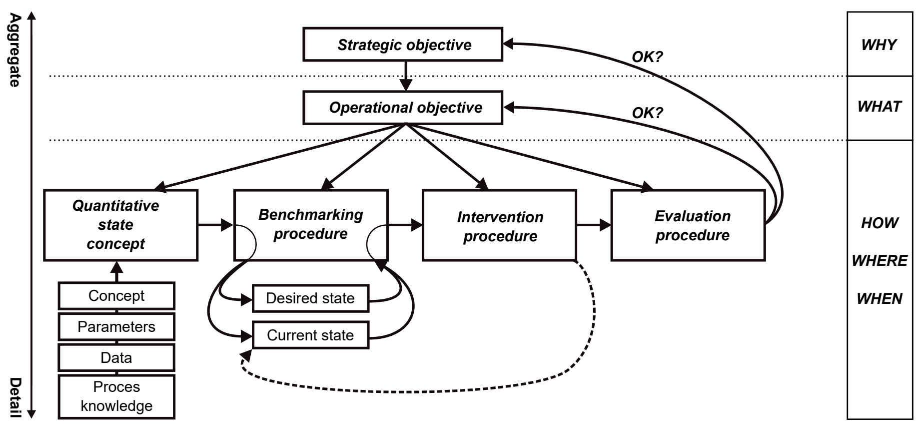

Figure 1. The 'basic Frame of Reference template' (modified from: Marchand, 2010, 2011)

It is important to identify, in a specific case, the envisaged authority responsible for the FoR as a whole, or elements thereof. The definition of elements may depend on the end user, so as to promote future uptake. Ideally, all elements of the 'basic FoR template' are made explicit in the end user-specialist interaction. Remaining 'white spots' represent information gaps for decision making and may become part of a knowledge agenda.

The FoR approach has been applied to a variety of projects, bringing together people from different disciplines, nationalities and backgrounds with policy and decision makers. It has been used (implicitly) since the 1990's in the Netherlands for the successful development and implementation of an integrated local – regional scale resolving coastal sediment management policy (Van Koningsveld and Mulder, 2004; Mulder et al., 2007; Van Koningsveld and Lescinski, 2007; Mulder et al., 2011). It was used in combination with the Argus video observation system in beach recreation planning (Jiménez et al., 2011), management of dynamic navigation channels (Medina et al., 2007) and coastline management problems (Kroon et al., 2007). It was used to define management policies for the Danube delta coast (Stanica et al., 2011), for North-West Mediterranean urban beaches (Jiménez et al., 2011), for a shingle beach in Pevensy (UK) (Sutherland and Thomas, 2011) and for Inch beach in South West Ireland (Gault et al., 2011). Ciavola et al. (2011a, b) applied it to find practical applications of real time flood predictions, that included storm induced morphology change, for coastal zone managers. Garel et al. (2014) used it to develop environmental monitoring schemes for offshore renewable energy projects. Laboyrie et al. (2018) propose the FoR approach as a tool for project assessment.

Application to BwN

Using the FoR as a rationalisation method for BwN projects, conceptual designs that emerge from the aforementioned five steps need to be broken down into clearly separated, yet interacting components, which we will call design elements. Next to a strategic objective, clearly defined operational objectives of each of these elements are fundamental. The performance of each design element can be assessed using the template of Figure 1. Once each element meets its operational objectives (the desired state), the design as a whole, consisting of the interacting elements, has to be checked against the strategic objectives. Apart from this, fitting the solution into the local governance context is crucial to move it forward to practical implementation.

In summary, this leads to the following rationalisation steps:

1. Define the strategic objective and break down the solution concept into design elements;
2. Specify operational objectives, boundary conditions, per¬formance requirements and limit levels for each element;
3. Elaborate on the elements using the Quantitative State Concept;
4. Check if each element achieves its operational objective(s);
5. Check if the interacting elements collectively achieve the strategic objective, and
6. Check how the designed project fits into the local governance context.

This objectification process can be used in each project phase, as well as for the transfer of crucial information between phases. The next section illustrates this with a practical example.

4. The Fort Steurgat case

Part of the 'Room for the River' program (Ministry of Transport Public Works and Water Management et al., 2006) was to reinstate the Noordwaard polder as a floodwater outlet, in order to cope with the increased river flow defined in the update of the regulatory design level river water discharges in the Dutch Rhine branches after the floods of 1993 and 1995. This meant that the village of Werkendam, including the historical Fort Steurgat, needed new flood protection infrastructure. Local stakeholders were against a high dike. Therefore, a lower dike design with a wave-attenuating foreshore was chosen (figure 2).

Figure 2. Final design of Forest-Dike Noordwaard (modified from: De Vries and Dekker, 2009).

The foreshore is 600m long and has a width of 60m near the edges up to 100m near the bend. It has a bank height of 0.8m above the original polder level in order to keep the roots of nearby vegetation (willow trees) from permanently submerged in water-saturated soil.

The willow species *Salix alba* and *Salix viminalis* were chosen because of their ability to cope with long inundation periods, their resistance against extreme storms and their ability to grow in clay soil. Trees are maintained by cutting, resulting in a stub from which the branches re-grow. This form of willow forest maintenance has been a common practice for many centuries in this area. The maintenance strategy involves zoning and alternate cutting to ensure sufficient wave dissipation capacity at all times. The willow forest and foreshore can be adapted to cope with changing boundary conditions if need be.

5. Rationalising a Building with Nature concept using the FoR approach

To demonstrate the applicability of FoR to the rationalisation of BwN projects, we apply the iterative six-step procedure to the case of Fort Steurgat in the next chapters. In Figure 3, the FoR structure is illustrated and numbers shown indicate the chapters where steps are elaborated.

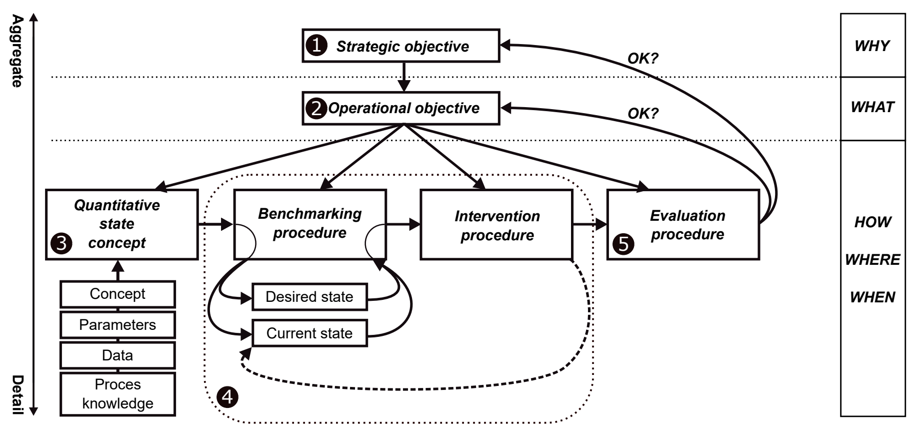

Figure 3. The five steps of the Frame of Reference provide an iterative link between detail quantification of services delivered (how, where and when) and aggregate level formulation of objectives (why and what) within an iterative process.

Step 1: Define the strategic objective and break down the solution concept into design elements (figure 3).

The strategic objective of the Fort Steurgat flood protection system was to design, construct and maintain a hybrid flood protection solution that complies with legally required safety levels while delivering additional nature and landscape value, including an as low as possible, grass-covered dike, less construction costs and more stakeholder satisfaction.

We adopt this strategic objective and the final design outlined in Figure 2 as a starting point to demonstrate the objectification process.

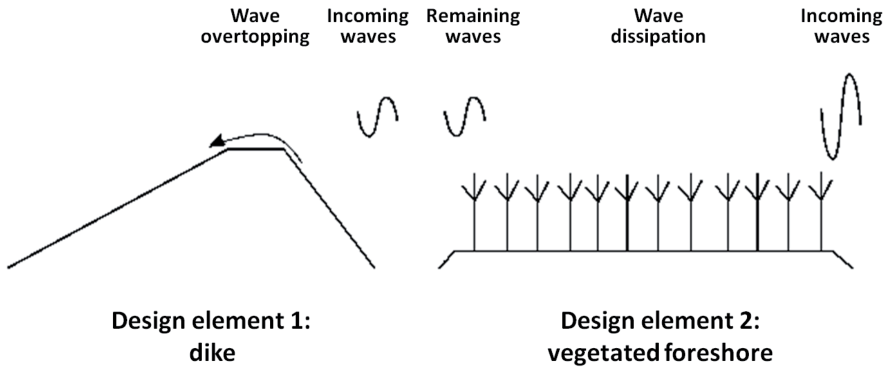

Figure 4. Visualisation of design elements for the foreshore-dike (hybrid) flood defence Noordwaard.

For any dike, geotechnical stability and crest height are key requirements. The strategic objective of having a low grass-covered dike indicates that overtopping will become the main design criterion and that geotechnical stability in that case requires special attention. Two elements of the conceptual design play a key role in achieving the strategic objective, viz. the dike protecting Fort Steurgat (slope, height, and dike cover) and the vegetated foreshore (width, height, and vegetation cover), see Figure 4.

Step 2: Specify operational objectives, boundary conditions and performance indicators for each element.

The next step in the process is the specification of operational objectives per design element. (see Figure 3). The Fort Steurgat flood protection system, as a whole, had the operational objective to provide protection against flood and wave conditions with a probability of occurrence of 1/2000 per year, as required by Dutch legislation (Ministerie van Verkeer en Waterstaat 2006, 2007) at the time.

Both design elements play a role in achieving this objective. Element 1 (dike) should be able to withstand the 1/2000 per year water level and associated wave overtopping. Element 2 (foreshore) should reduce the wave height at the toe of the dike to an acceptable level. Clearly, the two are interacting, the wave-attenuation that the foreshore needs to provide depends on the wave height the dike can manage, given its crest height, slope, and cover. The ideal combination is to be determined iteratively in a dynamic optimisation process. In the remainder of this analysis, the water level was fixed at the design level and was therefore not an operational objective that could be tuned in the design. Focussing on overtopping, this led to the following operational objective for the dike:

"To achieve sufficient dike height and wave dissipation on the dike slope to reduce overtopping under design conditions to maximum 2 l/s/m"

Design parameters are crest height, inner and outer slope, and dike cover. To meet stakeholder wishes, a very mild inner slope was chosen. This allowed choosing the relatively high overtopping discharge of 2 l/s/m. Iterations between dike and foreshore design ultimately led to the following operational objective for the foreshore:

"To achieve sufficient attenuation of the incoming waves to have a maximum significant wave height of 0.5 m at the toe of the dike"

Design parameters are the height and width of the foreshore, in combination with height, width, and density of the vegetation.

Step 3: Elaborate the design elements using the Quantitative State Concept

To make the step from objectives to technical design, it is necessary to capture the essence of the operational objectives in a Quantitative State Concept (QSC) (see Figure 3). The dike overtopping rates on a representative dike profile or cross section are legally required to be calculated with PC-OVERTOPPING (available via www.overtopping-manual.com). This tool therefore serves as a quantification tool in the QSC for Element 1.

For the foreshore, wave attenuation was quantified with the spectral wave model SWAN (Booij et al., 1999), extended with algorithms for wave attenuation by vegetation (Suzuki et al., 2012). De Oude et al. (2010) used this model as a QSC-tool for the design of the willow forest in front of the dike, yielding requirements for stem diameter, drag, and density. Once the QSCs have been specified it is possible to optimise the design in an iterative process, the benchmarking procedure (see Figure 3):

- fix boundary conditions and design parameters for the element;
- create a first design of the element;
- apply the QSCs to quantify services delivered by the element design;
- compare delivered services with required services (the benchmark);
- if insufficient, adapt the element design; if sufficient move to next step.

If it is not possible to iteratively deliver a technical design that achieves the benchmark, this may trigger a revision of choices made in the previous steps. The problem may arise from poorly defined objectives and/or QSCs, but lacking knowledge, data or operational tools might also be the cause.

In the Fort Steurgat case, this process led to a dike crest height of 4.25m above ordnance level (NAP) and an outer dike slope of 1:3. Such a slope with a closed grass cover on a 0.40m clay layer will withstand waves with Hs = 0.5 m for at least 20 hours (Van der Meer et al., 2012). For the foreshore it led to a required tree height exceeding the designed water level and a minimum vegetation factor (defined as the number of stems per m^2 x stem diameter x drag coefficient) of 2.4m-1. Note that this factor varies between seasons and with the state of maintenance.

Step 4: Check if each design element achieves its operational objective(s)

The final steps in the objectification process are used to evaluate the resulting design (see Figure 3). The evaluation should address two levels, viz. the operational objective(s) for each design element and the strategic objective for the design as a whole. Also, how it fits within the local governance context should be checked.

The evaluation procedure at the level of the design element checks if the resulting design meets its operational objective, i.e. achieves its specified desired state. In the Planning and Design phase, this may seem like a trivial step, but its true added value emerges when a design is actually constructed, operated and maintained. Especially when natural elements are integrated in the design, its effectiveness should be checked regularly to account for inherent dynamics and unforeseen behaviour. This is caused by the inherent variability of such an element as it develops through time, reacting to its environmental and anthropogenic surroundings.

Step 5: Check if the elements collectively achieve the strategic objective

Evaluation against the strategic objective usually provides the strongest triggers for redesign. In the present case, a logical question would be if the feeling of nature is achieved by the willow forest. It is good to keep in mind here that the local stakeholders' initial resistance was fuelled by the desire to prevent an unattractive and 'unnatural' high dike in front of their houses. Contributing to a more natural solution that would fit better into the local context was a main driver for the present design

Step 6: Check how the final solution fits into the local governance context

An important final step is a reflection on how the proposed solution fits into the local governance context. This includes identifying the authority responsible (hence the owner of the benefits), but also problems that may ensue from new infrastructure. It also encompasses checking whether the proposed solution is financially viable and compliant with existing laws and regulations. In this case, the grass-covered clay dike design, using clay from the foreshore, with optimal design of the willow forest for future mechanical maintenance, resulted in a lower overall cost for the dike section compared to the classical design that included a dike cover consisting of concrete blocks.

6. Applicability of the FoR approach across different project phases

The analysis in the previous subsections can be regarded as the outcome of the Initiation and Planning and Design phases. Continuously reviewing the resulting FoR when moving through the other project development phases is an effective way to prevent reduced effectiveness of the final solution or even failure of the solution to deliver the intended outcome.

Unanticipated practical decisions made during the construction phase, for instance, can influence the effectiveness of the overall scheme. In the Fort Steurgat case, the FoR from the Planning and Design phase specifies the height of the foreshore and type and density of vegetation to be planted thereon. The exact type of material to heighten the foreshore may not have been specified, the types of vegetation to be used may not be readily available, available equipment to profile the foreshore may not deliver the anticipated accuracy, the moment when a proposed ecosystem service needs to be delivered may not have been specified, tree growth could be slower or less dense than expected, etcetera. Anything left (un)intentionally implicit introduces the probability that further choices will inevitably reduce the effectiveness of the overall solution. Easy access to the project's objectives and insight in how the proposed solution intends to address these objectives helps to make decisions as much as possible in line with the project's original intentions.

Similar considerations apply to the operation and maintenance phase. Dynamic behaviour is inherent to nature-based solutions. This means that regular assessments of the functionality of the solution are required. In the Fort Steurgat case, dynamic issues to consider include timing when the solution should start to deliver its full wave dissipating service and the effect that seasonality, tree mortality, disease, regrowth, succession and maintenance might have on the project's performance (also see Borsje et al., 2011).

A complicating issue, especially for projects designed for rare events like extreme floods, is that it may not be possible to test the functionality under design conditions. In the Fort Steurgat case, for instance, the design relies on SWAN and PC-Overtopping, but given the natural conditions and the 1/2000 per year probability of occurrence within the design conditions, it is not very likely that wave dissipation and overtopping can be measured in the field. To overcome this issue, measured stem diameter, stem drag and stem density on the foreshore are used as a proxy.

7. Lessons learned from application of the FoR to BwN

Based on various applications of the FoR template, some recurring issues have arisen that may serve as lessons learned. When applying the 'basic FoR template', one can avoid common pitfalls by considering the following lessons learned:

(1) Check whether each element is filled with the kind of information prescribed in the 'basic FoR template', i.e.

- Try to avoid formulating objectives as actions. In the Noordwaard case, the objective is not to build a dike with a vegetated foreshore, but to have a safe situation that is acceptable to the stakeholders.
- Check whether the operational objectives are logically connected to the strategic objective and provide sufficient handles to further elaborate the design.
- A QSC should not be formulated as an action, it should rather be linked with models or measured data.
- Think ahead, who is the actor that you envisage as the 'owner' of the objectives, as well as the underlying decision formula.

(2) Check the logical coherence of objectives, state concepts and interventions

- For each step, think about the links with previous and following steps.
- Approach the FoR from different angles (e.g. demand driven, starting from the objectives; or technology driven, starting from the QSC or the intervention). It may provide new insights into the overall coherence.
- In the benchmarking step, check whether the proposed intervention method in fact eliminates the problem.
- Consider whether the suggested intervention matches with the actor who 'owns' the objectives and with stakeholder interests.

(3) Take your time to define the desired state in the benchmarking step

- Try to support benchmarks with scientific data. Often, literature is available, e.g. what kind of dike overtopping discharges have the potential to cause damage.
- Try to avoid subjective benchmarks. Desired states like 'sufficient naturalness', for a dune area, or 'historic atmosphere', for a beach front, can hard-

ly be objectively assessed. This will present difficulties in trying to drive any concept or policy that is based on this FoR towards the next phase of implementation.

(4) Make sure in the evaluation step to reflect on the operational objective AND the strategic objective; this step provides the main triggers to modify the scheme.

With respect to the design and implementation case described in this paper, the FoR was used a posteriori to quantitatively clarify the chain of required services delivered by the natural elements of this BwN solution. Its structure defines a procedure that allows for quantification, benchmarking, intervention, and subsequent evaluation, a requirement for the long-term sustainability of the strategic and operational objectives of the design. Although the FoR was originally applied to more traditional designs, this paper shows that by its stepwise and iterative approach, it clearly provides a foundation for rationalising BwN designs that include natural elements. One valuable step forward is the further elaboration of the QSC's to better describe the natural elements regarding interactions with the ecosystem (this would require operational objectives that include the services delivered to the ecosystem as part of the design, not the case in the example). Better knowledge of natural variability can help to iteratively optimize the FoR QSC and benchmarking procedure. The used QSC's describe a static situation of a natural element and therefore can have led to an overdesign (by taking a too extreme worst-case performance as reference) or to an underestimation of risk of temporary underperformance (by not taking sufficient magnitude of variability of service on the long term into account). Benchmarking, intervention, and evaluation procedures of the FoR at least take care of the second issue raised and the application of the FoR could contribute data and management experience to further optimize the QSC and benchmarking of the vegetated foreshore design element.

The FoR approach has been helpful in identifying design elements, identifying, specifying, and documenting the QSC for the living building block of the solution. It has contributed ex ante to help setup an evaluation protocol and supporting monitoring activity in the operation and maintenance phase to establish the flood safety protection status of the dynamically developing implementation on the project site. It has become clear that the iterative and cyclic process of the FoR approach is well suited to maintaining operational objectives for a dynamically developing implementation. While it is clear that the specification of solely hydraulic operational objectives could have led to a complete 'grey' design, the strategic objective included the value of landscape and nature as important parameters. This could have produced a set of additional operational objectives. However, in the dike design process, those natural aspects have been not further evaluated, possibly leading to a underperforming implementation from a 'green' perspective. It is expected that the FoR approach will also be able to provide a complete process for those objectives. Both aspects have not been further researched yet.

8. Conclusions

This paper has shown the use of the FoR approach to rationally identify and structure physically explicit building blocks of BwN concepts. As such, it provides a valuable addition to the five steps for the design of BwN solutions. The six rationalisation steps enable the translation of abstract design concepts into tangible solutions that may be evaluated objectively. Being quantitative and explicit (for instance the ecosystem services the design aims to utilise and/or deliver) aids a fair comparison of BwN and more traditional alternatives, for example in a Cost-Benefit Analysis or an Environmental and Social Impact Analysis.

The FoR-based rationalisation approach should be regarded as an investment to enable an implementation of the BwN concept in practice. As a prescriptive tool, the FoR yields benefits in each of the project development phases. In the Initiation and Planning and Design phases. it helps to define objectives, indicators, reference states, mechanisms for mitigation, and evaluation procedures. In the Construction phase. it helps to steer unanticipated, but inevitable practical decisions to maintain conformity with the original design objectives. In the Operation and Maintenance phase. it helps to design monitoring programmes and maintenance measures that are closely tied to the original design objectives through the well-defined QSCs. As a descriptive tool, the FoR can consequently be used to evaluate existing designs, monitoring programmes and maintenance schemes.

As an integrative documenting tool, the FoR approach also improves the transfer of crucial information between project realisation phases. This helps to reduce the risk of failure or underperformance due to miscommunication or loss of important information. The FoR method was shown to work for a wide range of problems and disciplines. We believe that the example in this paper illustrates the FoR's applicability as a tool for objectifying BwN designs. The complex behaviour of natural elements results in a variability of services delivered. This issue is now safeguarded in the iterative benchmarking, intervention, and evaluation steps of the FoR. It is acknowledged by the authors that further research into better understanding this variability and the possibility of its management will help to fortify the QSC's and the benchmarking and intervention steps of the FoR when working on objectification of future BwN designs and solutions.

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Objectifying Building with Nature strategies
Towards scale-resolving policies

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Abstract

By definition, Building with Nature solutions utilise services provided by the natural system and/or provide new opportunities to that system. As a consequence, such solutions are sensitive to the status of, and interact with the surrounding system. A thorough understanding of the ambient natural system is therefore necessary to meet the required specifications and to realise the potential interactions with that system. In order to be adopted beyond the pilot scale, the potential impact of multiple BwN solutions on the natural and societal systems of a region need to be established. This requires a 'reality check' of the effectiveness of multiple, regional-scale applications in terms of social and environmental costs and benefits. Reality checking will help establish the upscaling potential of a certain BwN measure when addressing a larger-scale issue. Conversely, it might reveal to what extent specific smaller-scale measures are suitable in light of larger regional-scale issues. This paper presents a stepwise method to approach a reality check on BwN solutions, based on the Frame of Reference method described in a companion paper (de Vries et al., 2021), and illustrates its use by two example cases. The examples show that a successful pilot project is not always a guarantee of wider applicability and that a broader application may involve dilemmas concerning environment, policy and legislation.

KEYWORDS

Building with Nature, ecosystem services, frame of reference, objectification, design, solutions

1. Introduction

Building with Nature (BwN) solutions utilise services provided by the natural system and/or provide new opportunities to that system (De Vriend and Van Koningsveld, 2012). In order for BwN-solutions to be effective, the functioning of the system in which they are embedded needs to be well understood. The BwN philosophy is applicable to engineering infrastructure development in a variety of surface water systems (De Vriend et al., 2015, Bridges et al., 2018, Laboyrie et al., 2018), but also at different scale levels, from a single project to regional-scale strategies. This also means that the system functioning at this larger scale needs to be considered and understood.

Where BwN solutions are supposed to fit into such a larger-scale strategy, objective evaluation beyond isolated pilot implementations is required to demonstrate the larger-scale functionality of multiple smaller-scale interventions. On the other hand, it is important to establish which smaller-scale engineering solutions are suitable for application at the larger scale (considering the desired overall effect at the system scale, which local solutions are likely to be effective?). Important evaluation criteria are the societal and environmental costs and benefits.

The Frame of Reference (FoR) method described in a companion paper (De Vries et al., 2021) provides an explicit framework to streamline the design of water infrastructure and other processes involving complex decision making. It starts from a clear definition of strategic and operational objectives. This method can be equally applied to the development phases of individual projects and to multiple projects at the regional scale. De Vries et al. (2021) demonstrate the applicability of this method in a project context. Application of the FoR method across different scales provides an important reality check for the viability of individual BwN solutions and the overall strategy to which they contribute. In that sense, such an assessment can become a key enabler for the wider acceptance of BwN-based strategies. This scale resolving scope, however, has yet to receive the same level of attention as the project/pilot scope. The objective of this paper is to fill this gap by applying the FoR-method in a step by step process to two cases with different types of measures in different environmental settings, in order to reality-check the benefit of upscaling the implementation of BwN at a regional-scale. Subsequently, we consider a broader spectrum of BwN solutions and see what larger-scale strategic objectives they aim to meet.

2. Reality-checking regional-scale BwN solutions

The "Frame of Reference" approach

The Frame of Reference (FoR) approach (Van Koningsveld, 2003; Van Koningsveld et al., 2003; Van Koningsveld and Mulder, 2004) was developed to match specialist knowledge with end user needs by making the essential components of a decision problem explicit. In that way, the FoR approach streamlines discussions between different actors, following an interactive process to achieve ongoing refinement. Fundamental to this approach is the definition of clear objectives at strategic and operational levels, reflecting key elements of the policy strategy. For the operational phase, indicators are defined to verify whether or not the objectives are met. The operational phase requires specification of the following elements:

- the Quantitative State Concept (QSC),
- a benchmarking procedure,
- an intervention procedure, and
- an evaluation procedure.

These elements interact as indicated in Figure 1.

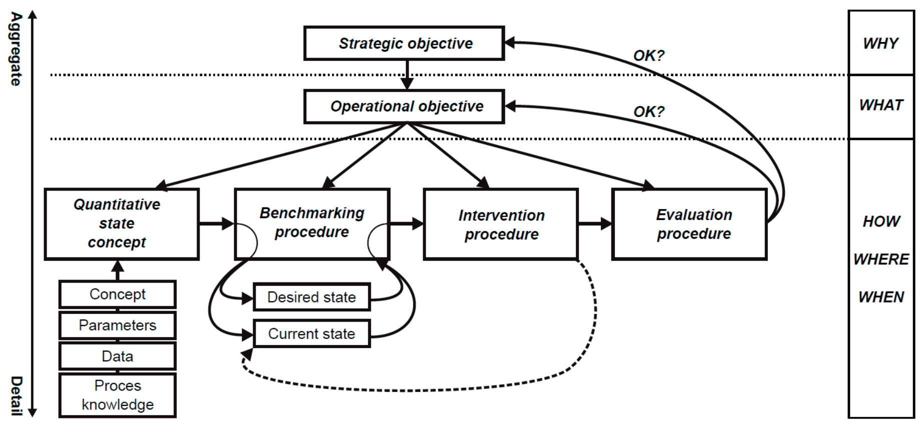

Figure 1. The 'basic Frame of Reference template' (modified from: Marchand, 2011)

Steps for scale resolving application of the FoR method

When applying the FoR method in a scale resolving management approach, recurring procedural steps are:

1. Define the regional-scale strategic and operational objectives and break down the realisation strategy into a number of logical elements (projects).

2. Specify strategic and operational objectives for each project individually.
3. Quantify the performance of each project individually in light of these objectives.
4. Determine to what extent each project meets its individual objectives.
5. Check if the combination of projects (the scheme) achieves the overarching strategic and operational objective(s), using plausible quantitative estimates of the effects.
6. Check how the designed scheme fits into the regional governance context.

Each individual project can be designed as a BwN intervention. The six-step objectification process proposed in the companion paper by De Vries et al (2021) can be used for that purpose. We will follow these steps in the following evaluation of the two example projects.

Sandy strategies for coastline maintenance (coastal, soft, abiotic)

Step 1: Large-scale strategic and operational objectives, and breakdown of the realisation scheme

The sandy shores of the North Sea Coast in the Netherlands have long been eroding as a result of the combined effects of sea level rise, reduced supply of river sediment and ongoing land subsidence. After finalisation of the Delta works, attention to countering this ongoing erosion has increased. This materialised into a policy to preserve functions and values in the coastal zone (*strategic objective*). An extensive study of coastal processes at various time and space scales (Stive et al., 1990) revealed that maintaining the coastline requires adding an amount of sand of the order of 10 million m^3 per year. Therefore, the Netherlands government established a sediment management policy aimed at keeping the coastline at its 1990 position, the Basal Coastline (BKL) (*operational objective*; see Van Koningsveld and Mulder, 2004). To that end, a volumetric coastline definition was laid down in law.

Note that this maintenance policy is different from interventions ensuing from the regular coastal safety assessments. The latter focus on dune erosion during a mega-storm event, rather than on the sand volume in the coastal profile.

The maintenance policy is presently implemented by means of beach or shoreface nourishments along the Dutch coast wherever the coastline recedes beyond the BKL. The design lifetime of these nourishments is generally some 5 years. Evaluation of this policy led to the conclusion that this approach meets the objectives as far as the upper shoreface is concerned, but that not enough sediment reaches the lower shoreface to balance erosion there. This led to a *second strategic objective*: to maintain the lower shoreface (the coastal foundation; see Mulder et al., 2007).

Step 2: Strategic and operational objectives per nourishment project

The operational objective of each maintenance nourishment is to locally prevent structural coastal erosion. The volume of an individual nourishment was typically 1-5 million m^3, which was sufficient to achieve the operational objective for a period of 3-5 years. The Delta Committee (2008), however, anticipated a significant increase in nourishment volumes, from the present 10 million m^3/year to 40 - 85 million m^3/year, depending on the rate of sea level rise. This might necessitate larger nourishments and/or new nourishment methods. In line with the BwN-philosophy, the idea emerged to concentrate the regular nourishments in space and time, relying on natural processes (currents, waves) to distribute the sediment over the wider coastal system. As compared with smaller-scale nourishments repeated every 3 to 5 years, utilising this ecosystem service was expected to achieve the *operational objective* in a more sustainable manner. It was expected to reduce the ecological and CO2 footprint of the nourishment policy while creating opportunities for recreation and nature development, thus providing ecosystem services and addressing *additional operational objectives*.

Figure 2. The Sand Motor; left: after placement in 2011; right: in 2017. (source: Rijkswaterstaat Beeldbank, https://beeldbank.rws.nl/; photos Joop van Houdt)

Step 3: Quantification of Project performance

In 2011 an experimental 21.5 million m^3 mega-nourishment project called the Sand Motor was implemented in front of the Delfland coast (Stive et al., 2013, *Figure* 2). The design process ultimately resulted in a hook-shaped peninsula that would provide space for juvenile dune formation and resting areas for birds and seals, with a shallow lagoon that would provide habitat to juvenile fish and other species. Part of the sand would be transported onshore by wind, promoting the dune formation along the beach. The hook-shape was furthermore assumed to be attractive for beach recreation. In anticipation of coastal science and management interest, an extensive monitoring program was carried out including deployment of a video observation tower on the beach. Based on pre-project sediment balance and numerical model studies, the project was framed as being sufficient for 20 years of coastal maintenance.

The overarching objective of the Sand Engine experiment was to test whether the anticipated benefits of such a concentrated mega-nourishment, viz. auto-distribution by natural processes, the development of habitats and realization of recreation potential, would indeed materialise. This was established via monitoring programs, measuring campaigns and multidisciplinary research programs (see Luijendijk and Van Oudenhove, 2019).

Step 4: Objectives met?

Although the objectives of the Sand Motor were not formulated sharply enough to allow for quantitative evaluation (e.g. De Weerdt, 2015), Luijendijk and Van Oudenhove (2019) conclude from the results of these efforts that the effects of the Sand Motor are partly beyond expectation (recreation, biodiversity) and partly less so (ecosystem recovery, aeolian transport into the dune area, juvenile dune formation on top of the nourishment). Also, the expectation that in the coastal cell between Hook of Holland and Scheveningen no further nourishments would be needed for 20 years turned out to be unrealistic: nature takes time to distribute the sand alongshore and, in the meantime, areas further away from the Sand Motor may need intermediate nourishing in the years to come. Yet, the number of nourishments in this coastal cell would be significantly less without the Sand Motor, which means less costs (mob/demob), less energy expenditure and less CO2-emissions. Also, because the sand is deposited in a much thicker layer, the environmental impact of the Sand Motor, in terms of disturbed seabed / benthic organisms, is much smaller as the nourishment footprint scales inversely proportional to its height. Table 1 illustrates this observation, showing that the footprint of the Sand Motor is approximately similar to the footprint of a regular nourishment area. As the regular nourishment has to be repeated another 8 times to realise the same total sand volume, its total impact becomes much larger – especially as the recovery time of benthic communities in the nearshore (~4-6 years) aligns with the return frequency of classic nourishment schemes.

	volume (10^6 m^3)	volume (m^3/m)	longshore length (m)	cross-shore width (m)	mean height (m)	footprint (10^6 m^2)
Average regular nourishment	2,4	600	4000	~300	~2.0	1,2
Sand Motor	21,5	10.750	2000	~650	~16,5	1,3

Table 1. Order-of-magnitude estimates of the footprint area of a mega-nourishment and an equivalent volume of regular shoreface nourishments (regular nourishments data from Rijkswaterstaat, Kustlijnkaarten 2019, period 2009-2018

All in all, the operational objective of maintaining enough sand in the coastal profile is met over a gradually expanding stretch of coast, as well as the additional operational objective of nature-driven distribution alongshore.

Little of the nourished sediment is lost from the coastal system, but not all of it is found back on the upper shoreface. This suggests that also the lower shoreface (the foundation) benefits. In that sense, the project has proven to be successful as an experiment and a showcase.

The Sand Motor experiment has also shown that a slightly different design may help to materialise the envisaged additional benefits (Luijendijk and Van Oudenhove, 2019):

- the rate of ecosystem recovery strongly depends on the sediment composition; if it is the same as before the nourishment, recovery is rather fast; in case of a different composition it takes much longer;
- aeolian transport into the dune area, as well as juvenile dune formation on top of the nourishment, also depends on the composition of the nourished material; shells, clay and coarse sediment may cause armouring of the top layer if not frequently reworked by wave action;
- a shallower lagoon would prevent anoxia of the deeper layers, as has been the case after some time in the lagoon of the Sand Motor; the lagoon would also fill up more rapidly and, with its fertile mud deposits, it would sooner become a green dune area;
- the lake at the Sand Motor tends to trap wind-blown sediment, at the expense of juvenile dune formation in front of the existing dunes;
- the environmental benefits of the hook-shape can be doubted, if it were only because it rapidly evolves to the more natural shape of a gaussian hump and therefore exhibits a very dynamic low biodiverse environment.

Finally, expectations among stakeholders and the public should be managed by careful framing of this type of high-exposure projects.

Step 5: Overarching objectives met?

Given this experience, are mega-nourishments the best method to maintain the North Sea coast if 40-85 million m^3 of sand is needed per year (Delta Committee, 2008)? In an analysis, 'before the fact', Mulder et al (2007) conclude on the basis of a numerical model study looking 150 years ahead that:

- repeated nourishments high on the profile (i.e. the beach or the upper shoreface) are effective in keeping the coastline in place (operational objective), but insufficiently compensate coastal retreat at deeper water; the resulting steepening of the profile leads to an increasing 'loss' of sediment to deeper water; from the perspective of the second strategic objective, however, this 'loss' is rather a gain, though by itself insufficient to maintain the coastal foundation;
- maintaining the coastal foundation along with sea level rise ultimately

reduces coastline retreat; hence a better maintained coastal foundation requires less coastline maintenance in the long run; It can be questioned though whether the reduction of coastline maintenance volumes compensates for the extra sand needed to maintain the coastal foundation. The latter also depends on the exact formulation of the objectives and the definition of the coastal foundation.
- both the coastline and the coastal foundation profit locally – and over a gradually increasing reach – from concentrated nourishments.

Apart from these qualitative conclusions, Table 1 shows that 40 million m^3 per year would mean roughly 16-17 regular nourishments per year, with a total footprint area of 20 106 m^2 and a disturbed coastal length of approximately 67 km. If the whole volume would be realised with mega-nourishments of the size of the Sand Motor, only 2 would be needed per year, with a total footprint area of 2,6 106 m^2 and only 4 km of initially disturbed length. Although a comparison of these numbers is probably not fair, they do illustrate the need to prepare for a different nourishment practice utilising larger nourishments.

To what extent the benefit/cost ratio of mega-nourishments is higher than that of smaller-scale traditional nourishments depends on the perspective taken. From the point of view of the short-term operational objective of keeping the coastline in place, traditional nourishments may be more cost-effective (immediate return on investment in terms of sand on the coast). Yet, the economy of scale works in favour of large nourishments. Mobilisation and demobilisation costs are less, as are operational costs, as larger trailing suction hopper dredges can be employed, and less sediment has to be pumped onshore. Van der Bilt (2019) showed for a regular nourishment project that approximately 60% of the total CO2-emissions were associated with pumped unloading. Avoiding this significantly reduces the energy expenditure and the CO2-footprint. Note that changing the preferred nourishment strategy (two 20-million m^3 nourishments per year, instead of twenty 2-million m^3 nourishments) demands a thorough revision of the present-day planning strategy for coastline maintenance.

When taking a strategic, long-term perspective, the additional physical, societal and environmental benefits of mega-nourishments may help turn the balance (Oost et al., 2016; Brown et al., 2016). To what extent this is indeed the case depends on the local conditions: not every location is suitable along a coast with so many vested interests and so much infrastructure (beach resorts, harbours, marinas, outfalls, landfalls, etc.).

Step 6: Governance context

The Netherlands government has a clear coastal maintenance policy in place, with well-defined strategic and operational objectives at the scale of the Dutch coast. Prevailing laws and regulations explicitly support the policy of dynamically preserving the coastline with the BKL as a reference, but this is not (yet) the case for the coastal foundation. Hence beach and foreshore nourishments have a legal basis and can be enforced, but other types of nourishments, like concentrated mega-nourishment, can be challenged by opponents claiming negative effects. This means that at present, mega-nourishments on the North Sea coast require consensus of many stakeholders, which clearly reduces the agility of mega-nourishments as a method of large-scale coastal maintenance. On the other hand, positive side-effects of mega-nourishments increase the number of potentially supportive stakeholders, hence the possibilities for finding additional funding sources.

With the lessons learned from the Sand Motor experiment, application of multiple mega-nourishments seems technically and ecologically feasible, though possibly complicated by the involvement of many stakeholders and vested interests.

Eco-enhanced scour protection (marine, hard, biotic)

Step 1: Strategic and operational objectives and breakdown of the realisation scheme

The North Sea is rich in marine resources including fisheries, aggregates (sand and gravel), oil and gas. It is one of the most productive seas in the world, with a wide range of plankton, fish, seabirds and benthic communities. The area contains some of the world's most important fishing grounds. The deeper northern regions of the North Sea have a higher diversity and less biomass than the shallower southern regions. Many human activities have an impact on the biodiversity of the North Sea. The marine ecosystems are under intense pressure from fishing, fish farming, seaweed farming, invading species, nutrient input, recreational use, habitat loss and climate changes; most notable are the effects of fisheries and eutrophication. As a result, the whole marine ecosystem in the North Sea is deteriorating. Similar trends are observed in many shelf seas around the world, caused by intensifying exploitation, eutrophication and pollution. (see, for instance, http://www.coastalwiki.org/wiki/Biodiversity_in_the_European_Seas#_note-North_Sea, http://reports.eea.europa.eu/report_2002_0524_154909/en).

Offshore wind farms play an important role in the transition to sustainable energy and much effort and money are spent to develop them. This raises the question to what extent these efforts can be directed to the benefit of ecosystem restoration. Commercial fisheries are not allowed in wind farms in the Netherlands sector of the North Sea (Staatscourant, 2018), but this only provides potential shelter and breeding ground to species that easily migrate, such as fish. Less mobile species, such as crustaceans, reef building worms and shellfish, once removed from the area, do not easily come back via re-colonisation, by lack of larvae sources, favourable biophysical or biochemical feedbacks, and specific habitats.

Recently, the Netherlands Government added an extra requirement to tenders for new wind farms in the North Sea: 'to *make demonstrable efforts to design and build the wind farm in such a way that it actively enhances the sea's ecosystem, helping to foster conservation efforts and goals relating to sustainable use of species and habitats that occur naturally in the Netherlands'* (Regulation 2.15, Netherlands Enterprise Agency, 2018). This nature-inclusive design requirement stimulates engineering consultants and contractors to look for eco-enhancing scour protection methods. It illustrates the government's additional *strategic objective* to rehabilitate the North Sea ecosystem and make wind farms contribute to it through eco-enhancing measures (*operational objective*).

In the framework of the overarching strategy towards renewable energy, the government has designated a number of areas in the North Sea for wind farming (*figure 3*).

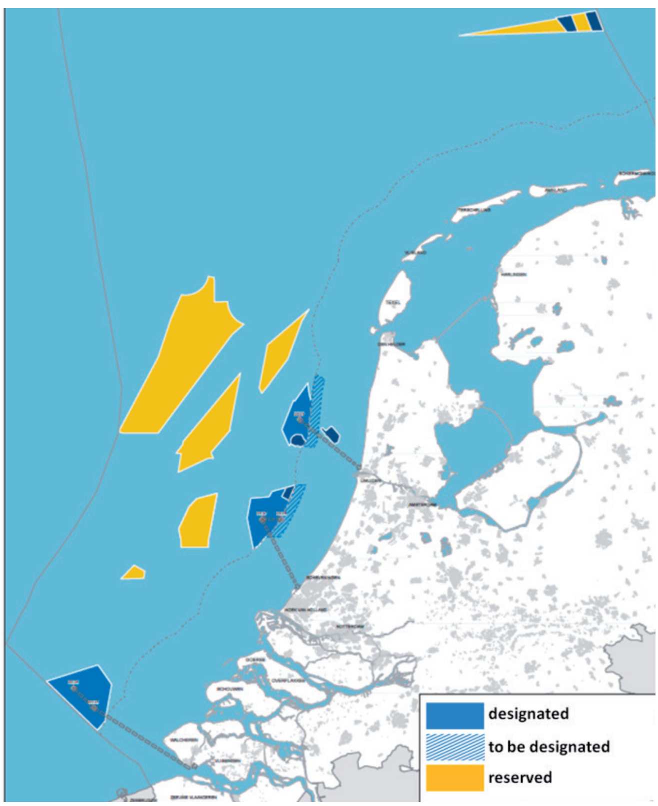

Figure 3. Designated wind park areas in the Dutch part of the North Sea

Realisation of these wind parks, however, is left to the market, so there is no all-encompassing realisation scheme consisting of envisaged individual wind park projects. Moreover, the open formulation of the above requirement does not enforce a coherent overarching realization scheme of eco-enhancing measures. Therefore, we will focus on the scalability of a single class of measures, viz. providing suitable hard substrate.

Step 2: Strategic and operational objectives per wind farm project

Apart from the obvious objective to produce a certain amount of wind energy, the government has introduced an additional *strategic objective*, namely the requirement to contribute to local ecosystem rehabilitation. This can be realized by creating habitat for a number of designated species (*operational objective*).

Depending on the situation, waves and currents may necessitate the seabed around the substructure (mostly monopiles) to be protected against scour, usually by a rock filter (*figure 4*). The design of these filters used to be based exclusively on technical and financial grounds, but in light of the 2018 requirement it has become attractive to explore how they can contribute to ecosystem rehabilitation.

Figure 4. Scour protection around monopiles: opportunity for habitat creation? (source: Van Oord)

Step 3: Project performance

There are basically three methods to ecologically enhance wind farms (Groen, 2019):

1. Habitat creation or enhancement, such that it is more suitable for a number of target species. Scour protection designs can be adapted to achieve this, but also specially designed elements placed in the space between the monopiles (hard substrate, rock mounds, etc.).
2. Stock enhancement, which aims at increasing the abundance of less mobile target species by introducing individuals (larvae, juveniles, adults) that have been reared or cultivated elsewhere. This new stock should be large enough to start a viable and self-sustaining colony within the wind farm.
3. Food enhancement, which aims at increasing the amount of food available for the target species. This may involve additional habitat creation and stock enhancement for the food or prey species.

Table 2 gives a suitability index of wind farms for a number of representative species as a function of the degree of eco-enhancement.

	NS	WF + SP	WF + ESP	WF + SP + SE	WF + ESP + SE
Atlantic cod	2	4	5	4	5
European lobster	1	2	3	2	5
Flat oyster	0	2	3	3	5
Ross worm	1	3	4	3	4
Total	4	11	15	12	19

Table 2. Suitability index (0 = very unsuitable, 5 = very suitable) of wind farms (WF) in the North Sea (NS) with a standard scour protection (SP), an enhanced scour protection (ESP) and stock enhancement (SE). Source: Groen (2019).

Focusing on habitat creation for crustaceans and shellfish, eco-enhancement should aim at the creation of shelter or hard substrate. Rock-filter scour protections around monopiles (*figure 4*) provide hard substrate, as well as shelter in the spaces between the rocks. If the top layer of the filter is made coarse enough, this may provide shelter to larger crustaceans, such as lobsters. Also, between the monopiles of a wind farm there is space for habitat creation. Hard substrate combined with spat seeding may help the return of the flat oyster in the North Sea (Kamermans et al, 2018). Offshore mussel cultures, once economically attractive, are expected to help enrich the marine ecosystem (Van den Burg et al., 2017). Even though fishing within them is not allowed, wind farms may function as breeding, seeding and nursery grounds for the surrounding sea, thus contributing to the stock for fisheries there.

From an ecological perspective boundary conditions are relevant. Therefore, the potential to optimise the ecological value of a windfarm depends on the location in the ecosystem. Factors such as depth and typology of the seabed, hydrodynamics of waves and currents, distance from coasts and river mouths that govern availability of nutrient and light, suspended sediment concentration and sediment transport, and characteristics of the surrounding ecosystem will determine the type of species communities that can establish successfully within the wind farm.

Groen (2019) analysed for a number of species the potential contribution of the Gemini wind farm, a 600 MW wind park in the North Sea north of Groningen, consisting of two plots of 75 monopile-based turbines. Apart from modifying the rock-filters with a coarser armour layer, he added rock piles, concrete tubes and shell-filled nets in the remaining space. Moreover, he imported lobsters and oysters as stock enhancement. *Table 2* gives an overview of indicative costs and estimated effects. It shows that significant stock increases can be achieved, but at significant extra costs, especially of the coarser armour layer and the adaptation of the filter it necessitates. Note, however, that these extra costs are minor as compared with total costs of the wind park.

Food enhancement will partly be natural, because the seabed is no longer disturbed and mobile species will re-colonize the area. A man-made contribution could be to discard by-catch from passing fishing vessels, but this is by no means sufficient enough and, at the moment, this is against prevailing regulations (in the EU by-catch has to be landed). So far, monitoring of ecological post-implementation project performance is not enforced by wind farm regulations from the Netherlands Government. This will hamper assessment of project performance from a nature-inclusive design perspective, hence feedback of experience onto new projects.

		Original design	**Enhanced design**
Costs (1000 US$)	Filter	1995	2888 - 4115
	Armour	2095	2851
	Rock piles	-	68
	Concrete tubes	-	184
	Shell-filled nets	-	153
	Lobster stock enhancement	-	288
	Oyster stock enhancement	-	955
	Total	**4090**	**7387-8614**
Effects	Estimated number of codfish	1,500 - 93,000	3,000 - 240,000
	Estimated number of lobsters	< 1,000	2,000 - 36,000
	Estimated number of oysters	< 1,000	> 20,000
	Estimated area covered by Ross worm	15,000 m^2	22,000 m^2

Table 3. Indicative costs and effects of eco-enhancing the design of the 150 monopile 600 MW Gemini wind farm. Source: Groen (2019)

Step 4: Objectives met?

In the example shown, the strategic objective of contributing to ecological enhancement will probably be met. Since concrete operational objectives have not been defined, it is not possible to establish the extent to which they are met. Since the effects are estimates based on ecological knowledge gleaned from other locations and other substrates, and there is an influence of the local boundary conditions on what habitats will be established, there is uncertainty how much of the estimates will be (partly) achieved in reality.

Step 5: Overall strategic and operational objective(s) met by the scheme as a whole?

As long as there are neither quantified objectives, nor a coherent realisation scheme, this question cannot be be answered. Yet, the potential effects of a single 0.6 GW wind park (Table 3, bottom part), combined with the ambition of realising as much as 11.5 GW wind energy production on the Dutch Continental Shelf of the North Sea by 2030 (also see Figure 3), gives the hope that there is potential of a significant degree of larger-scale ecosystem rehabilitation. It can be envisaged that the large scale and wide distribution of offshore wind farms will act as stepping stones for species to re-colonise large parts of the North Sea. This needs to be supported by an overarching policy framework that sets clear ecological goals, that allows a translation into operational objectives, otherwise well-meant initiatives per wind park are bound to be wide ranging in technical solutions, and suboptimal or ineffective at the larger scale.

Step 6: Governance context

In order for this rehabilitation potential to materialise, co-ordination between wind park developments now and in the future is necessary. This requires an overarching ecological restoration strategy, setting targets for biodiversity and ecosystem dynamics and resilience. This must be supported by national or international legislation enabling the implementation of this strategy. In that regard, the aforementioned requirement of the Ministry of Economic Affairs (2018), though not objectifiable enough, can be considered as a sign of political will.

3. Other cases

The applicability of the BwN philosophy, and the need to consider the upscaling potential of individual projects, is much wider than the two examples described above. Environments in which BwN has been applied range from marine, via coastal and estuarine, to riverine and inland lacustrine. The infrastructure development may involve abiotic interventions (sand, mud, rock) intended to enhance the ecosystem, biotic ones (seeds, larvae, vegetation, biobuilders) meant to aid or replace hard engineering structures, or mixtures of the two (see Table 4 for a number of examples).

Environment	Abiotic	Mixed	Biotic
Marine	Landscaped sand extraction sites (de Jong et al., 2015)	Eco-enhanced scour protection (Lengkeek et al., 2017)	Coral rehabilitation (Doropoulos et al., 2019)
	Increase speed of habitat recovery by depth variation	Rehabilitate shelf sea ecosystem by habitat creation	Restore ecosystem by seeding or transplanting coral
Coastal	Sand Motor (Luijendijk & van Oudenhove, 2019)	Mangrove rehabilitation (Winterwerp et al., 2013)	Marrowgrass plantation (McHarg, 1969)
	Reduce effective impact on submarine ecosystem / Create sandy supratidal habitat for pioneers	Restore mangrove-based ecosystem and fish stock	Create conditions for pioneer dune vegetation
Estuarine	Shoal nourishment (van der Werf et al., 2019)	Oyster reefs (Walles et al., 2016)	Spartina introduction (Chen at al., 2008)
	Restore intertidal habitat and bird foraging area	Maintain intertidal habitat / formation of live oyster banks	Maintain intertidal marsh / create habitat for other species
Riverine	Longitudinal training dams (Collas et al., 2017)	Willow forest foreshore (de Vries et al, 2021)	Reedbed creation (Sussex Wildlife Trust, 2013)
	Create more diverse river bed habitat	Restore native vegetation, create wetland habitat	Create habitat for endangered bird species
Lacustrine	Houtribdijk sandy foreshore (Steetzel, 2017)	Marker Wadden (Natuurmonumenten, 2019)	Reedbed creation (Sussex Wildlife Trust, 2013)
	Create sand-rich habitat for lacustrine vegetation	Create bird-paradise / clean up surrounding waters	Create habitat for endangered bird species

Table 4. Examples of ecological objectives (obj.) to which BwN-solutions (case) in different environments contribute

4. Discussion

The cases described herein illustrate that for BwN solutions to achieve their full potential at the system scale, they need to be based on a thorough understanding of the natural system, plausibly embedded in a large-scale strategy, as well as part of a larger scale co-ordinated policy arrangement, supported by corresponding legislation and regulations. Moreover, techniques to quantify the effects of multiple BwN projects at the scale of the ambient biotic and abiotic systems need to be developed or improved and supported, more than at present, by post-project monitoring programs. This will ultimately enable plausible estimates of the regional-scale effects and evaluation against overarching strategic and operational objectives at this scale level.

Since it interacts with the natural system, and is part of the natural system, BwN inherently involves uncertainties as it is subject to natural variability and dynamics. This means that plausible estimates of the effects are the best one can give, exact quantities make no sense. It also means that objectives concerning the ecosystem need to be formulated in approximate terms and should focus on the system's resilience, rather than on numbers of individual species. A way forward could be habitat area mapping (specific for each species community) and habitat quality assessment (considering various kinds of local influence factors and larger-scale factors such as connectivity). They can be the basis for estimating both local and large-scale effects. If climate change comes into play, the rate of change of environmental conditions such as temperature is important. Since the infrastructural projects applying BwN solutions are often designed for many years ahead, climate change scenarios have to be taken into account when considering the long-term effects.

The present analysis focuses mainly on the ecosystem, but other environmental aspects, such as carbon and nitrate emission and sequestration also need to be considered. Greenhouse gas emissions of dredging operations to realise sandy solutions can be optimised, but so far, the costs of emission reduction are often much higher than the value society attributes to it at the emission market. CO2 as well as nitrate are bound by vegetation, but they also stimulate certain species, so the question is whether it is the desired vegetation that survives in the long run. This raises the issue of maintenance of the nature component of BwN solutions in order to keep them functioning. Post-project monitoring is vital to make progress here and allow future improvement to such BwN designs.

5. Conclusion

Reality-checking of BwN-solutions for larger-scale applicability requires two perspectives: (1) what is required to realise the large-scale strategic objectives and (2) what is the performance of a single BwN-project in the light of these requirements? The Frame of Reference method offers a systematic way to evaluate BwN-solutions from these two perspectives.

The cases considered herein make clear that plausible quantification of effects and evaluation of effectiveness are only possible if objectives have been formulated in quantifiable terms. They also show that effectively applying multiple BwN-solutions at a regional scale requires a well-defined overarching strategy and legislation directing realisation. In many cases, both are still lacking.

Yet, it has become clear that many BwN-solutions have a distinct up-scaling potential for many types of ecosystems. It is evident that post-implementation monitoring is scarce, hampering the iterative process of the FoR and therefore the degree of learning from realised innovations. Mainstreaming BwN clearly requires more work at various fronts and by various parties.

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Engineering roles in Building with Nature interdisciplinary design

Educational experiences

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Abstract

Building with Nature (BwN) infrastructure designs are characterised by disciplinary integration, non-linearity, diverse and fluid design requirements, and long-term time frames that balance the limitations of earth's natural systems and the socio-technical systems created by humans. Differentiating roles in the engineering design process may offer strategies for better solutions. Four complementary engineering design roles were distinguished, namely: Specialists, System Integrators, Front-end Innovators, and Contextual Engineers. The key research question addressed in this paper asks, *how can the introduction of engineering roles enhance interdisciplinary processes for BwN design?* Three Building with Nature design workshops with international groups of students from multiple disciplines and various education levels provided the ideal context for investigating whether engineering roles enhance such interdisciplinary ways of working. Results indicate that the application of engineering roles in each of the three workshops indeed supported interdisciplinary design. A number of conditions for successful implementation within an authentic learning environment could be identified. The engineering roles sustain an early, divergent way of looking at the design problem and support the search for common ground across the diverse perspectives of the team members, each bringing different disciplinary backgrounds to the design table. The chapter closes with a discussion on the value of engineering design roles and their significance for the Building with Nature approach.

KEYWORDS

Engineering roles, interdisciplinary ways of learning, Building with Nature design, authentic learning experiences

1. Introduction

The future of engineering in society is changing dramatically as the 4th industrial revolution sets the pace for artificial intelligence that will be embedded in every aspect of our lives (Jescke, 2016) and we are confronted with increasingly complex societal problems associated with environmental challenges, such as climate change (Schwab, 2017; Kamp, 2016). In this emerging future, complex decision-making processes can no longer be realised in isolation. Instead, extensive collaboration with diverse stakeholders, a pro-active attitude, multidisciplinary expertise and technology-based and innovative solutions, are required. Building with Nature is an ecosystem-based approach to hydraulic engineering that seeks to design innovative multidisciplinary solutions rather than conventional hydraulic infrastructures (Slinger et. al., 2015; 2016). Building with Nature strives to use natural materials, ecological processes and interactions, in designing effective and sustainable hydraulic infrastructures for areas threatened by environmental and climate change (Waterman, 2010). It requires multifunctional engineering design competence and draws on knowledge of ecological systems, governance systems, and understanding of the physical and social environmental context within which the infrastructures are placed. Additionally, it requires the management of complex decision-making processes (see Bontje, 2017; Oudenhoven et al., 2018), posing challenges to the existing disciplinary and sectoral boundaries and the time frames of conventional coastal governance (Raymond et al., 2017).

Such a multifunctional, ecosystem-based approach is much needed as about eighty percent of the world population will be living in urban lowland areas by 2050 (De Vriend & Van Koningsveld, 2012), areas which will be under threat of flooding due to to sea level rise and the increased occurrence of storms. Building with Nature projects require the involvement of specialists in ecology, economics, civil engineering and the social sciences. Additionally, local stakeholder involvement is crucial to the success of Building with Nature projects (Bontje et al., 2017). Therefore, Building with Nature requires a different way of interdisciplinary thinking and acting than most engineering fields, to arrive at a better design result (De Vriend et al., 2015).

This paper explores and evaluates the application of a training method to enhance interdisciplinary thinking. Three Building with Nature workshops form the contextual design setting in which international student teams and senior experts from diverse disciplinary backgrounds as well as a broad group of local stakeholders undertake authentic design challenges. Although Building with Nature designs require the integration of disciplinary content knowledge (a.o. civil engineering, ecology, governance, spatial design), the training is targeted at skills related to collaboration within design teams – by means of introducing so-called 'engineering roles' (see below). The key research question addressed in this paper therefore reads:

How can the introduction of engineering roles enhance interdisciplinary processes for BwN design?

The concept of engineering roles was first created by the Free Spirits Think Tank at Delft University of Technology in 2015 in response to the question "What do future engineers need to know?" (Kamp & Klaassen, 2016). Four complementary roles were distinguished, namely: Specialists, System Integrators, Front-end Innovators, and Contextual Engineers. The Think Tank members considered that the increasing complexity of societal and environmental problems meant that monodisciplinary approaches would be inadequate and that simply collecting multiple disciplinary experts together in a design team would also be insufficient. Instead, a multidisciplinary team of experts skilled in adopting different engineering roles appropriate to the design context, while still honouring their disciplinary knowledge, was required. Team members need first and foremost to use their disciplinary knowledge to synthesize and integrate across different knowledge bases, but also need to be able to shift their personal (engineering) role within the design team so as to enable innovative solutions and new ways of working together (Kamp & Klaassen, 2016).

The three one-day, place-based Building with Nature design workshops served as thematic hubs in which to test the relevance of the engineering design roles, designed by the 4TU Centre for Engineering Education, in a practical interdisciplinary educational context. The workshops were conducted under the auspices of the NSF-PIRE research program (Partnerships for International Education and Education) 'Coastal Flood Risk Reduction'. This is a collaborative partnership between Texas A&M University in Galveston, Rice University in Houston and Delft University of Technology in the Netherlands, involving senior academics as well as PhD, Masters and Bachelor students. An annual, two-week long exchange programme in The Netherlands forms part of the programme. The interdisciplinary, Building with Nature workshops focussed on Texel in 2016, Petten in 2017, and Kinderdijk in 2018. The first workshop in 2016 also served as a pilot intervention for the NWO CoCoChannel research project, focussed on the southwestern corner of Texel. In each of these Building with Nature workshops, the effects of the engineering design roles on the educational experience of the participants was evaluated.

After first theoretically grounding the character of the Building with Nature design process and solution space, the necessity for engineering roles within interdisciplinary design is examined (Section 2). This serves to establish Building with Nature design settings as suitable environments for learning interdisciplinary skills. Next, the configuration of the Building with Nature design sessions is described in terms of the participant selection (Section 3.1), the three design assignments (Section 3.2), their nesting within a game structuring approach in the workshops (Section 3.3), and how the evaluation of the effects of the engineering roles on the Building with Nature design processes will be undertaken (Section 3.4). In Section 4, the 2016 pilot workshop is presented in which the Building with Nature design approach is tested and the effects of the engineering roles are explored. Finally, the ways in which the engineering design roles influenced the workshop outcomes – the Building with Nature designs – and the learning of participants in 2017 and 2018 are presented and analysed in Section 5. The chapter closes with a concluding discussion on the value of engineering design roles and their significance for the Building with Nature approach in Section 6.

2. Theoretical grounding

2.1 The Building with Nature design process and solution space

Building with Nature (BwN) is an emerging field, which requires integration across social, environmental and engineering disciplines (Slinger et al., 2016). Solutions need to be multifunctional and integrated (Kothuis, 2017). Inter- and transdisciplinary approaches offer integration processes whereby design teams can arrive at solutions that fall within a feasible boundary space. This boundary space can be envisaged similarly to the doughnut economic model (Raworth, 2017), as squeezed between societal needs and the earth system boundaries that need to be taken into account in any BwN design. The BwN solution space therefore represents a complex multidimensional space balancing the limitations of earth systems (outer blue shapes) and the socio-technical systems created by humans (inner green shapes).

The solutions space is typically multifaceted, a dynamic space changing per location and yielding different and separate insights at the case issue level, compared with the self-organising complex patterns at the overall system level (Newing, 2009). Therefore, Building with Nature solutions are characterised by disciplinary integration, non-linearity, fluid design requirements, and long-term time frames. This requires an interdisciplinary approach, merging multiple stakeholder insights. According to Fortuin (2015), educational activities which may stimulate an integrative interdisciplinary approach (particularly in the environmental sciences) should involve a real-life complex environmental problem, close collaboration in a team, changing perspectives, transcendence of disciplinary knowledge to experience complex reality, interaction with external stakeholders to encounter the norms and values held in society, and a reflection on the design/research process in the light of societal norms and values. A Building with Nature design process intrinsically satisfies these conditions as integration across the ecological and engineering knowledge fields is necessary, at a minimum. Additionally, the situation of the design in a particular place means that the values of local actors and the fit with the social, cultural heritage have to be taken into account. An engineering roles approach, which we will introduce below, proved to support students in adopting different perspectives as they design integrated solutions within the multifaceted, environmentally and socially dynamic Building with Nature solution space.

Figure 1. The Building with Nature solution space (in orange), squeezed between societal (socio-technical) needs (in green) and earth system boundaries (in blue) (adapted from Raworth, 2017). The depicted earth system boundaries and the activities such as recreation are not exhaustive or fixed, additional green and blue shapes can be added as required by the specific location.

2.2 Engineering roles and interdisciplinary design

The engineering roles of Specialist, System Integrator, Front-end Innovator and Contextual Engineer are defined as complementary roles applicable across diverse engineering fields from environmental engineering to aeronautical engineering, each addressing a different heuristic question, and guiding the investigation of the problem to come to a solution (Kamp & Klaassen, 2016). While the Specialist focuses on *phenomena*, System Integrators emphasize *the integration of different components within the overall system*, Front-end Innovators address the *user experience* and try to bridge the gap between technology and society by designing consumer-oriented products, and the Contextual Engineer addresses *the conditions* under which the technology can ethically, legally and culturally be used by creating rules, regulations, or cultures of acceptance in society (*Box 1*).

The following types of engineers tend to play different roles in projects and work environments, as they start with different heuristic questions (A complete description is digitally available from http://issuu.com/danielleceulemans2/docs/future_proof_profiles_digital):

- **Specialist:** How can we advance and optimize technology for innovations and better performance using scientific knowledge?
- **System Integrator:** How can we bring together disciplines, products or subsystems into a functioning whole that meets the needs of the customer/environment?
- **Front-end Innovator:** How can we advance and apply knowledge and use technology to develop new products for the benefit of people (end users)?
- **Contextual Engineer:** How can we exploit diversity-in-thought to advance and apply knowledge and use technology in different realms to develop products and processes for the benefit of people in different cultures and contexts?

Each role cannot realise a technological solution without the others and is needed to realise integrated solutions for complex problems (Kamp & Klaassen, 2016).

Box 1. Description of the engineering roles

The engineering roles are intentionally not specified in terms that are characteristic of a particular environmental engineering discipline and thus are more abstract. They are part and parcel of the process of negotiating meaning (Beers, 2005) and this makes them potentially applicable across a broad spectrum of design problems. Ideally, the roles avoid a situation where different perspectives are merely aligned, but instead help in achieving integration rather than just aligning across diverse problem and solution perspectives. More importantly, each of these roles is essential in realizing an integrated design solution. As such, they are conceived as stimulating the integration of different disciplines and concomitant interdisciplinary ways of working.

Interdisciplinarity can be understood as combining two or more disciplines at the level of theory, methods, or solution space, to form a transcendent and innovative understanding or solution, that in turn can possibly transform the mono-discipline(s) (Repko, 2007; Menken & Keestra, 2016; Fortuin, 2015). Two interdisciplinary ways of working can be distinguished, namely: within a team of experts with different disciplinary backgrounds, or an individual using the theory, methods and solutions from disciplines other than their area of expertise in seeking an answer to their research or design questions. Here, we are primarily interested in interdisciplinarity in teams. Interdisciplinarity in a team means that each participant's disciplinary constructs, concepts, and procedures are brought into question, are criticized and debated, as similar terminology often holds different meanings within different disciplines. The factual knowledge of participants and their reflective and problem-solving skills across tasks and solutions, constitute elements of the interdisciplinary learning process (Stentoft, 2017). This prompts them to challenge their prior beliefs and requires participants to remain open to review and even redefine their understanding and ideas (Boix Mansilla, 2010).

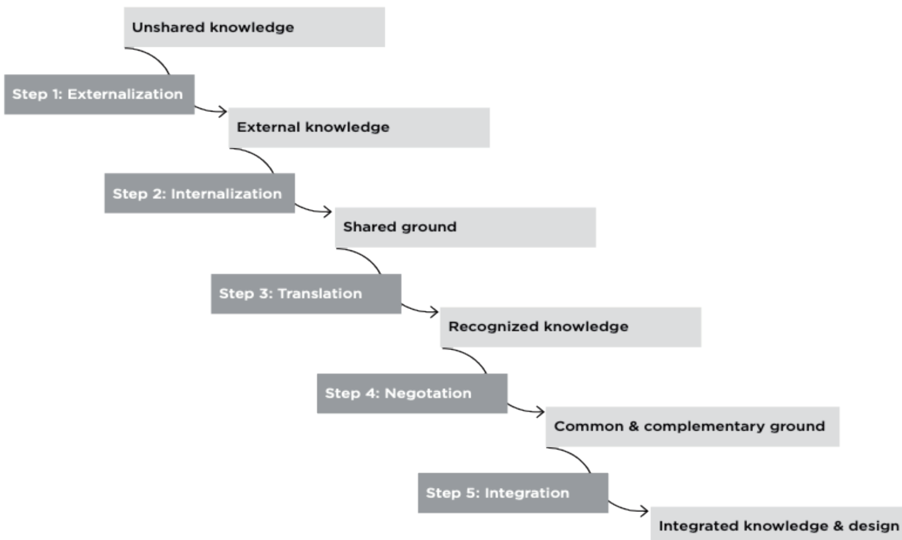

Figure 2. From unshared to integrated knowledge by B.L.M. Kothuis (2017, p. 218) adapted from P. Beers, (2005, p. 12)

Redefinition involves clarifying or modifying the concepts and assumptions used by relevant disciplines in order to reach a common meaning (Repko, 2007). According to Beers (2005), engaging people's thinking in interdisciplinary teams is a demonstrated precondition for richer solutions to complex problems. Creating common ground, in which meaning is aligned through negotiation with all the team members, is thus necessary for the construction of shared knowledge (Beers, 2005; Van den Bossche et al., 2006). Whereas Beers (2005) distinguishes four steps as necessary to move from unshared to constructed knowledge in multidisciplinary teams, Kothuis (2017) adds an extra step to arrive at integrated knowledge and design. She affirms that an additional step in which the shared knowledge is translated into recognizable knowledge for the disciplines involved in the design process, is essential in moving to truly integrated knowledge. Moreover, Kothuis (2017) has shown that this conceptual model of knowledge construction through negotiation is a valuable tool, particularly in Building with Nature research teams.

Team members will hold different assumptions and values on how to conduct an interdisciplinary effort. Being open to ways of doing outside of a participant's own discipline is challenging. Accordingly, differences in value sets and assumptions regarding outcomes need to be identified and negotiated in meaning making discussions (Jay et al., 2017). The idea is that engineering roles may assist in engaging in such "negotiation of meaning" (Beers, 2005).

Hooimeijer et al. (2016) demonstrated that the engineering roles take on different levels of relative importance depending on the context and phase of a design. The engineering design roles are minimally interdependent to facilitate the flexible realisation of an integrated solution. Different roles are needed in different phases of the design process. For instance, each Specialist has monodisciplinary knowledge that is then provided to a System Integrator who builds larger objects, systems or services, or to a Front-end Innovator who designs products, systems or services needed by industry or the public. The Contextual Engineer facilitates the technological innovations and may have the role of, or support, a client, a government authority, a legal or cultural change agent.

The claim is that engineering roles stimulate an interdisciplinary approach to the realisation of common ground within a design team, including discussions about norms and values across disciplines and an appreciation of diverse stakeholder perspectives. They help in shifting perspectives, finding and recognizing common ground, and in the development of more innovative and integrated solutions, so that they fall within the Building with Nature solution space doughnut.

3. Designing the Building with Nature design workshops

3.1 Participant Selection

As an innovative design concept, the Building with Nature workshops were intended to extend the participants beyond their comfort zone. Each workshop was attended by between 20 and 30 carefully selected participants with different disciplinary backgrounds, nationalities and levels of education. In 2016, there were 10 students from educational organisations in the Netherlands (2 Phd's, 8 MSc's), and 9 students from educational organisations in the United States of America (USA), (6 Phd's, 2 MSc's, 1 BSc), In 2017 there were 10 from the Netherlands (2 Phd's, 7 Msc's, 1 BSc) and 16 from the USA (5 Phd's, 3 MSc's, 7 BSc's). In 2018, there were 12 from the Netherlands (3 PhD's, 9 MSc's) and 16 from the USA (4 Phd's, 4 MSc's, 8 BSc's). The institutions involved were Delft University of Technology, the University of Twente, Vrije Universiteit (VU) Amsterdam, IHE-Delft, Texas A&M, Rice University and Jackson State University. Each of the American student participants went through a stringent selection process in Texas, involving a personal motivation letter and interview. The Dutch students were selected based on their disciplinary backgrounds to ensure a wide distribution across disciplinary fields. The senior researchers, experts and local stakeholders were selected based on their interests, local knowledge and their ability to communicate about their disciplinary expertise in an understandable manner. Accordingly, the disciplines of all the participants differed substantially, ranging from civil engineering to spatial planning, economics, ecology, hydrology, architecture, computational hydraulics, communication, oceanography and policy analysis. The backgrounds of the local stakeholders varied, but a representative of the local water authority and a Building with Nature expert was present in each case.

Figure 3. Case study contexts for the Building with Nature design workshops in 2016, 2017, and 2018, indicating the form that the engineering role intervention took in each case (in black).

3.2 Design Assignments

The design assignments given to the participants in the workshops represent real-world, societal challenges in which innovative solutions are required for long-term flood defence. Each of the assignments required the integration of knowledge on the dynamics of the bio-geophysical system into the engineering design process. Further, each assignment required the integration of the local knowledge of stakeholders regarding values, norms and social and ecological system functioning to arrive at a feasible Building with Nature solution to the local long-term flood defence problem. The design assignments for each of the workshops are listed in *Box 2*.

Each design team was required to (i) name and depict their Building with Nature design with diagrams and drawings, (ii) describe the dynamic characteristics of the design, (iii) describe their design process, and (iv) provide a 5 minute poster pitch. They were supplied with a bucket of material, including handouts with background information and maps of the case study site as well as writing, drawing and crafting material. The material was supplied to encourage them to be creative in fulfilling the design requirement instructions and preparing their Building with Nature design pitch for the other teams, local stakeholders and experts.

2016 Texel: Design alternative coastal management strategies (or improve the current strategy) using the natural channel-shoal dynamics to ensure safety from flooding and serve other functions

2017 Petten: The Hondsbossche and Pettemer Sea Defence no longer met the required safety standards. Design alternative coastal protection strategies (or improve the current strategy) so as to comply with required safety standards both now and in 2050, taking compatibility with the bio-physical, social and institutional environment into account in your integrated design.

2018 Kinderdijk: The Alblasserdam-Kinderdijk dike requires strengthening to continue to meet flood safety standards. Produce integrated designs for the area that achieve flood safety for the Alblasserwaard polder, as well as improving the accessibility of Kinderdijk, and creating additional ecological value through the application of Building with Nature principles.

Box 2. The Building with Nature Design assignments for participants in the 2016, 2017 & 2018 workshops

The assignments focused on collaborative design activities to engender learning. Each assignment served as a catalyst for interdisciplinary assessments of physical flood risk and modelling, characterising the socio-economic setting, analysing land-use change and the built environment, and coming up with innovative designs and mitigation measures to address residual impacts. In each case, attention was paid to the effectiveness of hard structures as opposed to soft flood defence infrastructures in combating the adverse effects of flood events.

The case study locations of the "Razende Bol" near Texel (2016), the Hondsbossche and Pettemer Sea Defence at Petten (2017) and Kinderdijk near Ablasserdam (2018) are depicted in *Figure 3*.

3.3 A game structuring approach

The game structuring method was first applied successfully in South Africa (Slinger et al., 2014) before being implemented in Houston in Texas (Kothuis et al., 2014), on Texel in the Netherlands (d'Hont & Slinger, 2018), and in Tema in Ghana (Kothuis & Slinger, 2018). The game structuring method represents an extension to problem structuring approaches, and is focused on incorporating diverse stakeholder values into a common understanding of a complex real-life problem situation (Cunningham et al., 2014). The method comprises a series of six steps, namely:

1. Get acquainted
2. Identify stakeholders and main interest groups
3. Determine relevant systems and their values (how they are used and appreciated)
4. Develop possible outcomes
5. Vote on the outcomes
6. Explore the space for commitment to action.

Step 4 is the integrated design step in which the design teams develop different potential solutions and outcomes. In each of the three Building with Nature design workshops this step was nested within Steps 2 to 5, which are deemed necessary for obtaining sufficient contextual information to be able to design. Step 6 was omitted as this is most relevant for workshops in which local residents and authorities commit to engaging in complex decision making processes for their area. Experts provided information via presentations in Step 3, and Step 2 was sometimes preceded by a presentation by a local stakeholder or water authority representative to provide information on local interests, concerns, and regulations. In a game structuring workshop, participants are encouraged to consider negative, as well as positive, future outcomes (i.e. utopian and dystopian design outcomes) so as to extend the solution space by considering a broad range of options. Dystopian futures often provide sharp insights into the values held by stakeholders.

In 2017 and 2018, following the evaluation of the pilot design workshop (see section 3.4), Steps 2 and 3 were explicitly integrated with the engineering design roles and a final evaluation/reflection step was added.

3.4 Evaluation of the effects of the engineering roles

The introduction of the engineering roles concept into the three Building with Nature design workshops may be viewed as an intervention in a complex socio-technical and environmental system (McKenney & Reeves, 2018) aimed at establishing whether and to what extent engineering roles enhance interdisciplinary ways of working in Building with Nature design processes. Because little is known of the utility and effectiveness of the engineering roles in design education, the first workshop represents a pilot intervention, and the following two workshops represent iterations to improve upon the experiences of the previous workshop(s).

The 1st Building with Nature Living Lab Workshop in 2016 was conducted in Delft, but was attended by experts and local stakeholders familiar with southwest Texel. A role questionnaire was administered to determine the preferred role of each participant, and was then used to compose teams with mixed roles (4 roles in one team), nationalities, disciplines and education levels. The preferred roles could mostly be enacted within the design teams. Where this was not possible, participants were assigned a role different from their preferred role. Significant time was allocated to explaining the engineering roles to the participants. At the end of the workshop, they evaluated the engineering roles by filling in a journey map (*figure* 4). This evaluation method is qualitative, and aims to gain as much insight as possible into the perception and experiences of the participants with the engineering roles. Key aspects of the design process (e.g. design process, consultations) are visualized on the journey map and participants map their experiences as positive , neutral, or negative with respect to these key aspects (open circles), and sub-aspects (closed circles) (*Table 1* and *Figure* 4). Subsequently, the qualitative data from the journey map were clustered and used in redesigning the intervention for the next workshop. Other evaluations included the observations of the workshop facilitators.

Design process	Consultations	Roles	Needs for coaching
Problem definition	Experts	Value for education	In future education
Design criteria	Stakeholders	Crossdisciplinary	
Exploration of solutions	Others	perspectives	

Table 1. Aspects and sub-aspects of the design process as mentioned on the Reflection journey map in Figure 4.

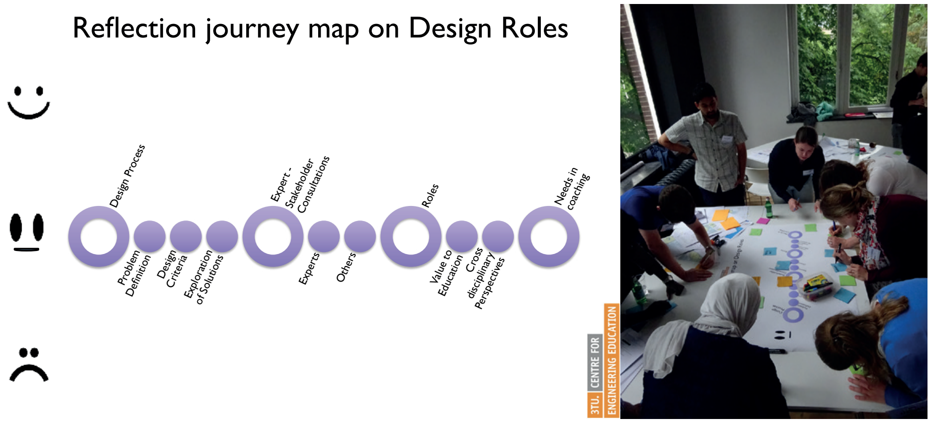

Figure 4. Evaluation of the engineering roles used in the 1st Building with Nature Design workshop.

In 2017, the design problem concerned the strengthening of the Hondsbossche and Pettemer Sea Defence, near Petten in North-Holland. The workshop was held on location. Drawing on the experiences of the previous year, the engineering roles were no longer assigned specifically to individuals, but formed an integral part of the design assignment. Prior to the workshop, the participants completed the "Engineering Role Questionnaire" to discover their preferred engineering roles. Each team member was then assigned responsibility for ensuring that a particular engineering role perspective (possibly their preferred role, but not necessarily) was adopted in the design process, yet every team member could give input on each role. The engineering roles were integrated into Steps 2 and 3 of the game structuring method, and the evaluation was administered via a questionnaire in the bus on the return journey. The questionnaire comprised sixteen (5 point Likert scale) questions regarding participants' perceptions of the elements in the workshop process relating to the engineering roles; the explanation of the roles, the use of the roles in the design process, the impact on negotiation of meaning and the relevance of the engineering roles. The questionnaire had a 100% response rate (25 out of 25). The reliability (internal consistency of the questionnaire) expressed in the Cronbach alpha (measuring from .00 unreliable to 1.0 reliable) is .93. Results are presented by means of descriptive frequencies, as the participant numbers do not allow statistical analysis beyond descriptive results.

The 3rd workshop was held on location at Kinderdijk with the same engineering role allocation process as in 2017. The design worksheet (*figure 5*) was simplified so that completing the engineering roles component of the workshop required less time. Consequently, the roles were only considered in Step 4 of the game structuring process where the stakeholders and challenges were clustered from the perspectives of the four engineering roles. The engineering roles were also used in the final phase to reflect back on the extent to which the design criteria were considered and met in the final designs, and to make sure the different stakes originating from the role's perspectives were covered. Additionally a substantive content-based evaluation was undertaken at the end of the 3rd workshop, while the evaluation was administered via a questionnaire in the bus on the return journey. The questionnaire contained thirty (5 point Likert scale) questions about recognition, usefulness, ease of use and so on, and had a response rate of 27 out of 27. This questionnaire contained many of the same questions as the 2017 version and a number of additional questions. The internal consistency of the questionnaire, its reliability, measured by Cronbach's alpha is .91. Results are again presented as descriptive frequencies owing to the low number of participants.

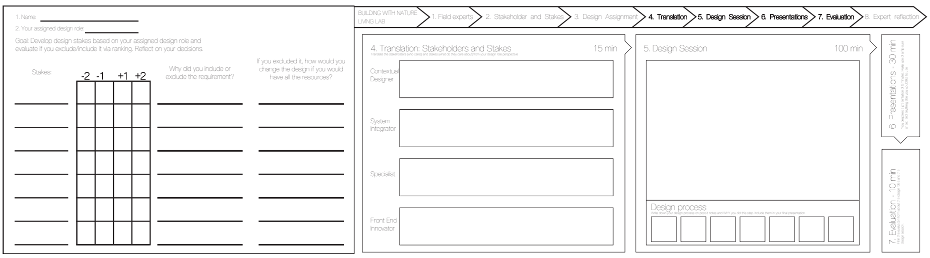

Figure 5. Design worksheet 3rd workshop at Kinderdijk.

4. Piloting the engineering roles within a Building with Nature design process

In the pilot workshop in 2016, the potential Building with Nature solutions generated by the different design teams were diverse, and were characterized by substantial attention for dynamic natural processes and societal interests such as education (*figure 6*). The input from stakeholders via presentations and their availability for consultation during the day meant that the final designs included new and relevant Building with Nature knowledge.

The positive, neutral and negative issues identified by the participants in each of the keyword categories on the journey map used in evaluating the engineering roles in the first workshop in 2016 are reported in *Table 2*. Selected quotes provide an impression of the findings in relation to the engineering design roles and the responses they elicited.

Participants indicated that the engineering roles forced them to think about different issues in the design process and to explore different perspectives on the problem. In general, they facilitated the definition of boundaries for the solution space. Finally, they gave structure to the design process, helped them to think outside of the box yet to keep a clear focus and not get lost in engineering detail.

Figure 6. Teams involved in designing integrated Building with Nature solutions for the Razende Bol pilot case study near Texel.

The stakeholder consultations were divided into the identification of stakeholders for the design versus the consultation of experts who were present at the workshop. Participants indicated that they valued the experts' input: "Experts were awesome!!". Consultations helped in deepening an understanding of the dynamics of the problem situation regarding the "Razende Bol" at Texel.

The feedback on the adoption of the engineering roles was diverse. Some participants claimed that their design team used all the engineering roles. Others stated that they were better helped by the disciplinary background information provided by experts in presentations.

Some queried whether the roles actually added to the design assignment at all. Still others remarked that the roles helped in deciding "what to talk about", and there were three people who identified completely with their engineering roles. Most of the participants who failed to enact their role indicated that they did not understand their roles, felt pressured, or had an equal score on different roles, or simply had a "good" group process without adopting the engineering roles. All in all, there was a diverse experience amongst the participants in regard to engineering role adoption.

The design process [19 post-its: 15 positive, 2 neutral, 2 negative]	
Positive	"This was my "natural" role, although I had a tie between specialist, system integrator and contextual engineer. I found this role best fitting to my personality and working strategy."
Neutral	"Everyone in the group contributed to the design process. I did very well in defining the problems, however the diversity in the group roles didn't match with one approach."
Negative	"Having a given role made me feel like I had to be in that role and the other roles I couldn't participate in and felt pressured to be only in that role."
Stakeholder consultations [10 post-its: 5 positive, 1 neutral, 4 negative]	
Positive	"Think about pros/cons doing whole process."
Negative	"Morning brainstorming on stakeholders/challenges took too long." (3x)
Roles [21 post-its: 7 positive, 5 neutral, 9 negative]	
Positive	"Working with students from other disciplines and filing different roles made me think out of (my) the box!! "
Neutral	"Need more information on specific roles and some orientation on roles might help."
Negative	"I was an expert/specialist based on the survey. But, I personally do not know anything about the subject. So, that did not help with the design procedure."
Crossdisciplinary perspectives [8 post-its: 6 positive, 1 neutral, 1 negative]	
Positive	"I like being in this role b/c I had to look @ many aspects of these issues, not just one specific one."
Coaching needs [7 post-its, 3 neutral, 4 negative]	
Neutral	"I would need more coaching in what my role really means to profit from it, other than I just do what I always do. Also I took the role of specialist a bit, not really working with the roles."

Table 2. Responses of participants to the engineering design roles in the 2016 Texel workshop.

While the value for education was not rated highly, the relevance of the engineering roles for interdisciplinary design largely received positive feedback. Most participants emphasised the usefulness of different perspectives in identifying strengths and weaknesses in the designs. The roles helped in keeping the overall design objective as the focus instead of the expertise of individuals, and supported learning from people with other disciplinary backgrounds.

Clearly, future design assignments need to include structured guidance from a role perspective for participants to benefit optimally from the engineering roles. The provision of specific information on the engineering roles in advance and during the workshop could support enacting the roles more effectively. Based on this insight and the successful application of the game structuring approach in aiding students to develop Building with Nature designs in this pilot application, the 2017 workshop design was adapted to explicitly link the presenting experts and their preferred roles and to provide a worksheet to guide the participants in the design process from a role perspective. No changes were made to the game structuring approach.

5. Engineering roles in the interdisciplinary design processes

In 2017 and 2018, the integrated Building with Nature designs produced by the participants ranged widely across the potential solution space. All designs included biophysical and social elements and adopted a long-term time frame. In the Hondsbossche Pettemer case study, participants placed more emphasis on the design requirements in relation to stakeholder values and engineering perspectives, whereas in 2018, the participants paid more attention to the problem definition, taking the local constraints to the solution space into account. This led to slightly less diverse designs for the tidal river area of the Ablasserdam-Kinderdijk.

The distribution of engineering role preferences across the workshop participants in 2017 and 2018 are depicted in *Figure 7*. In 2017 the majority of participants preferred the specialist role or multiple roles, and there were few system integrators. By contrast, in 2018 nearly half the participants preferred a Contextual Engineering role, with 33% exhibiting a System Integrator profile and 17% preferring the Specialist role. Noteworthy is that the Front-end Innovator role is completely absent in 2018. All four roles were assigned to the design teams, which meant that some participants, and teams, had to leave their comfort zone(s) and adopt a new way of thinking supported by the engineering role.

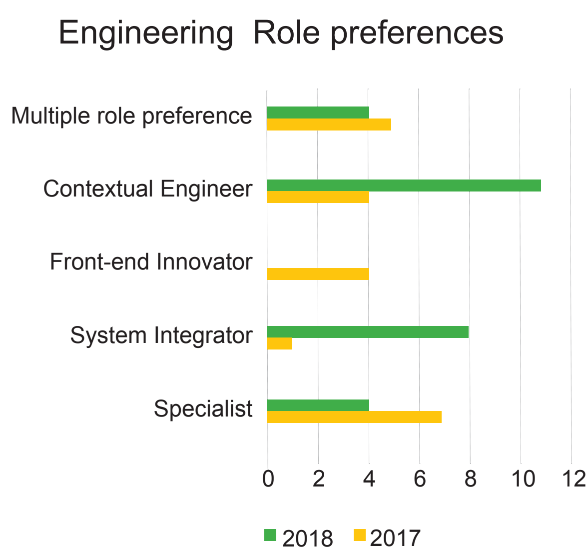

Figure 7. Distribution of engineering role preferences across the participants in 2017 and 2018.

The perceptions of participants regarding the engineering roles in the 2017 and 2018 Building with Nature workshops is reported in *Table 3* and analysed thereafter.

	Questions	% on a scale from 1-5 aggregated		Mean (variance)	
	Explanation	**2017**	**2018**	**2017**	**2018**
1	The roles were clearly explained	46 % (strongly) agreed 26 % neutral 27 % (strongly) disagreed	33 % (strongly) agreed 30 % neutral 38 % (strongly) disagreed	3.3 (1.1)	2.9 (.97)
2	I recognized the role in the behaviour of the experts that presented at the beginning of the day	63 % (strongly) agreed 30 % neutral 8 % disagreed	59 % agreed 30 % neutral 11 % disagreed	3.8 (.91)	3.4 (.96)
	The Design Process				
3	I have made use of my personal engineering role during the session	77 % (strongly) agreed 19 % neutral 4 % strongly disagreed	33 % (strongly) agreed 29 % neutral 37 % (strongly) disagreed		3.6 (.89)
4	I felt the roles opened up new perspective in the problem definition phase / The roles helped open up a variety of stakes	61 % (strongly) agreed 15 % neutral 23 % disagreed	48 % (strongly) agreed 22 % neutral 29 % (strongly) disagreed	3.6 (1.1)	3.1 (1.06)
5	The roles helped define the design requirements	54 % (strongly) agreed 11 % neutral 29 % (strongly) disagreed		3.4 (.79)	
6	The roles helped to create a framework for approaching the design challenge	65 % (strongly) agreed 15 % neutral 15 % disagreed		3.7 (.97)	
7	The roles have contributed to the structure of the design process	65 % (strongly) agreed 26 % neutral 7 % disagreed		3.7 (.87)	
8	The reflection part of the worksheet helped to close the design loop (meet requirements sufficiently)	45 % (strongly) agreed 27 % neutral 24 % (strongly) disagreed			
9	Working on the worksheet added quality to our final results	57 % (strongly) agreed 27 % neutral 11 % disagreed			
	Negotiation of meaning				
10	The roles supported a broad discussion on engineering solutions	61 % (strongly) agreed 19 % neutral 15 % disagreed			
11	The roles helped me to create common ground between the different perspectives that could be taken	45 % (strongly) agreed 31 % neutral 20 % (strongly) disagreed			
	Relevance of working with engineering roles				
12	I can see the relevance of these roles for building with nature design sessions	81 % (strongly) agreed 8 % neutral 8 % disagreed	45 % (strongly) agreed 37 % neutral 18 % (strongly) disagreed		3.4 (1.04)
13	The roles have added value for education	77 % (strongly) agreed 15 % neutral 4 % disagreed	52 % (strongly) agreed 33 % neutral 11 % disagreed		3.8 (1.4)
14	The roles have added value for the (technical) work environment	72 % (strongly) agreed 20 % neutral 4 % disagreed	59 % (strongly) agreed 11 % neutral 30 % disagreed		3.4 (1.04)
15	I can see the relevance of the roles for my disciplinary field	77 % (strongly) agreed 15 % neutral 4 % disagreed	30 % (strongly) agreed 37 % neutral 33 % (strongly) disagreed		3.0 (1.05)
16	I would recommend others to experience working with engineering roles/I would recommend working with the roles to a friend	63 % (strongly) agreed 23 % neutral 8 % disagreed	67 % (strongly) agreed 22 % neutral 11 % disagreed		

Table 3. Perceptions on the engineering design roles in the 2017 & 2018 Building with Nature workshops.

In the 2017 workshop, a dedicated approach to working with the engineering roles was instituted. The engineering roles were positively received (*Table 2*) as participants considered that they supported the design process by opening up new perspectives and instituting a broader discussion of potential engineering solutions, such as solutions that include dynamic ecological processes or changes in social needs over time. Most participants adopted their engineering roles during the design process and view the engineering roles as relevant to Building with Nature design processes.

Prior to the workshop in 2018, the participants received an online leaflet and handout with engineering role descriptions. While only nine people reported reading the online leaflet prior to the workshop, the handout supported 16 people in their interpretations of the engineering roles. The workshop started later than planned in 2018 owing to traffic delays, and the explanation of the engineering roles was rushed. This is reflected in lower score assigned to the factor "The roles were clearly explained" in 2018, compared with 2017 (*Table 2*).

In 2017, 77% made use of their engineering roles, whereas in 2018 half of the participants did not work with the engineering roles (Question 3, *Table 2*), although they recognised their relevance (Question 12). In 2018, 45% considered that the engineering roles specifically contributed to Building with Nature design, whereas 81% of participants recognised the relevance of the engineering roles to Building with Nature design in 2017. This difference is in part explained by the focus on stakeholder values in setting design requirements in 2017 as opposed to a constraint-focused problem definition in 2018. However, the experienced usefulness of the engineering roles seems also to reflect how seriously participants work with the roles and how much guidance they receive on applying the role prior to the workshop and within the design assignment. Overall both in 2017/2018, the roles were perceived to create added value for education (Question 13), the work environment (question 14), and students state they would recommend others to use the engineering roles in the design process (*Table 2*). Further, in terms of creativity, 56% of the participants in 2018 felt the roles enhanced the divergent thinking process, while 15% neither agreed nor disagreed and 29% disagreed. However, the engineering roles were less useful in supporting convergent thinking, as only 33% felt it supported them with 30% neither agreeing nor disagreeing and a further 36% disagreeing. Overall, the roles were perceived to be useful in developing the most appropriate design solutions (67% agreed/strongly agreed) and for developing an integrated design (59% agreed to strongly agreed) and a more complete design 60% (agreed to strongly agreed). Finally, most of the participants considered the engineering roles relatively easy to use.

The integrated Building with Nature designs demonstrate an extremely wide distribution across the solution space for both the Hondsbossche and

Pettemer Sea Defence case study and the Kinderdijk case study. A broad range of combinations of bio-geophysical and societal needs are evident in the design concepts, albeit designs for the tidal river area of Ablasserdam-Kinderdijk were less diverse.

The process of BwN design needs to adhere to the economically viable, environmentally friendly, quality of life bounds imposed by the doughnut model proposed in the introduction of this chapter. Moreover, the process also has to integrate across disciplinary sub-components and include the values of the stakeholders (CIGAS model, Kothuis et al., 2014) and take the different design-engineering roles into account. The engineering roles helped in explicating the values addressed in the problem definition and its translation into (diverse) design requirements. For example, the System Integrator can connect the problem of adequate emergency services (value) to the requirements of access to the beach, good road infrastructure and minimal pollution (design requirements). The Contextual Engineer can connect the problem of enhancing/preserving the natural environment and personal prosperity (values) to the requirements of recreational space and cultural heritage preservation activities (design requirements). Specialists can connect the problem of knowledge development on coastal infrastructure (value) to the requirements of structural stability, flood safety standards, and characteristic flora and fauna (design requirements). Deepening insight into design processes via the engineering roles, while trying to balance the biophysical and social aspects (a characteristic of Building with Nature projects), means that participants gained experience in interdisciplinary design. These integrative skills are becoming ever more important for future engineers to be able to deal with the complex and interdisciplinary design questions in the coming decades. From the workshops it turned out that teaching these skills to engineering students by means of engineering roles was helpful.

Summarising the evaluation of the participant's perceptions in the 2017 and 2018 Building with Nature workshops revealed that the use of engineering design roles supports the inherent interdisciplinary character of the Building with Nature design process. This is particularly relevant in the divergent and the evaluative phases of the design, where the integration and completeness of a design proposal is assessed. Knowledge of the diverse perspectives and values held by stakeholders and the implications for the local environment and the lived experience of the people affected by the proposed Building with Nature design makes for a more informed problem definition and widens the solution space. The participants valued that they were challenged to connect their engineering design competence to an authentic Building with Nature situation in each of the workshops. Most participants therefore considered the engineering roles particularly relevant for their future technical working environment, as well as for their education.

6. Concluding discussion

Building with Nature infrastructure designs are characterised by disciplinary integration, non-linearity, diverse and fluid design requirements, and long-term time frames that balance the limitations of Earth's systems and the socio-technical systems created by humans. Three Building with Nature design workshops therefore provided the ideal context for investigating whether engineering roles enhance such interdisciplinary ways of working. In the first workshop in 2016, the explicit consideration of engineering roles within Building with Nature design processes was piloted. A modified version of the initial engineering roles prototype was then applied and evaluated in the second and third workshops in 2017 and 2018, leading to insights both on the engineering design roles and the interdisciplinary design context of Building with Nature.

Results indicate that the application of the engineering roles in each of the three workshops indeed supported interdisciplinary design. The engineering roles stimulate the consideration of stakeholder values and discussions about norms and values across disciplines as well as an appreciation of diverse stakeholder perspectives. Within the design team, engineering roles help the interdisciplinary discussion by shifting perspectives, finding and recognizing common ground, and the realisation of integrated solutions that fall within the solution space of the BwN doughnut.

A number of conditions for successful implementation within an authentic learning environment could be identified, namely:

- A clear and concise explanation of the engineering design roles,
- Some time to internalize the engineering role perspective before having to apply it,
- Effective integration of the engineering roles into a pre-structured design process,
- A design assignment that requires divergent thinking,
- No assignment of a single role to an individual person, but rather attaching the engineering role to the assignment in such a way that each team member can contribute to any and every engineering role perspective.

The engineering roles sustain an early, divergent way of looking at the design problem and support the search for common ground across the diverse perspectives of the team members, each bringing different disciplinary backgrounds to the design table. The engineering roles represent a new set of bridging values and the responsibility to engage in interdisciplinary processes, needed to successfully accomplish complex design processes as BwN. Both the engineering roles and the individual disciplinary perspectives contributed to the analysis of a complex real problem situation. However, reflecting on the design process from the engineering role perspective sustained integrative thinking in the early design process, and it sharpened the specification of design criteria and the evaluation at the end of the design process. These contributions are particularly relevant to Building with Nature design assignments, which require working across disciplines, coping with complex and fluid design requirements and accommodating non-linearity and dynamic environmental and social contexts. The inclusion of multiple perspectives in the definition of the design requirements, specifically those of local residents and authorities, served to broaden the solution space and the diversity of the final designs. Shifting the focus from "stakeholder requirements" to "a constraint-focused problem definition", led participants to value the use of engineering roles and helped them to be better equipped for interdisciplinary design challenges.

Further, it is likely that the engineering design roles would be more valuable for education at undergraduate and early postgraduate levels, rather than for PhD candidates who are familiar with the design cycle. The Building with Nature elements might be better identified when students already have strong training in this field or there is a marked identification with experts in the field and their engineering design roles. However, although experts are highly competent, they may be unaware of how they enact their engineering roles in their research or implementation practice. This can make it difficult for student participants to acquire deeper learning on engineering roles through interaction with the experts.

The engineering roles have been tested three times in small workshops. Each time the intervention was adapted to fit with the demands of the NSF-PIRE program within which it was nested. This makes it difficult to draw broad conclusions that can be generalized. Nonetheless, we expect that the engineering design roles can support interdisciplinary learning processes in diverse environmental and engineering projects, and call upon researchers to add to the knowledge base on interdisciplinary design by evaluating applications of the engineering roles in diverse settings. We are particularly intrigued whether others will obtain similar results and are interested to learn whether the innovative character of Building with Nature solutions produced in the workshops are replicated. The interdisciplinary and contextual challenges of designing Building with Nature solutions provided a fertile testing ground. We urge others to apply the principles that we have provided above to create suitable educational settings and instructional processes as the next testing ground for interdisciplinary, environmental engineering design processes.

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SPATIAL DESIGN

Urban dunes
Towards BwN design principles for dune formation along urbanized shores

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Abstract

Sandy shores worldwide suffer from coastal erosion due to a lack of sediment input and sea-level rise. In response, coastal sand nourishments are executed using 'Building with Nature' techniques (BwN), in which the sand balance is amplified and natural dynamics are instrumental in the redistribution of sand, cross- and alongshore. These nourishments contribute to the growth of beaches and dunes, serving various design objectives (such as flood safety, nature, and recreation). Nevertheless, human interference (such as buildings and traffic) along urbanized sandy shores may have significant, yet poorly understood, effects on beach and dune development. Better insight is required into the interplay of morphological, ecological and urban processes to support Aeolian BwN processes for dune formation and contribute to the sustainable design of urbanized coastal zones. This paper aims to bridge the gap between coastal engineering and urban design by formulating design principles for BwN along urbanized sandy shores, combining nourishments, natural dune formation and urban development on a local scale to strengthen the coastal buffer. The first part of the paper analyses sedimentation processes in the (built) sea-land interface and identifies spatial mechanisms that relate coastal occupation to dune formation. Hence a preliminary set of design principles is derived by manipulating wind-driven sediment transport for BwN dune formation after nourishment. In the second part of the paper, these principles are applied and contextualized in two case-studies to compare their capability for BwN in different coastal profiles: the vast, rural, geomorphologically high dynamic profile of a mega-nourishment (Sand Motor); versus the compact, highly urbanized, profile(s) of a coastal resort (Noordwijk). Conclusions reflect on the applicability of BwN design principles within different coastal settings (dynamics, urbanity) and spatial arrangements facilitating BwN dune formation.

KEYWORDS

Building with Nature, nourishment, dune formation, urban coast, design principles

1. Introduction

Sandy shores offer a multitude of ecosystem services; regulation- (e.g. flood protection), production- (e.g. drinking water, tourism) and cultural services (e.g. recreation), all depending on the quality of supporting services (e.g. natural balances of water, nutrients and sediment). For *sandy* shores especially, the long-term physical existence is dependent on the sediment balance in response to sea-level rise. Therefore, sediment balances and dynamics are conditional to any spatial design of sustainable urbanized sandy shores.

Examples of such a design are sand nourishments where, in accordance with 'Building with Nature' techniques (BwN), the sand balance of the system is amplified and natural dynamics are instrumental in the redistribution of sand cross- and alongshore. The Netherlands have been employing sand nourishments for coastal management since 1990, with an average yearly nourishment volume of 12 million m^3 of sand since 2001, serving different design objectives (flood protection, nature, urban and/or economic activities). Typical magnitudes of individual nourishments vary between 0.5 and 2 million m^3 (Mulder et al., 2011); whilst the Sand Motor is an experimental mega nourishment of 20 million m^3. Results are positive, featuring seaward trends for shoreline development and improved safety levels (Giardino et al., 2012, 2013, 2014).

After nourishment, the sediment is transported by natural processes (waves, tide, wind, etc.) to become part of the beach and dune system. These dunes depend on wind-driven sand transport to recover from storm erosion and to counterbalance for sea-level rise and higher storm impacts due to climate change (Morton et al., 1994; Carter, 1991; Keijsers, 2015; De Winter & Ruessink, 2017). This makes the supply and free movement of sediment essential for dune formation as part of the coastal buffer.

A main concern is that coastal zones are becoming increasingly urbanized, not only in the Netherlands, but also globally (Hoonhout & Waagmeester, 2014; Hall, 2001; Schlacher et al., 2008; Malavasi et al., 2013). This includes recreation, traffic, beach housing, and waterfront development. Stabilization of the Dutch coastline through nourishments has attracted more economic development and led to a twentyfold increase of beach housing in the last decade (Armstrong et al, 2016; Broer et al., 2011; Panteia, 2012; Buth, 2016).

These forms of urban occupation may have significant, yet poorly understood, effects on beach and dune development, affecting the sediment transport to the dunes (Nordstrom and Jackson, 2013). Better insight is required into the interplay of morphological, ecological and urban processes to support BwN for the consolidation of urban coastal zones. A complicating factor is that urban and nourishment strategies are often developed and modelled in isolation. Synergizing these systems not only creates chances to improve dune formation after nourishment, but also gives way for a nature-based reinforcement of the coastal profile in response to sea-level rise, whilst maintaining its function as a vital recreational landscape.

This paper fuses insights from coastal engineering and spatial design to formulate BwN design principles that combine nourishment strategies and urban development to strengthen the coastal buffer. They employ wind-driven (aeolian) processes and spatial interventions for sediment allocation, promoting dune formation. Such an approach depends on the sediment supply from nourishment strategies – in terms of amount, frequency and location (along the coast, on the shore face or beach) – on the regional scale (Mulder et al., 2011) and (adaptive) urban typologies for waterfront development. They set the preconditions for combined morphological and urban development on the local scale, as first outlined by Van Bergen and Nijhuis (2020).

The first part of the paper employs typological research (de Jong & van der Voordt, 2002) to analyse sedimentation processes in the (built) sea-land interface and identifies local spatial mechanisms that relate coastal occupation to dune formation, based on literature-review, GIS-analysis and field experiments (par. 2). Hence a first set of Aeolian design principles is derived to stimulate positive interaction between wind-driven sediment transport and urban construction for dune formation (par. 3).

The second part of the paper discusses two design studies (de Jong & van der Voordt, 2002) that apply and contextualizes the design principles in two coastal settings with contrasting profiles, nourishment regime, and urbanity:

- The vast profile of a mega-nourishment (Sand Motor), featuring a 'low frequent, high volume' nourishment strategy (20Mm^3/25 years) with dominant geomorphological dynamics in a rural setting.
- The compact profile of a coastal resort (Noordwijk), featuring a 'high frequent, low volume' nourishment strategy (5Mm^3/5 years) in an urbanized setting.

Both case-studies explore how the BwN design principles can be employed to compose spatial arrangements accommodating nature-based dune formation (par. 4). This requires an interplay of nourishment, the desired coastal buffer profile and directed sediment transport in the beach-dune interface. Conclusions reflect on the applicability of the BwN design principles within different coastal settings and spatial arrangements to facilitate BwN dune formation (par. 5).

2. Conditions for dune formation

Dunes are a natural coastal phenomenon that can take on many forms and expressions (Van Dieren, 1934). The development of dunes is dependent on geomorphological and ecological mechanisms that operate differently and according to the conditions as put forward by their spatial and geographical context. Alterations in geomorphological parameters and human intervention with wind-driven sediment transport lead to different types of dune formation. In general, there are three main factors that affect dune formation.

The supply of sediment

Sediment is transported ashore by natural processes (waves, tide, wind etc) contributing to beach and dune development. Coastal nourishments mined in the North Sea and transported by ships, bring more sediment into the nearshore, thereby increasing the available sediment budget to land ashore. Up to 25% of the nourished volume can become available for transport to the dunes (Van der Wal, 1999). Sustainable dune formation occurs when the supply of sediment exceeds coastal erosion.

Wind-driven (aeolian) transport is essential for dune formation and recovery after storms. Mega-nourishments can also offer temporary wider and gradually sloping beaches, a positive condition for dune formation (Puijenbroek, 2019). Wider beaches not only provide accommodation space for dunes to form (Galiforni-Silva et al., 2019), but also enlarge the so-called fetch-length: the length of (dry) beach where wind can blow and pick up sediment (Delgado-Fernandez, 2010). The fetch length is related to the wind direction: at more oblique directions (SW and NW in Holland), wind covers a larger stretch of beach before reaching the dunes. The wind driven sediment transport is also dependent on the erodibility of the beach surface, which is related to the ground water levels, and affects the dune topography evolving (Galiforni-Silva et al, 2018) Furthermore, nourished sediment may be coarser and contain more shells, preventing the wind from picking up sediment (Hoonhout, 2019). Thus, sediment availability, fetch-length and ground level height are determining factors for the stimulation of dune formation.

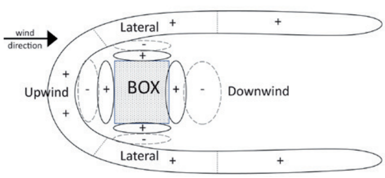
Aeolian sediment transport

Wind has three mechanisms for sediment transport: creep, saltation and suspension. Creep (sediment rolling over the beach) generally starts at wind force Beaufort 4. Saltation occurs when grains are picked up from the bed and make short jumps before hitting the bed again and expelling new grains. Around wind force Beaufort 5-6 sediment transport becomes more substantial and so-called 'streamers' occur (Williams, 2019): episodic clouds of repeatedly bouncing particles moving close to the beach. Smaller particles can even become suspended and are carried by the wind over long distances.

Once transported, the sediment is deposited when wind speeds decrease and is trapped at the lee side of objects, the (vegetated) dune foot or the winter flood mark where seaweed and driftwood are deposited. Seeds from pioneering vegetation as Sand Couch and Marram Grass germinate here in spring, stimulating and growing along with sand deposition. If no large storms occur, the first embryonic dunes will form.

Interaction between sediment transport and built objects

Beach buildings alter the wind field and therefore affect sediment transport in their vicinity. The diversion of airflow around a building can decelerate the wind, causing sedimentation (e.g. in front or at the lee side of buildings) and results in a horseshoe deposition pattern (figure 1). Conversely, it can also lead to an acceleration of wind, promoting scour and an increase of sediment transport such as below beach housing on poles (Peterka et al., 1985; Nordstrom, 2000; Jackson & Nordstrom, 2011; Smith et al., 2017). An elementary study on flow dynamics in a CFD computer model (Van Onselen, 2018) has indicated that buildings on low poles (< 0,5m) still stagnate wind flow below and directly behind the building, whilst buildings on higher poles (1 -2m) accelerate the wind compared to non-built situations (figure 2). However, the relationship between sedimentation and pole height needs further investigation.



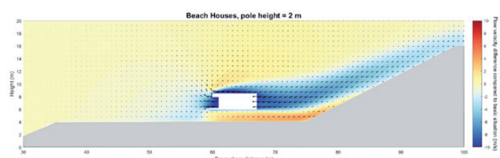


Figure 1 (left). Horseshoe pattern of sediment deposition around a built object (source: D. Poppema, 2019).

Figure 2 (right). Increased flow velocity (orange) below beach housing on 2m high poles (source: Van Onselen, 2018).

Field experiment spring 2019

Effects of elevated beach housing on sediment transport have been investigated in the ShoreScape project during a field experiment in spring 2019. 1:5 scale models with increasing pole heights (in steps of 25 cm) were placed on an wide beach at the Sand Motor (figure 4) for 6 weeks. In weeks 1, 3 and 6 morphological changes around the boxes were measured by Terrestrial laser scanning. From the laser data, sections, difference maps and volume calculations were derived.

Analysis of the elevation difference through maps and sections show that the lower the poles, the more local deposition (and erosion) of sediment, probably due to the larger disturbance of wind speed at ground level. The overall calculated volume change is positive (+7m^3 per box in 6 weeks). This makes non-elevated objects suitable for the local 'harvesting' of sediment (see figures 3, 4, 7a and 7b).

The sedimentation pattern around the elevated boxes is more dispersed. The deposition tail is located at a larger distance from the object, keeping the deposited sediment available for further wind transport

(i.e. the tail is less sheltered by the building). This makes elevated buildings suitable for transitional sediment transport. (see figures 4, 6a and 6b).

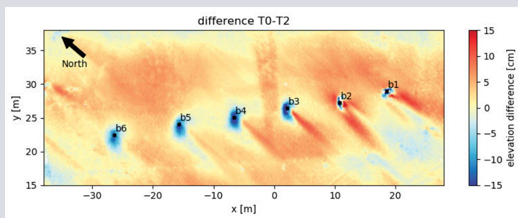


Figure 3 (left) and 4 (right). Final photo and elevation difference map of the beach group - in red the concentrated local deposition (up- and downwind) around the non-elevated boxes (B1, B2); versus local erosion (in blue) and dispersed tails around the boxes with increasing pole-height (B3 (+25cm) - B6 (+1m)

3. BwN design principles for dune formation

The optimization of BwN for dune development along urbanized coasts clearly asks for an integrated spatial design that – besides the chosen nourishment strategy on a regional scale –, is based on design principles at a local scale, taking account of all factors influencing aeolian sand transport in the beach dune interface. Design principles are spatial concepts used to organize or arrange structural elements of the design, in this case, the aeolian sedimentation process. In the previous paragraph the geomorphological and urban mechanisms that influence aeolian sediment transport for dune formation are described. Their spatial parameters can be employed as design principles for sediment allocation at the sea-land interface. A first attempt to define such principles is presented below (figure 5), derived from three determining mechanisms of aeolian sediment transport: A) mobilization, B) acceleration and C) deceleration. For each of them, specific spatial interventions and sediment patterns apply, leading to a preliminary set of six BwN design principles, listed below.

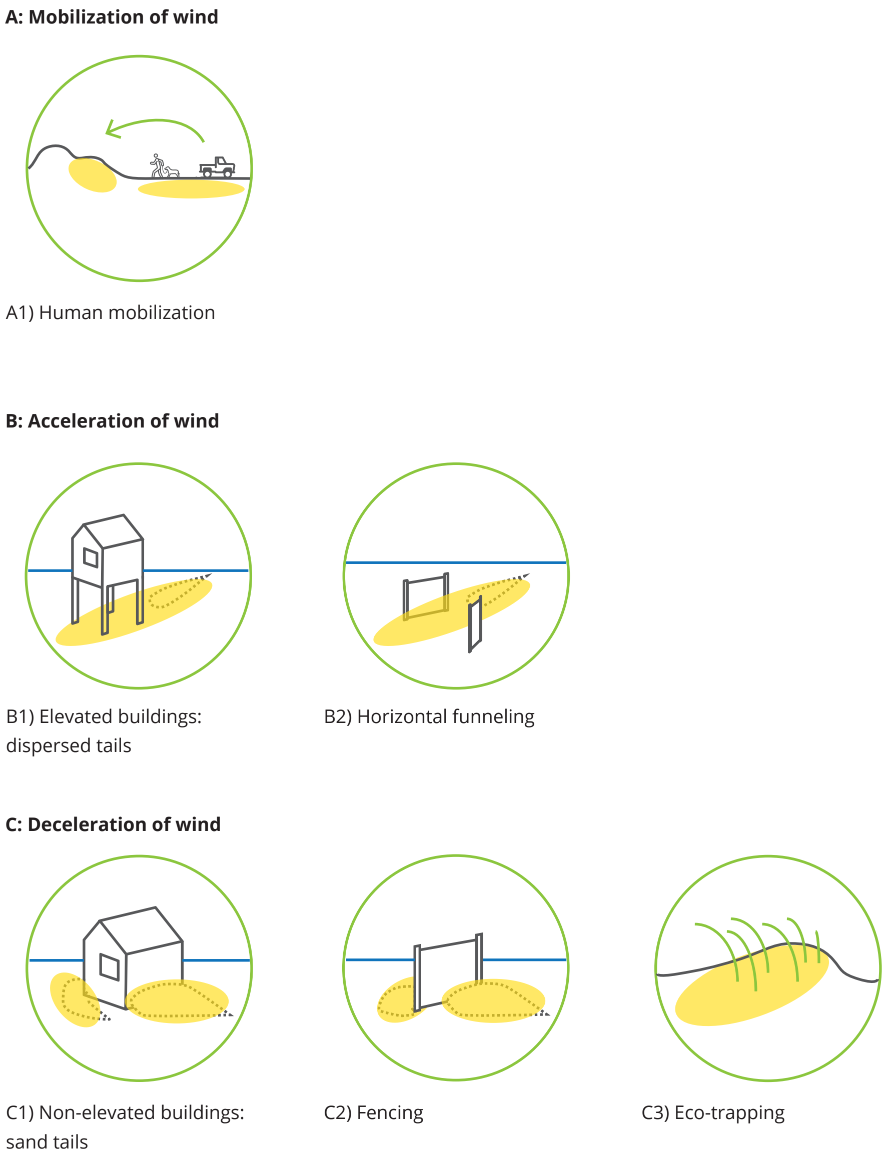
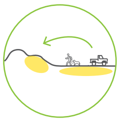


Figure 5. Overview of the six Aeolian design principles

A: Mobilization of wind

Nourished sediment is brought ashore by tidal and wave-driven currents, mobilised by waves and then blown from the beach to the dunes by the wind. Here, spatial interventions can be made to increase inland sediment transport.



Design principle A1): Human mobilization

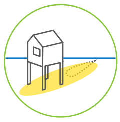
Recreation and urbanization in coastal zones can lead to an increase in sediment mobility, due to grouting by traffic (visitors, cars), beach maintenance and sand removal.

Human mobilization of sediment may have both positive and negative effects on the build-up of the dunes. Intense tramping leads to a decrease of vegetation and erosion, bringing embryonic dune growth to a halt (figure 6). But grouting of the beach by traffic can also improve the availability of fine sediment for wind transport to the dunes. This *mobilization* effect can be applied for BwN design.

Figure 6. Example of urban mobilization at beach access points (white circles) intervening with embryonal dune growth (green). Aerial photo: PDOK.nl

B: Acceleration of wind

Acceleration of wind speed causes erosion and increased sediment transport. This can be induced by funnel-effects through the vertical or horizontal convergence of the wind flow.



B1) Elevated buildings: dispersed tails

Diversion of wind around built objects on poles (> 0,5m) causes an acceleration of wind flow below and behind the building (Van Onselen, 2018), leading to a local increase of sediment transport. This sediment is transported downwind and deposited in the vicinity of the building (figures 4 and 7). These *dispersed tails* collect sediment but also keep it exposed for transitional sediment transport, from the beach to the fore,- and the back dunes, for example.

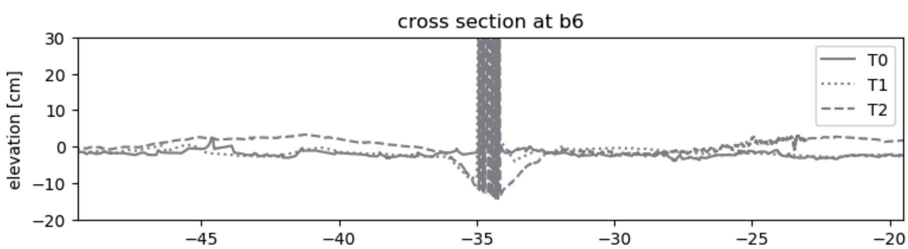
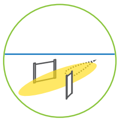


Figure 7 a,b. Photo and section of scale model (100 cm elevated) showing the scour below the model and dispersed deposition after six weeks of exposure at the Sand Motor.

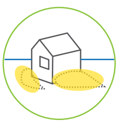


B2) Horizontal funneling

Wind directed into a V-shape (or funnel) is locally accelerated, causing erosion. Behind the funnel, this sand is deposited by the subsequent deceleration of the wind. Examples are (narrow) beach access points, where sediment is blown in, accelerated and transported upward, to be deposited at the top. A similar setup could be used for urban configurations. Furthermore, by placing built objects in a V-shape, the incoming sediment flow becomes less fragmented compared to row housing. *Funneling* is applicable to accelerate sediment transport inland.

C: Deceleration of wind

Obstacles create diversion of wind flow, leading to a local increase of erosion and of deposition. The reduction of windspeed by a lay-out of half-open obstacles, such as fences and vegetation, promotes deposition, to widen the dunes, for instance.



C1) Non-elevated buildings: sand tails

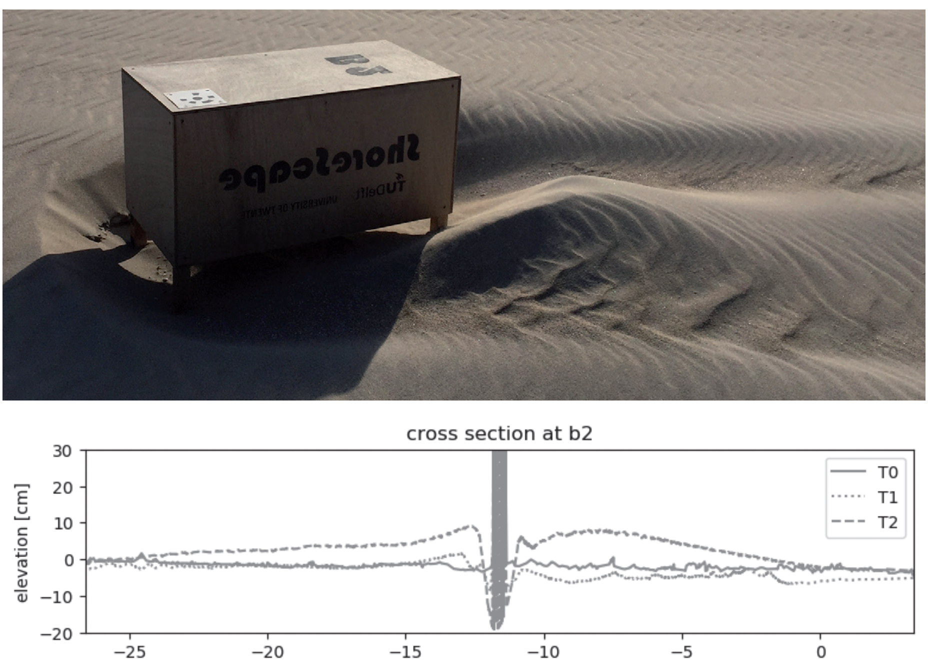
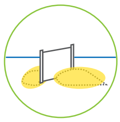


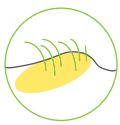
Figure 8 a,b. Final photo and section of scale model (0 cm elevated) showing the concentrated deposition (Sand tail) and horseshoe shaped erosion.

Diversion of wind around beach buildings causes wind to accelerate (picking up sediment) and decelerate, leading to local deposition of sediment on the lee sides, or the formation of '*Sand tails*'. The deposition starts in horse-shoe patterns (Poppema, 2019), but can accumulate in combined tails at the back of the building under changing wind conditions as illustrated by GIS-analysis (Van Bergen, 2020) and fieldwork (figure 8). The surplus in deposition can be used for the local harvesting of sediment (e.g. seaward extension of the foredunes).



C2) Fencing

This principle is based on increased sediment deposition around semi-transparent fences on the beach (Goldsmith, 1985). Due to its half-open structure, the wind is mainly decelerated, instead of being diverted, leading to a local deposition of sediment. The local deposition can be used to build up (fore)dunes, for example in non-vegetated places.



C3) Eco-trapping

The foliage of plants decreases wind speeds and traps sediment to support the build-up of the dunes in width and height (Van Dieren, 1934). Furthermore, vegetation is very effective in stabilizing sediment due to its extensive root system. Species like Marram Grass can even grow along with the process of deposition. However, due to these mechanisms beach vegetation can also block sediment transport to the (fore)dunes. Vegetation plays a role in '*Eco-trapping*' both passively, through natural succession, and actively by planting. At the beach and in the foredunes this relates mainly to Beach Couch and Marram Grass and in the mature back dunes to scrubs and forest which prevent sediment from blowing inland.

4. Application of BwN design principles in two case studies

The BwN design principles are tested in two different coastal settings to explore spatial arrangements that support dune formation. This is done by a design study for two cases (figure 9), each with a contrasting profile, nourishment regime and level of urbanity:

- The extensive profile of a mega-nourishment (Sand Motor), featuring a 'low frequent, high volume' nourishment strategy ($20Mm^3$/25 years) with dominant geomorphological dynamics in a rural setting.
- The compact profile of a coastal resort (Noordwijk), featuring a 'high frequent, low volume' nourishment strategy ($5Mm^3$/5 years) in an urbanized setting.

Figure 9. Map of the Netherlands and the two case-study locations.

First, the spatial conditions of the cases and their corresponding coastal profiles are discussed. Depending on the design objectives and desired profile, BwN design principles can be applied to support the sediment transport to the dunes. This leads to a (dynamic) spatial arrangement illustrating if and how multiple use of the coastal profile can be made compatible with BwN dune formation processes.

Case-study Sand Motor: application of BwN design principles in a mega-nourishment context

The Sand Motor (South Holland) is an example of a 'high volume, low frequent' BwN nourishment strategy ($20Mm^3$/25 years) in a rural setting. The hook-shaped peninsula of 128 ha was constructed in 2011 and designed to slowly erode, thereby feeding the adjacent shore with sediment. This promotes dune growth for coastal safety, whilst expanding natural areas and space for leisure activities (Taal et al., 2016). This case study analyses the resulting dune formation at the mega-nourishment so far and explores, via design study, how BwN design principles might contribute to *accelerated* fore dune formation as aspired buffer.

Figure 10. Aerial photo of mega-nourishment Sand Motor just after construction in 2012, showing accretion at the south side (source: RWS).

Dune formation processes after mega-nourishment

The Sand Motor landscape (2011-2019) features extensive beaches, increased recreation (e.g. beach pavilions) and a highly dynamic geomorphology. Erosion of the peninsula and the continuous dispersion of sediment along the coast have induced an accreting shore on the south side in the first years (figure 10 and 11a). This was followed by a retreating shoreline and embryonic dune growth on the beach from 2016 onwards (figure 11b). These embryonic dunes catch and stabilize sediment, but block sediment transport to the foredunes.

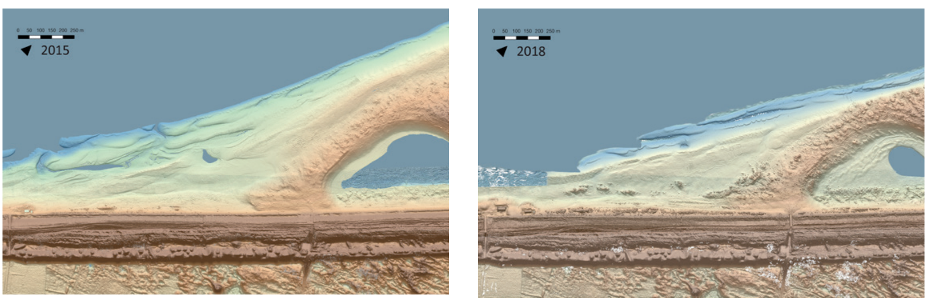


Figure 11 Elevation maps of the south side of the Sand Motor. Figure 11a (left) shows the accreted shoreline (2011-2015); figure 11b (right) shows the eroding shoreline and embryonic dune growth (2016-2018).

Vegetated foredunes are a desirable state for sediment to accrete in a sustainable way (van Vliet et.al., 2017) offering maximum resistance during storms (coastal buffer). Assuming that a quarter of the nourished sediment

(20Mm³) becomes available for aeolian dune formation (after Van der Wal, 1999), this volume (5 Mm³) would correspond with an additional foredune, for instance, of +100m wide, 3m high and 15 km long; and an estimated BwN construction time of 21 years. This calculation shows the potential for BwN foredune formation as a coastal buffer following mega-nourishment. However, this process is now delayed by the embryonic dunes at the beach, blocking sediment transport to the foredunes.

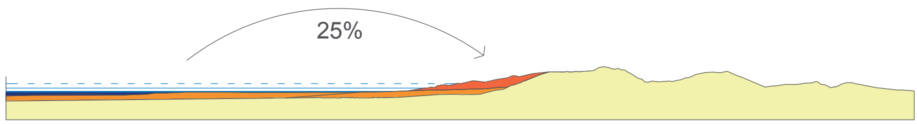


Figure 12. Section of the Sand Motor, its initial volume and aspired buffer (in red, ≈ 25% of nourished volume).

Spatial arrangement to accelerate BwN Dune Formation

Given the observed land-shaping processes, BwN principles were applied to study how *direct* sediment flow to the foredunes could be improved to accelerate the BwN build-up of the coastal buffer.

Firstly, the principle of '*Human mobilization*' applies to limit the growth of (vegetated) embryonic dunes and mobilize sediment for aeolian transport inland. This could be organized by relocating the existing recreational program (beach pavilions and -housing) to the south wing, intensifying pedestrian traffic (figure 13).

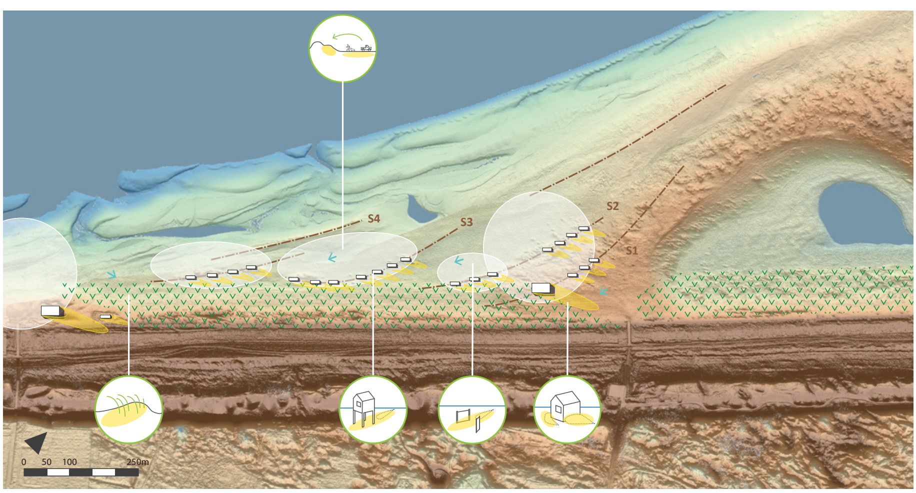


Figure 13. BwN ensemble of beach houses situated on beach ridges of the south Sand Motor to keep sediment mobile (white circles) and harvest sediment (yellow) for landward foredune formation (green).

At the same time, these seasonal beach buildings on poles offer chances to collect and direct sediment transport to the back for further transport inland. This sediment can be collected during a sequence of summers (S1, 2, 3, 4) in a dynamic urban set up (*Horizontal Funnelling*), that moves along with the shifting shore and transport zone. The resulting '*Dispersed tail*' patterns then act as local aeolian sand sources during winter to feed the foredune zone. Once transported to the dune foot, the '*Sand tails*' of the remaining buildings and (planted) Marram Grass offer opportunities for accretion and stabilization of sediment ('*Eco-trapping*'); an old Dutch coastal tradition of BwN.

Case-study Noordwijk:
Application of BwN design principles in an urbanized waterfront

Noordwijk aan Zee is a seaside resort along the coast of South Holland, featuring an urbanized waterfront maintained by a regular 'high frequent-low volume' nourishment strategy (2Mm^3/4 years since 1998).

In the past, Noordwijk has faced several urban transformations. It began as a fishing village but developed into (luxury) seaside resort around 1900, turning the front dunes into a coastal strip of hotels along a boulevard. In World War II, this strip was partly torn down for military defence purposes, but was reconstructed afterward and densified. The resort now hosts 1,1 million day-visits and 0,5 million overnight stays a year, including conferences, upmarket lodging and beach development (de Witte-Romme et al., 2018). In 2003, Noordwijk was appointed as a weak link in the coastal defence line and transformed once more with a 'Dike-in-Dune' reinforcement in 2008 (figure 15a), anticipating future climate changes and sea-level rise. Although close access to the beach and sea view was maintained, the northern boulevard lost its direct contact with the beach (figure 14).

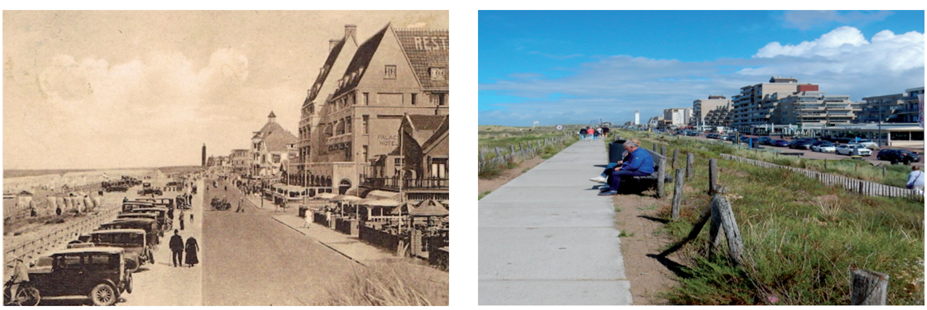


Figure 14. Photos of boulevard Noordwijk in 1920 (left, source: deoudedorpskernnoordwijk.nl) and after reinforcement in 2020 (right, photo J. van Bergen).

Future flood safety reinforcement models for Noordwijk

The present flood safety level of the Noordwijk Dike-in-dune accounts for a sea-level rise of 30 cm in 2050 (60 cm in 2100). To withstand higher sea level rise scenario's, future reinforcements of Noordwijk will be inevitable. To investigate the feasibility of BwN solutions to provide a necessary reinforcement after 2060, Mulder et al. (2013) took a two-step approach. First, using a dune erosion model DUROS+ (Vellinga, 1986) a number of potential sandy reinforced profiles were calculated (Boers and Mulder, 2014), able to withstand storm conditions after a sea-level rise to 85 cm in 2100 (figure 15b, 'Dike in dune plus' and figure 15c, 'Sand Buffer'). Next, a nourishment evaluation tool ('Ntool'; Huisman et al., 2013; Giardino et al., 2013-A) was applied to confirm that a regular, high frequent sand nourishment strategy (increased SLR, four year intervals), would be able to deliver (most of) the required seaward extensions of both profiles in 2060. However, these calculations are based on the free natural transport of sediments and is crucial for its success. The current high occupancy rate (70%) of the beach by pavilions can affect this process.

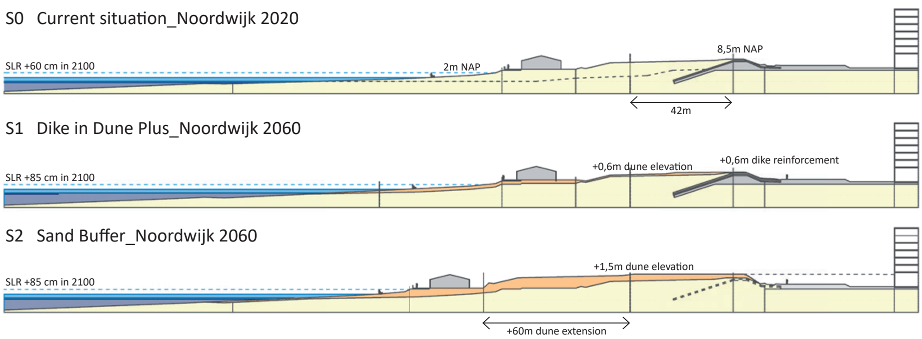
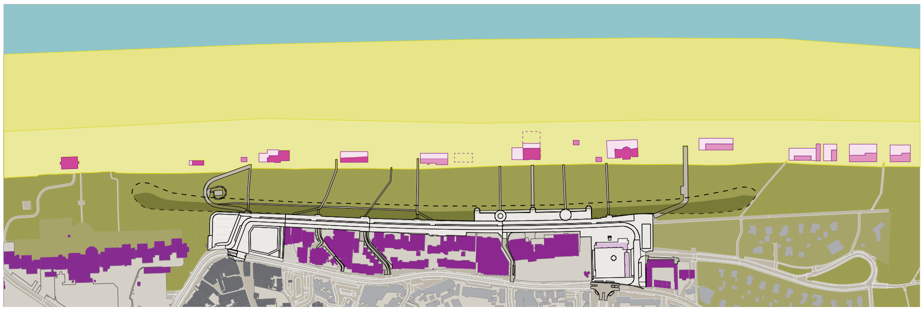


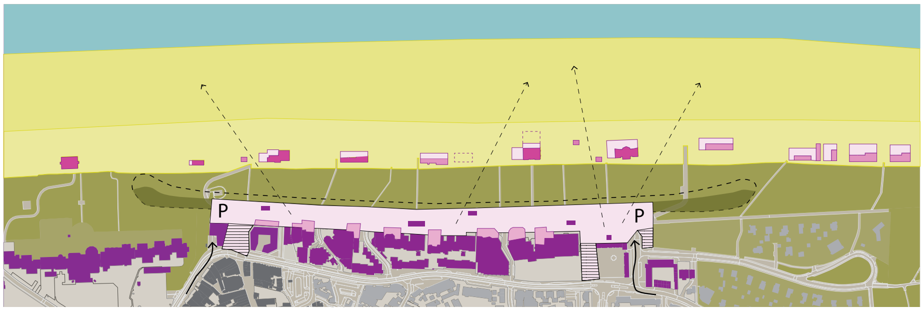
Fig 15 a,b,c. Cross-sections of Noordwijk boulevard. S0 – Current situation 2020 with 'Dike-in-dune' reinforcement implemented in 2008; S1 – potential reinforcement model to counteract effects of a sea-level rise increase to 85 cm in 2100, by a slight heightening of the existing dike (+60 cm) and dunes (+60 cm); S2 – id. by a Sand Buffer only, avoiding a costly dike reinforcement (Image by author, after Mulder et al., 2013).

Urban models for future waterfront development of Noordwijk

The future reinforcement of Noordwijk, as discussed in the previous section, illustrates that more room is needed within the existing coastal profile to adapt to sea level rise. The expected dune reinforcement pressures the existing values of the current waterfront, such as the sea view and beach vicinity; and makes a reassessment necessary. In this design study, four future urban models were composed to facilitate future urban coastal occupation. These urban models are based on two main choices that (re)define the urban coastal profile (fig 16).

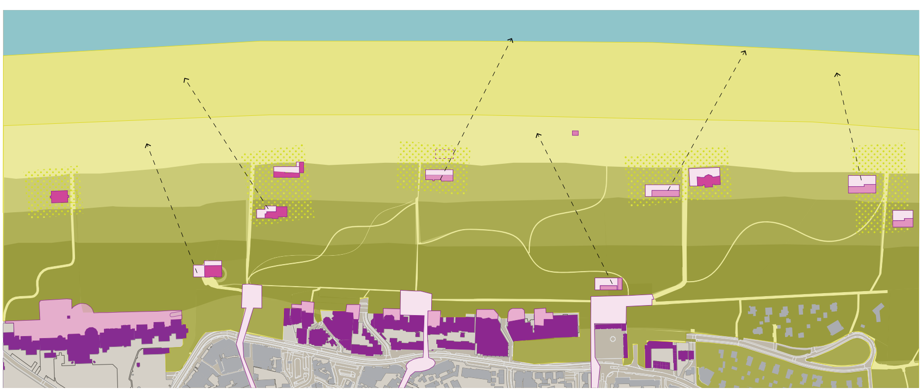


U1. Traditional boulevard



U2. Elevated boulevard, with parking below

U3: corridor model, with compact beach housing



U4: Terraces model, with beach pavilions distributed within the beach-dune landscape

Figure 16. Overview of four urban models for the future waterfront development of Noordwijk; based on parallel versus perpendicular access and varying beach layout. Images by the author.

1. **Reassessment of the waterfront layout.** The current boulevard typology (U1) acts as a distributor for beach access, parallel to the shore whilst offering sea view, public facilities and close beach access. These qualities are facilitated best by compact (but costly) reinforcements, such as Dike-in-dune. The boulevard can be elevated (U2, with parking below) to provide extra room for reinforcement in height. An alternative is the corridor typology (U3, U4), that gives direct perpendicular beach access, reorganising the urban program along public routes from the town to the sea. This offers opportunities for dune extension in between the corridors.These dunes would marginalize a boulevard but could offer a more exclusive landscape setting for the hotels and room for urban dune development instead, creating alternating spheres of urbanity along the coast.
2. **(Re)arrangement of the urban beach layout**, such as beach pavilions and -houses: The current beach layout is linear (U1, 2), featuring a strip of 16 beach pavilions & terraces (50% year-round) with equal spatial layout. They now cover around 70% of the foredunes, obstructing sediment transport to the dunes. An alternative could be to cluster pavilions around the main beach corridors (U3) or to distribute them within the dune landscape (U4, Terraces model) to differentiate spatial quality and urban use along the beach and in the dunes. The more open dune foot allows for natural dune growth.

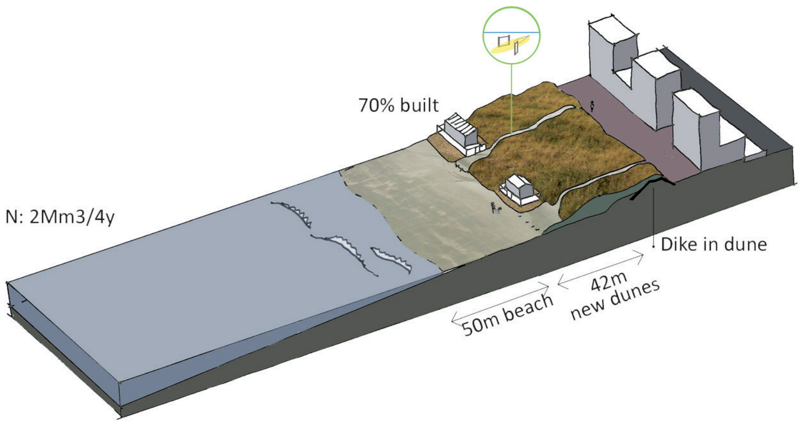
Matching models for future flood safety reinforcement and urban development

The combination of the two potential reinforcement models (S1 Dike-in-dune and S2 Sand Buffer, Fig. 14b and 14c) and urban models (U1-4, figure 16) lead to two feasible future coastal profiles for Noordwijk, each with its own distinct features. Test profile 1 'Dike-in-dune plus' (S1+U1 = T1, figure 17b) stays close to the traditional boulevard typology as an urban balcony at the sea with the most compact Dike-in-dune reinforcement. Test profile 2 'Sand Buffer (S2+U3 = T2, Fig. 16c) rearranges and concentrates the urban program onto two main routes to the beach, allowing for more free sediment flow to widen the dunes.

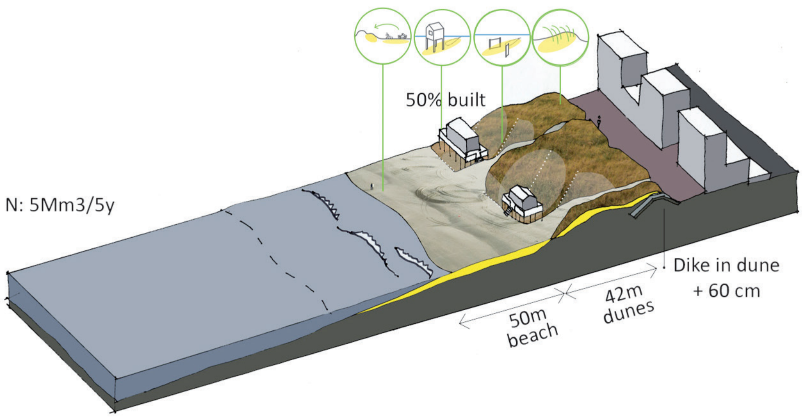
Application of Aeolian design principles to stimulate BwN dune formation

The success of BwN dune formation not only depends on the nourishment strategy but also on the spatial layout of the sea-land interface, affecting wind-driven sand transport. The urbanized context and the current compact profile of Noordwijk (figure 17a) make it a major challenge to allow for free sediment flow and accommodate dune formation. Within this context aeolian design principles (see par 8.3; marked *italic* in text) can be applied to stimulate the gradual build-up of the aspired test profiles (Figures 17 b and c):

Current profile: Dike in Dune 2020



Testprofile 1: Dike in Dune Plus 2060



Testprofile 2: Sand Buffer 2060

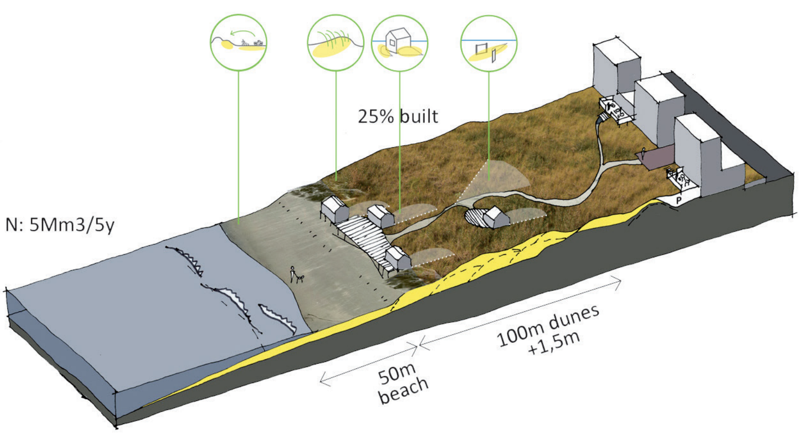


Figure 17 a. The current profile of Noordwijk has a 6,5m high Dike-in-dune construction, with 42m wide dunes. The beach is relatively narrow (50m) limiting the fetch and space for dune formation. Beach buildings block a large part (70%) of the dune front, limiting sediment flow. Although this profile design has not intentionally incorporated BwN-processes, the numerous beach accesses help to transport sediment deeper into the dunes (corresponding with the design principle of *Horizontal Funneling*).

Figure 17 b. The Dike-in-dune Plus profile of Noordwijk 2060 requires a 60 cm elevation of the existing dike and dunes. To this end, a regular nourishment strategy is implied to compensate an increase in SLR to +85 cm in 2100. The current boulevard typology is maintained. To stimulate dune growth, the principle of '*Human mobilization*' of the beach and foredune zone helps to keep sediment mobile for inland transport. A nature-based (BwN) elevation of the dunes (+60cm) is stimulated by an open dune-foot (reduced occupation rate) alternated by pavilions on poles (*Dispersed tales*) and beach access (*Horizontal Funneling*) to facilitate sediment transport inland (+60 cm). '*Eco-trapping*' stabilizes sediment in the back dunes and prevents it from reaching the boulevard.

Figure 17 c. The 2060 Sand Buffer profile of Noordwijk consists of a dune that, due to successive nourishments starting in 2020 (compensating an increase in SLR to +85 cm in 2100), gradually grows in height (+1,5m) and width (+60m). The former boulevard has been transformed and provides a new landscape setting for the hotels with parking below. A central beach access ends in a boardwalk with clustered beach houses, leaving 75% of the dune foot open for BwN dune formation. In the first stage, elevated pavilions (*Dispersed tails*), beach access points and blow-outs (*Horizontal Funnelling*) facilitate sediment transport for dune-elevation (similar to profile 1, but with a more open dune foot). In the second phase (figure 16c) '*Eco trapping*' and the '*Sand tails*' of the concentrated (seasonal) pavilions facilitate extension of the dunes. A wide beach (fetch) could further enhance this process.

5. Conclusion: comparing BwN design principles in diverse coastal settings

There are several aspects that contribute to a successful BwN build-up of a coastal buffer. The objective of this paper is to fuse insights from coastal engineering and spatial design to formulate BwN design principles that combine nourishment strategies, wind-driven sediment flows and urban settlement for BwN dune formation.

First sedimentation processes in the (built) sea-land interface were analyzed to identify spatial mechanisms that relate coastal occupation to dune formation. Hence, a preliminary set of aeolian design principles was derived, employing urban and ecological interventions to stimulate BwN dune formation after nourishment. These principles mediate between two drivers: the nourishments, that provide sediment for dune formation and the urban beach development, that affects sediment transport.

To contribute to the gradual build-up of the coastal buffer, the design principles employ manipulated wind flow for sediment allocation. These types of sediment transport are generic but dependent on the requested type of dune formation (e.g. widening or heightening the dunes). Each transition requires a specific set of principles, clustered in different zones and sequences within the coastal profile:

- Heightening the dunes, for example, is a slow sedimentation process, and the sediment needs to be tilted to the back dunes. This is promoted by a mobilized, dynamic dune foot zone, a gradual slope of foredunes and accelerated wind flow stimulated by *Elevated buildings* and *Horizontal Funnelling*.
- Widening the dunes benefits from a wide beach as a long wind fetch and space to accommodate dune growth; next to stable, vegetated foredunes to collect and fixate the sediment. This is matched by design principles as *Sand tails* behind buildings, *Fencing* and *Eco-trapping*.

Secondly, the developed aeolian design principles were applied in two case-studies to compare their functionality for BwN in different coastal settings. The nourishment strategies in both cases provide enough sediment to build up the coastal profile, but generate different conditions for BwN to take place, altering the role of the BwN arrangement:

The Sand Motor case study shows that the design principles are applicable in a mega-nourishment situation - featuring an extensive, dynamic profile - and can help to stimulate sediment transport from the beach to the foredunes. '*Human mobilization*' helps to source sediment and stops vegetation, whilst beach housing on poles (*Dispersed tails*) collects sediment for inland transport. '*Eco trapping*' finally stabilizes sediment in the foredunes to extend the coastal buffer. Here, the BwN arrangement acts as a form of *responsive* spatial design: following morphological development and transforming in time, as illustrated in figure 18.

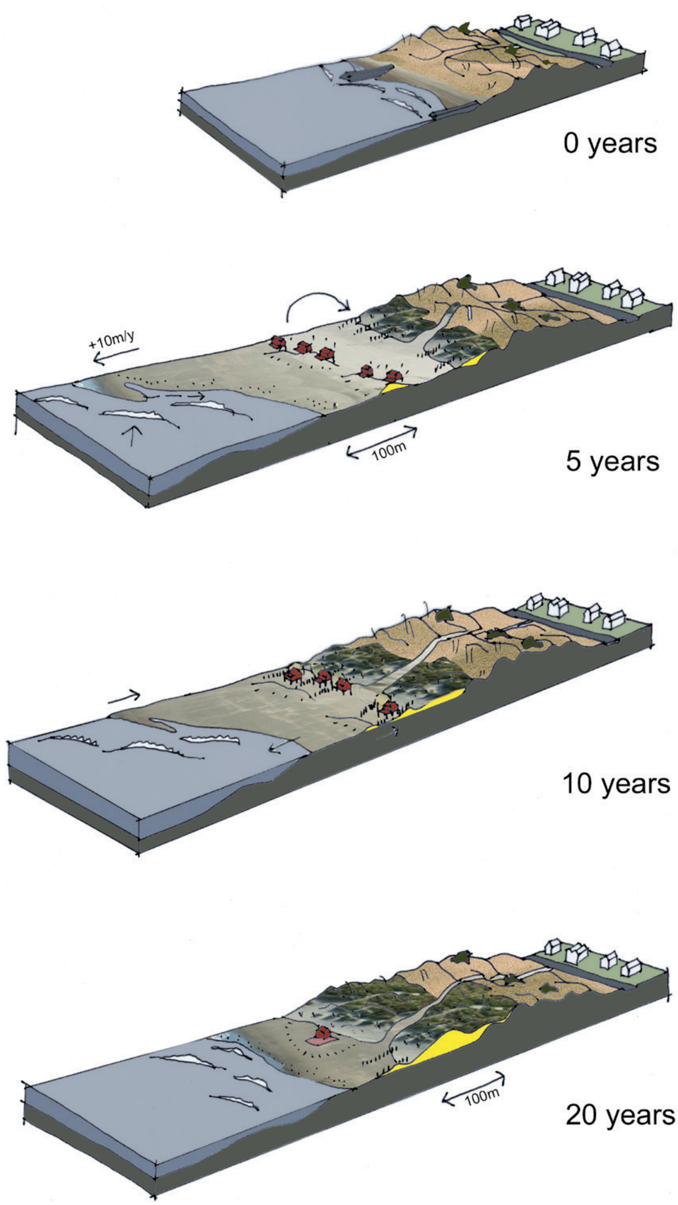


Figure 18. Design sequence of BwN foredune formation following mega-nourishment. 0y: the coastal profile before nourishment; 5y: the coastal profile after mega-nourishment, with extensive beaches; 10y: the coastal profile in 5-10y with an eroding shoreline; and 20y: the concluding profile, with a narrow beach and consolidation of the dunes.

The Noordwijk case features two relatively compact profiles for future reinforcement, dependent on small, high frequent nourishments. Without a vast beach as a resource, the design principles play a more important role in the harvesting and steering of sediment to the designated places: dune morphology now follows the urban layout and urban arrangements facilitate dune growth, as a form of *directive* spatial design.

Furthermore, in Noordwijk urban parameters, such as sea view, beach access, and beach housing have a defining role in the coastal profile design, balanced with the (future) requirements for coastal safety. Optimization of these profiles for BwN could eventually lead to alteration of the waterfront layout, such as the transformation of the Noordwijk boulevard; or nourishment strategy, creating more room for future reinforcements and BwN.

Both design studies illustrate how coastal nourishment and urban development can be intertwined to support the BwN build-up of the coastal buffer. Synergizing these developments not only creates chances to improve dune formation after nourishment, but also gives way for a BwN-based reinforcement of the coastal profile in response to sea-level rise, whilst maintaining its function as vital recreational landscape. The case studies illustrate that the developed aeolian design principles are applicable in diverse settings, but their position and sequence vary depending on the aspired coastal profile. This makes the coastal profile, integrating morphological, urban and ecological programs, an important design tool and spatial framework for the allocation of aeolian design principles.

Research by design can assess each profile and identify the various zones needed for the BwN process. Further research is needed to categorize, extend and cluster the design principles to spatial arrangements fitted for each zone within a specific coastal profile. This includes the assessment of the related boundary conditions such as nourishment type and urban demands. To quantify the morphological effects of the design principles, an additional dedicated field test is foreseen, as well as computer model tests, see also the chapter by Wijnberg et al. (2021, p. 244). These give way for a BwN design approach in the sea-land interface, as a new symbiosis of coastal occupation and dune formation.

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Building with landscape
On-site experimental installations informing BwN methodology

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Abstract

The multi-dimensionality of BwN calls for the incorporation of 'designerly ways of knowing and doing' from other fields involved in this new trans-disciplinary approach. The transition out of a focus on rational design paradigms towards reflective design paradigms such as those employed in the spatial design disciplines may be a first step in this process. By extension, the knowledge base and design methodologies of BwN may be critically expanded by drawing on ways of knowing and doing in spatial design disciplines such as landscape architecture, which elaborates the agency of the term 'landscape' as counterpart to the term 'nature'. Operative perspectives and related methodologies in this discipline such as perception, anamnesis, multi-scalar thinking, and process design resonate with specific themes in the BwN approach such as design of/with natural processes, integration of functions or layers in the territory and the connection of engineering works to human-social contexts. A series of installations realised for the Oerol festival on the island of Terschelling between 2011 and 2018 serve as case studies to elaborate potential transfers and thematic elaborations towards BwN. In these projects inter-disciplinary teams of students, researchers and lecturers developed temporary landscape installations in a coastal landscape setting. Themes emerging from these project include 'mapping coastal landscapes as complex natures', 'mapping as design-generative device', 'crowd-mapping', 'people-place relationships', 'co-creation', 'narrating coastal landscapes', 'public interaction' and 'aesthetic experience'. Specific aspects of these themes relevant to the knowledge base and methodologies of BwN, include integration of sites and their contexts through descriptive and projective mappings, understanding the various spatial and temporal scales of a territory as complex natures, and the integration of collective narratives and aesthetic experiences of coastal infrastructures in the design process, via reflective dialogues.

KEYWORDS

Building-with-Nature, landscape architecture, design methodology, hydraulic infrastructures, mapping coastal landscapes, aesthetic experience, co-creation

1. Introduction

Building with Nature (BwN) offers an alternative mode of praxis for infrastructural challenges such as hydraulic infrastructures and coastal flood barriers, whereby nature and natural processes are actively engaged to serve goals such as flood safety (De Vriend, et al.,2015). At the same time BwN aims to address broader sustainability goals such as minimizing damage to natural environments and increasing ecological value around hydraulic infrastructures. To this end, the knowledge base and methodologies of BwN include and combine such fields as ecology, environmental science and engineering, as well as other disciplines involved in the built environment. The interweaving of these disciplines is commendable and promising, and resonates with intra-disciplinary developments in other areas of applied sciences. Most BwN results however, are still limited to multi-functional outcomes whereby nature, recreation and other uses are accommodated. The fact that more elaborate or hybrid outcomes are rare suggests that a true hybridization has yet to fully emerge, and that contributions leading to a further synthesis of these fields are welcome and necessary.

A first topic in this discussion is the elaboration of BwN in the area of design and design thinking. Design can be considered a culture of thinking aimed at altering an existing condition/situation/artifact into a preferred condition/situation/artifact (Schon, 1983). Exactly how the designer moves from the existing to the new, however, can differ markedly. Of these various methods, Dorst & Dijkhuis (1995) elaborate two essentially different meta-approaches to design: the Rational Problem-solving approach and the Reflection-in-Action approach (figure 1).

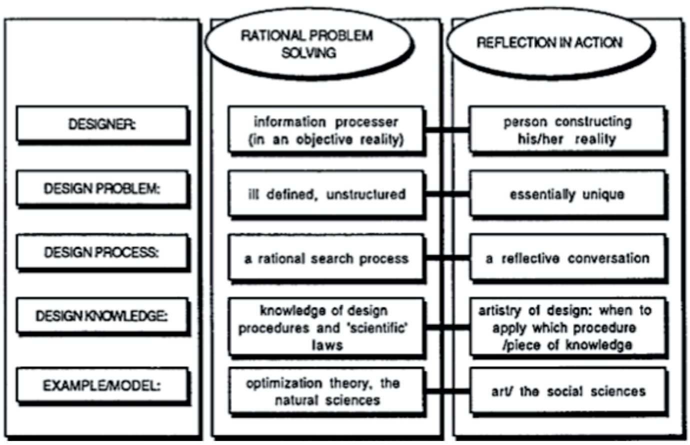


Figure 1. Matrix of rational problem solving paradigms versus reflection-in-action paradigms. (Image: Dorst & Dijkhuis, 1995)

Broadly speaking, the present state of BwN can be said to articulate design and the design process predominantly in the rational problem-solving paradigm. In the first instance then, the evolution of BwN as design process calls for its expansion out of a solely rational design paradigm, to include paradigms from the reflective design perspective. More unambiguously, the multi-dimensionality of BwN implies a necessary venture outside the confines of engineering towards ‘designerly ways’ found in other fields involved in this new intra-disciplinary approach.

By extension, the knowledge base and design methodologies of BwN may be critically expanded by drawing on ways of knowing and doing in disciplines engaging with the reflective design perspective, evident in some spatial design disciplines such as landscape architecture. As such, this paper elaborates the potential of landscape architecture as part of BwN’s broader ‘interdisciplinary venture’. Although sharing a similar focus (physical/built environment planning, design and management), landscape architecture can be said to predominantly engage the reflection paradigm in the design process. Moreover, landscape architecture is of specific interest for its focus on ‘design with nature’, a theme it shares with BwN. In landscape architecture discourse, design-with-nature is a notion that underpins the discipline and extends back to mankind’s first manipulations of the natural environment (Girot, 2016). As such, BwN can be seen as a new chapter in an age-old tradition.

Of interest here is the way in which the term nature is interpreted; more precisely, in landscape architecture nature is juxtaposed by the term ‘landscape’, which forms the operative idiom of the discipline. Within this idiom three epistemological frames arise in the discourse: landscape as earth-life system, landscape as habituated milieu, and landscape as experiential scene/setting (Corner, 1999a; Van der Velde 2018). In turn these frames backdrop a quartet of operative perspectives and related methodologies for spatial (landscape) design praxis, namely (1) Perception, (2) Anamnesis, (3) Multi-scalar thinking, and (4) Process design (Marot 1999, Prominski 2004). These perspectives are relevant for this paper in that they resonate with three themes found in BwN that deserve attention in expanding and sharpening its knowledge base and methodologies: (1) design of/with natural processes, (2) integration of functions or layers in the landscape and (3) connection of engineering works to their human-social context.

To narrow down a review and migration of ways of knowing and doing from landscape architecture to BwN, a selection is made from the repertoire of the discipline to those projects operating in the same context such as coastal landscapes, or those engaging with infrastructural challenges such as flood safety. Coastal landscapes formed the setting of a series of landscape architectural projects realised for the Oerol festival on the island of Terschelling between 2011 and 2018, under the auspices of the chair of landscape architecture at the faculty of architecture, TU Delft. The Oerol projects formed part of the master of landscape architecture elective programme, a 12-week long design-and-build module for students from landscape architecture, architecture, urbanism and industrial design, led by researchers and lecturers from the chair. Given the setting of the festival on the island of Terschelling, the problematique of climate change and flood safety formed an implicit, and sometimes explicit, backdrop to the studio. The cooperation between Oerol Festival and the chair stemmed initially from the broad ambition to create a synergy between art, science, nature and landscape. As such the projects were positioned in the 'expedition' programme of the festival, an auxiliary set of projects to complement the theatre and music agenda of the 10-day long festival. In each of the projects student teams led by researchers and staff researched, conceptualized and constructed temporary design-and-build installations to be visited by the (festival) public over a period of 10 days. For master track students it was an opportunity to take part in a 'live' design assignment and build a physical installation, to learn how to collaborate with fellow students and external stakeholders, work with a festival audience in a multidisciplinary environment, and bring together different notions of nature and landscape. A recurring conceptual frame for the projects was the notion of place: understanding how landscapes form specific locales and what landscape architectural methods can do to reveal and engage a 'sense of place'.

In the following, an examination is made of the collection of On-Site projects in the period 2011-2018 to glean various ways of knowing and doing relevant to BwN. In the first part, an overview is given of the projects and their thematic focus, followed by a discussion of these themes and their outcomes in relation to the ways of knowing and doing in BwN. Lessons learnt are summarized and related to the BwN perspective in the conclusion.

2. Landscape as agency in Oerol on-site projects

First generation: 'Landscape Mirror' & 'Feed the Wind'

The first participation in the festival's project series, the 2011 'Landscape Mirror' project, explored different landscape types present on the island such as polder, village, forest and dune, represented these landscapes in a built diorama on the beach using materials such as sand, wood and cloth. To recreate the clash between natural and man-made forces provisory dikes were built of beach sand on the shoreline, in an empirical attempt to spatialize and communicate erosion and sedimentation processes for the festival public (figure 2).

Figure 2. Island landscape diorama, 'Landscape Mirror' project (Photo: Inge Bobbink)

Figure 3. Temporary water garden, 'Feed the Wind' project (Photo: Daniel Jauslin)

A *camera obscura* installation close by in the dunes allowed visitors to experience both the immediate and the distant polder, village, forest, and dune landscapes simultaneously. The unpredictable island weather provided some useful lessons as on one of the first days, a storm surge washed away the largest part of the project, offering an unpolished experience of the power of nature. In the 2012 project 'Feed the Wind' (Jauslin & Bobbink, 2012), aeolian forces which incrementally shaped sand into the barrier islands of the Wadden sea, and the ways in which man used this power to further shape the island of Terschelling, were explored in an enclosed (water) garden. The festival public were invited to bring in sand and use foot pumps to spread it out in the pond in a pattern echoing natural sand transport in the Wadden sea area (figure 3).

Second generation: 'Institute of Place Making' & 'Institute of Time Taking', 'Pin(k) a Place'

A shift in focus to the design process and the landscape of the island characterized the second generation of projects. In the 2013 project 'Institute of Place Making', detailed mapping studies by design teams revealed the complex morphogenesis of the island including erosion, sedimentation and vegetation, and their manipulation through grazing, cultivating, dune and dike-building, and settlement (infra)structures (Pouderoijen & Piccinini, 2013) (figure 4).

Site experience and on-site experiments also became part of the design process, through meetings and interviews with local inhabitants and festival visitors. This was done by asking them to collect material from a place on the island they related to and to give a short description about this relationship. Feedback was analysed and classified into categories in an attempt to generate scientific insights about people-place relationships. Findings were communicated back to visitors in an on-site exhibition in which they could browse through a range of possible relationships other than their own (figure. 5).

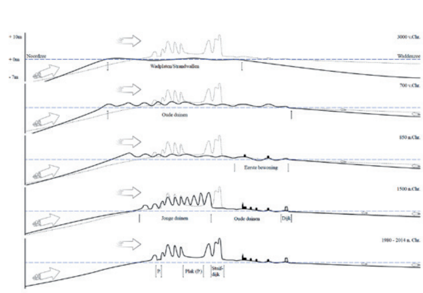


Figure 4 (left). Sectional representations of island morphogenesis, 'Institute of Time-Taking' project
Figure 5 (right). Cabinet of curiosities, 'Institute of Place Making'project

This approach was extended in the 2014 project 'Institute of Time Taking', with a focus on individual experience of landscape comparing sensorial and scientific approaches. Mapping the site and context of Terschelling formed a foundational step in this project, whereby the design process included a detailed set of descriptive and projective mappings of the spatial development of the island. In 2017 the 'Pin(k) a Place' project explored the people-place relationship further by examining what a specific forest landscape meant to people in a real-time physical experiment whereby visitors located and described the emotion of a certain point in a given forest environment (Piccinini, & van der Velde, 2017). In what might be termed a form of 'crowd mapping', multiple and alternative layers and meanings of a given landscape were revealed, complementing professional understanding of sites and landscapes.

Third generation: 'Institute of Poldering' & 'ForeSea'

In 2015 a collaboration with *Vogelbescherming Nederland* (VBN/Birdlife Netherlands) led to a project highlighting the decline of meadow birds in agricultural landscapes. The installation was designed to both depict and question the relation between (consumer) behaviour, landscape, and nature, and to show how farming was a delicate balance between business and sustaining a biodiverse and attractive landscape (figure 6). In 2016 a similar problematique backdropped the 'ForeSea' installation, an immense three-dimensional info-graphic depicting sea-level rise as result of visitor behaviour (figure 7).

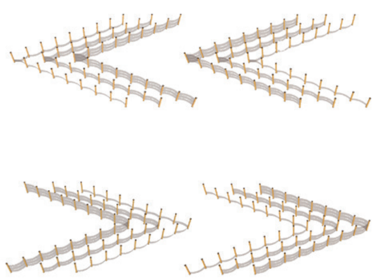
Both installations were designed as 'open-ended' constructions whereby visitor input decided the ultimate form. In this mode, the 2015 project saw a timber construction 'creep' incrementally across the meadowlands and the 2016 project developed into a dense three-dimensional airborne web of coloured threads visible from increasingly further distances. Although the primary purpose of this third generation of projects was communication, they now also took on a role of exploring how landscape architecture can address contemporary societal problems and spatial challenges by revealing the role of humans in landscape change and development.

Figure 6 (left). interactive installation, 'Institute of Poldering' project
Figure 7 (right). Dynamic info-graphic, 'ForeSea' project

Fourth generation: 'Aeolis - Gap the Border'

The issue of sea-level rise and coastal defence became an increasingly prominent theme in what can be seen as a fourth generation project realized in 2018. Whereas the 2016 'ForeSea' project raised awareness of the societal challenge of sea level rise, the 2018 project 'Aeolis - Gap the Border' actively engaged the agency of landscape in the problematique of coastal defence (Van der Velde & Van Bergen, 2018). For the coastal defence of Terschelling it is necessary for the fore and rear dunes to receive more (sand) deposits in order to keep pace with sea level rise. This premise set the scene for the first phase of the project in which aeolian techniques for dune formation were explored by students in field workshops for rapid prototyping and compositions for sediment accretion (figure 8).

By stimulating sediment accretion on the beach and in the dunes these experiments explored how to assist dune growth and compensate for coastal erosion. In early on-site workshops, 'fencing' in the form of hessian screens turned out to be a promising technique for sediment accretion.



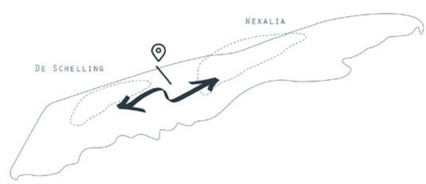


Figure 8 (left). Sand accretion prototype, 'Aeolis-Gap the Border' project
Figure 9. (right) 'Stitching' location, 'Aeolis-Gap the Border' project

Moving to the site and context of Terschelling itself, the design process turned to detailed descriptive and projective mappings of the spatial development of the island. This research revealed a complex history of natural and anthropogenic processes interacting together, including erosion, sedimentation and vegetation, and their manipulation through grazing, cultivating, dune and dike-building, and settlement (infra)structures. In line with these findings a site for the installation was chosen where the two former islands of Terschelling (Der Schelling & Wexalia) were united into one island during the middle ages (figure 9).

The technique of projective mapping led to understanding the site as a result of natural forces and anthropogenic interventions over many centuries, which was then translated into a preliminary zig-zag line placed perpendicular to the coastline from the foredune to the shoreline. This configuration effectively spatialized a large-scale (historical) stitching of the two islands together (figure 10). The goal to capture and transport sand driven by the (angled) winds across the beach with the hessian fences, led to the further development of the scheme into a woven configuration of columns and screens in the beach-foredune complex. As such the design became a connective assembly of screens at different heights in a zigzag configuration, leading from the dynamic surf zone to the less dynamic foredune zone over a distance of 200m (figure 11).

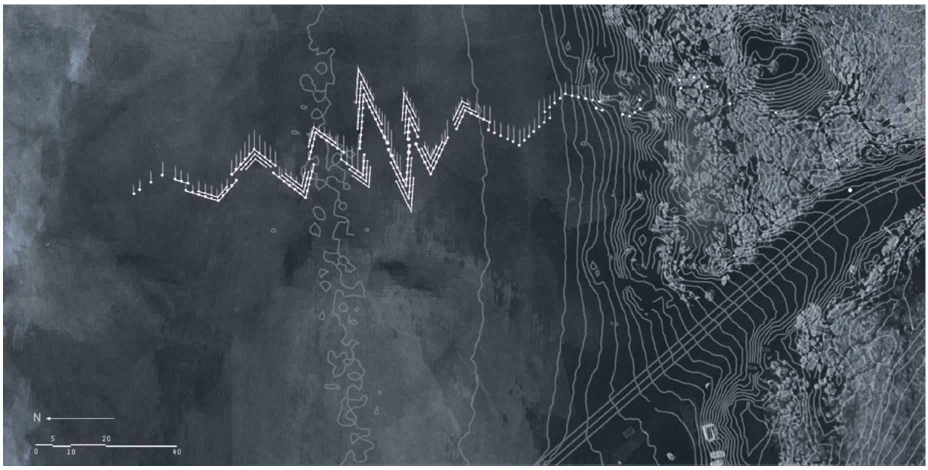


Figure 10. Screen assembly plan, 'Aeolis-Gap the Border' project

Figure 11. Installation elevation, 'Aeolis-Gap the Border' project

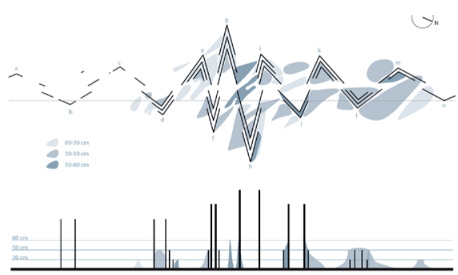


Figure 12 (left). Overview of installation from dunes, 'Aeolis-Gap the Border' project
Figure 13 (right). Accumulated in situ sand accretions, 'Aeolis-Gap the Border' project

In the final built installation, stepped fences were designed to trap different modes of sediment such as creep, saltation and suspension. The angled structure was able to trap sediment from various wind directions, including the less-favourable offshore winds, thus stopping sediment from blowing back into the sea. Rows of fences also served as tunnels for sediment transport to the inner parts of the installation while elevated 'blowholes' accelerated trapped sediment to the inner chambers of the installation, were it could settle further as start of embryonic dune growth. With the project forming part of the 'expedition' program of the festival, the public visited the installation over a 10-day period. A route was set out for visitors, starting in the mature dunes behind and above the installation. Here the public were introduced to the necessity of dune formation, with a route along panels showing the different phases of dune formation and ending in a panoramic overview over the installation (figure 12).

From this point they could observe the various stages of dune formation, including the effects of human intervention such as the decline in vegetation around beach accesses, but also the effects of 'tramping' which helps keep sediment mobile for transport. Descending to the installation, visitors passed through the central axis of the installation where they could observe the progress of accretion in the installation, by measuring its progress at stops on the route. As a BwN project exploring assisted dune development using natural forces (sediment transport by wind), the installation demonstrated novel effects on wind and sand transport and performed well in many facets of sand transport and accretion (figure 13).

In this way, although not intended purely as an installation to generate scientific results, it contributed as a conceptual model and prototype to elaborate different means for sediment accretion in response to site, wind and human dynamics. Some items of the installation, such as the stepped fences, did not fulfil their promise in the short timeframe of the festival. Other aspects, such as its angular shape did well in the prevailing south-west (offshore) wind, stopping dune sediment being transported back to sea. An unexpected outcome was the effect of higher screens which turned lower openings into 'blow holes' during higher wind speeds, transporting sediment deeper into the installation.This effect compares to beach pavilions on stilts, where the carrying construction also functions as a medium for deeper sediment transport due to higher 'compressed' windspeeds beneath the structure. It shows the spatial effects of architectural interventions in the beach dune interface that can inform future built form edifices to enhance dune formation in the fore dune zone. These insights were fed back into the ShoreScape research project of the Delft University of Technology and University of Twente to see how they can be translated to operational mechanisms for sediment transport and new urban typologies for the beach-dune interface.

3. Discussion

The contribution of the Oerol projects to the discourse and practice of BwN are further elaborated by discussing them in the frame of the four operative perspectives of landscape architecture (perception, anamnesis, multi-scalar thinking, and process design), in relation to the existing knowledge base and methodologies of BwN (design of/with natural processes, integration of functions or layers in the landscape and connection of engineering works to their human-social context).

Mapping Coastal Landscapes as 'Complex Natures'

Mapping and modeling the successive (re)workings of the territory over time was a defining aspect of early Oerol projects such as the 'Institute of Time-taking'. As methodologies, these activities draw on both the 'anamnesis' and 'process design' perspectives by revealing the incremental change of the island over time. In exposing the interaction of both natural and anthropogenic forces in this evolution, they demonstrate the historical complexity of coastal environments with relevance to BwN initiatives (figure 14). More critically, they reveal the essential interaction between man and nature on the island, and by extension raise important questions for the BwN approach: have not anthropogenic elements in these landscapes become an irreplaceable appendix to the abiotic and the biotic?; and by extension: should BwN restrict its understanding of nature to non-anthropogenic environments and 'natural' conditions?

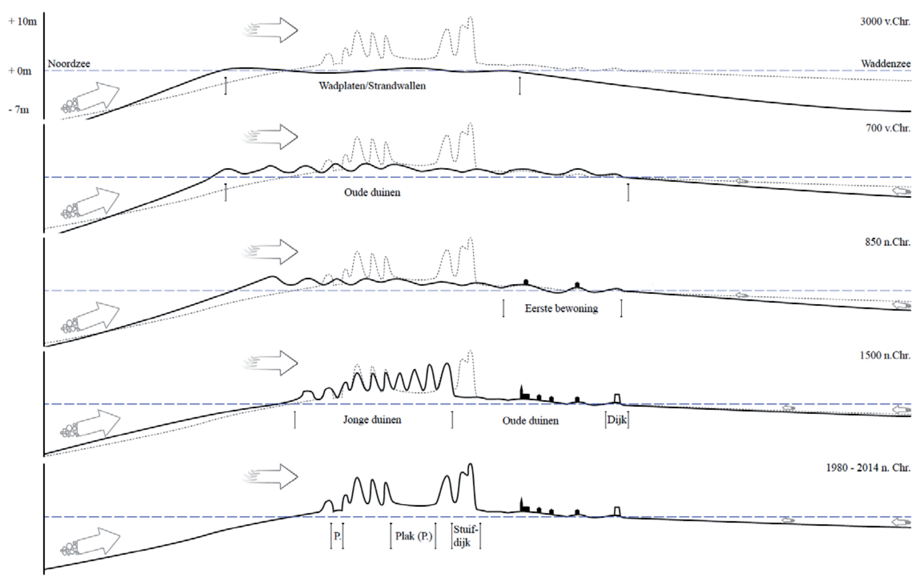


Figure 14. Sectional study of landscape formation, 'Institute of time-taking' project, 2014

In answering these questions - and before proceeding to applications - BwN might first attempt to define its understanding of nature; as Williams (1983) observes, nature is one of the most complex terms in the English language, a predicament undoubtedly relevant to other languages. He goes on to note that nature is an abstraction, a set of ideas for which many cultures have no one name, *"a singular name for the real multiplicity of things and living processes"* (Williams, 1980). From the perspective of landscape architecture the meaning of the term nature can be said to be relative to the context of the intervention; if natural and anthropogenic forces in a locale have conflated to such a degree that their distinction is irrelevant, the 'nature' of the territory is just so. By extension, a Building-with-Nature project should creatively engage with the amalgam of natural and anthropogenic forces present, within the framework of its broader sustainability objectives.

Mapping as Design-generative Device

As a methodology, mapping implies a deep understanding of the natural and anthropogenic forces at play in the territory, their interaction over time, and critically, their interpretation towards the infrastructural challenge at hand. As such, while the outcomes of these first projects had little relevance for BwN as solutions for flood defense or other civil engineering challenges, the 2018 project took this thematic through towards a solution with methodological relevance for infrastructural outcomes. The 'Aeolis-Gap the Border' project used mappings of the island to inform the location and configuration of a system of screens, which accreted sediment by capturing wind-blown sands. Leaving aside a discussion of the ultimate success of the screens in dune development (impossible to judge in the short time of the festival), the linking of the island's historical development to the solution is useful for BwN in that it engages not only the natural processes of the island, but also with the cultural forces that worked with the 'nature of the island' over centuries to shape it. As such, by translating the results from landscape mappings (historical development, layers etc) into a spatial concept, the incorporation of the embedded, deep-time working-with-nature character of the island was revealed and engaged. An implicit position here is that the island itself harbours vital information for the rollout of BwN for coastal defence, which in turn has a potential for elaborating and incorporating new patterns of occupation in coastal landscapes with benefits for the acceptance of large-scale infrastructural interventions in coastal environments.

In respect to the process itself, unlocking the island's 'DNA' is rarely a deductive process, but instead uses the agency of mapping selectively and even subjectively. Corner (1999b) observes that mappings are not neutral or passive devices for measurement and description, but, instead, (should be) seen as imaginative and operational tools. He goes on to note that '… mapping enables the designer to *construct* an argument, to embed it within the dominant practises of a rational culture, and ultimately to turn those practises towards more practical and collective ends' (Corner, 1999b). The possibilities (and implications) of this stance for BwN are significant; it suggests that an operative relationship can be constructed between mappings of the territory and infrastructural interventions, but that this process demands a combination of close readings and creative (re)constructions, competencies that do not exist in one single discipline as yet.

'Crowd-Mapping', People-place Relationships & Co-creation

If mapping is to be seen as an imaginative operation, then constructive mappings as a generator for design solutions might also include non-professional mapmakers. This notion emerges from the second-generation projects, which shifted investigations of the territory towards (human) perspectives of the landscape & the mapping of the social dimension of place. This shift responded to an emerging theoretical frame for the projects: understanding how landscapes form specific locales and what methods can reveal and engage a 'sense of place'. As such, the teams explored not only the identity of a particular site and territory by mapping its bio-physical and urban-infrastructural form, but also its socio-cultural 'DNA'. How landscape are perceived and appreciated by locals, visitors and other user groups thus became a central theme. In the 2013, 2014 and 2017 projects perception of landscape and different ways people connect to it led to several interactive ways of investigation to structure visitor observations, such as imaging, mapping, description and classification (figure 15). What these outcomes may mean for BwN solutions are yet not entirely clear, but they do show that perceptions of landscapes (and by inference different ideas of what 'nature' is) are more diverse than those held in professional circles. By extension, non-professional contributions as generative devices to develop BwN solutions could be much more fertile than generally assumed. At the very least, revealing and working with the 'embodied knowledge' of coastal landscapes has a critical advantage over conventional BwN approaches in terms of public relations. In the first place, by working with what people (can) know, and by extension relate to. More fundamentally, for local communities who have been part of the shaping of the island in the first place (and see how this is used to develop a new approach for dune development) there is a shift in the authorship of the work from the engineer to the island and its people. By extension, the acceptance of (innovative but uncertain) BwN measures can be expected to improve. Thus, while co-creation within BwN remains largely underdeveloped, its potential is much greater than currently acknowledged and may be even more so when inhabitants are allowed to adopt a BwN project and develop it further in different ways. This can be seen in the Sand Motor project on the South Holland coast, which shows that BwN projects may be more suitable for this kind of shared use than traditional, 'hard' solutions.

Figure 15. Landcape preferences mapping, 'Pin(k)-a-Place' project, 2017

Narrating Coastal Landscape infrastructures

'Crowd-mapping', people-place relationships and co-creation also prompt a parallel topic critical to (the future of) BwN. In the context of increasing demand for innovative and sustainable solutions for hydraulic infrastructures, there is a need to not only embed BwN projects in their bio-physical context but also to develop social acceptance of these measures as an alternative response to challenges such as climate change. In this frame, while the outcomes of many Oerol projects may seem in the first instance to have little relevance as solutions to flood defense, they do engage the public to experience environments in various ways, with potentially important lessons for BwN.

These approaches arise through the perspective of landscape (architecture) as an understanding and the choregraphing (perceptions) of outdoor environments. Early projects were conceived as narrative installations to transfer ideas to the festival audience through interactively building replicas of island landscapes with students and visitors. They explained how landscape works by immersing visitors in an experience of how different island environments evolved, thus making the public aware of the tradition of the barrier island landscape and the constant struggle between land and sea. Later projects such as 'Institute of Place Making', 'Institute of Time Taking', and 'Pin(k) a Place' brought to light the importance of landscapes as settings for experience and identity for individuals and communities. In the third-generation projects, awareness became an interactive component to make people conscious of the role they play in shaping landscapes through their own behavior. This was elaborated through public interaction with the installation, transforming it through the actions and opinions of individuals. For BwN, these approaches can serve as an example to engage communities by making people aware of sea level rise, and the need for BwN responses to it. The 'Aeolis-Gap the Border' installation for example begins by making aspects of the landscape that are normally invisible (such as sand transport, or effects of recreation, loss of beach vegetation, beach development) visible. In fact, the sand landscape of Terschelling can be said to have become the main feature, and the installation a facilitation and visualization of it. A necessary broadening of BwN involves making invisible landscape-forming processes visible, translating them architecturally, and sharing them with a larger audience in order to increase awareness of the landscape.

Public Interaction and Aesthetic Experience in BwN Design Processes

A more structural engagement with individuals, communities and societies in various phases of BwN projects is a final theme, not just as informative moments but as an integral part in the phases of hydraulic infrastructure projects (initiation, plan development and construction). Openings in this direction can be seen in the 'Aeolis-Gap the Border' project, where visitors and residents became aware of the history of this coastal island, of climate change and vulnerable coastal landscapes, and became familiar with succession in the dune landscape as a necessary step in response to sea level rise. However, the project also made them critical; is this science? Is this art? Is this disturbance of the landscape? As such, the project engaged the collective memory of the audience to evaluate new BwN techniques, not just in a technical way but also in a cultural sense, as an act of 'landscape building'. The physical installation served as a testing ground for people to understand, accept and participate in science, and engage with the adaptation of the dune landscape that results from it. The design of prototypes is thus not just about investigating scientific questions and technical solutions but also to bring science to a wider audience, to start a dialogue about science and its role in the transformation of landscape. This kind of approach is exemplified by the BwN projects such as the Sand Motor, which is not only the result of technical parameters but also incorporates recreational and cultural practices. Some even suggest a step beyond this paradigm. Meyer (2008) argues that while ecological health, social justice and economic prosperity are the three dominant modes of sustainable landscape development, aesthetic environmental experience is the crucial missing link to effectuate this goal. She observes that 'the performance of a landscape's appearance, and the experience of beauty, should have as much currency in debates about what a sustainable landscape might, and should be as the performance of its ecological systems' (Meyer, 2008). As such, what may be considered as a purely artistic aspect of installation works such as the aesthetic constellation of hessian screens in the 'Aeolis-Gap the Border' project (and thus removed from the 'real work' of BwN infrastructure), can be viewed as a necessary part of the wider practice of BwN which aims to sustainably address the effects of climate change. In this way BwN projects may also be expected to contribute to public debate on the role of science and its cultural transition in the context of the future of coastal landscape of the Netherlands.

4. Conclusion

BwN is a new approach now being implemented in several pilot projects. The approach is still in an early stage of development and in need of elaboration in terms of its knowledge base and design methodologies. The multi-dimensionality of BwN calls for the incorporation of 'designerly ways of knowing and doing' from other fields involved in this trans-disciplinary approach. As such, the successful evolution of BwN implies a transition away from purely rational design paradigms towards attitudes and procedures in reflective design paradigms employed in related spatial design disciplines. Centring in on the knowledge base and methodologies of BwN, these may be critically expanded by drawing on emerging ways of knowing and doing in spatial design disciplines such as landscape architecture, which presents itself as a potential source through its elaboration of the agency of the term 'landscape', as counterpart to the term 'nature'. Landscape forms a relevant idiom with a set of operative perspectives and related methodologies for spatial design praxis, such as perception, anamnesis, multi-scalar thinking, and process design. These are relevant to BwN as an approach which engages with natural processes, synergizing functions and connecting solutions to the cultural component of coastal environments.

A series of festival projects in the period 2011-2018 elaborate these themes in different ways. The first generation of Oerol projects were directed towards the understanding of landscape as natural and cultural mosaic and the social perception of landscape. Second and third generation projects made the step towards an architectural intervention in the landscape as a result of public dialogue, which also raised awareness for societal challenges such as the vitality of polder landscapes or the threat of sea level rise. A fourth generation project brought the problematique of BwN to the landscape of Terschelling, revealing how a broader elaboration of coastal defence is possible that not only addresses flood safety (and ecology) but also the deeper bio-physical and human-social characteristics of the territory. Themes emerging from these projects include: 'mapping coastal landscapes as complex natures', 'mapping as design-generative device', 'crowd-mapping', 'people-place relationships', 'co-creation', 'narrating coastal landscapes', 'public interaction' and 'aesthetic experience'. Specific aspects of these projects relevant to the knowledge base and methodologies of BwN, include integration of sites and their contexts through descriptive and projective mappings, understanding the various spatial and temporal scales of a territory as complex natures, and the integration of collective narratives and aesthetic experiences of coastal infrastructures in the design process, via reflective dialogues.

For a further elaboration of BwN it may be productive to examine and develop its epistemological foundations. The landscape epistemes 'landscape as earth-life system', 'landscape as habituated milieu', and 'landscape as experintial scene/setting' are a useful starting point for this work.

Acknowledgements

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Detailed project documentation is available online at: http://iopm.nl

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Pioneering Sand Motor

The Sand Motor as source to rethink anthropogenic coastal modifications in cultural public space

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Abstract

Now that people all around the world are slowly starting to rethink how humanity and the planet are interrelated, new questions have arisen around the understanding of time and the perception of place. It's not merely a technical or a political challenge that we are facing, it is also a *cultural* one. The Sand Motor - as the first of its kind - uses the forces of the wind and waves as active agengies of change, but can it be valued as a driving force for humanity to change as well?

Drawing from primary artistic research of the sea, coastal transitions, climate change and human appropriations in The Netherlands and abroad, we can state that the ephemeral nature of the Sand Motor itself challenges a polyphonic discourse for co-creation of experiential knowledge. The Sand Motor can be perceived as a man-made intervention in public space, an open-air, publicly accessible research site. Over the past 10 years, Satellietgroep redefined the Sand Motor as a cultural phenomenon, connecting the Sand Motor to the realms of art, culture, and heritage. This essay discusses a series of human-inclusive art projects, in which the Sand Motor evolves from a non-place into a vital learning environment for the cross-pollination of ideas and experimentations to rethink culture and nature. They demonstrate that pioneering *with* the Sand Motor should include pioneering *with* the social and cultural values of this artifact, not only to raise public and professional climate-consciousness, but also to adopt it as a *human-inclusive* landscape. This may well be the most underestimated value of the Sand Motor itself, and of the concept of Building with Nature in general.

KEYWORDS

Art, polyphonic discourse, co-creation of experiential knowledge, vital learning environment, public climate-consciousness

1. Introduction

The Dutch have a rich cultural and innovative relationship with the sea. The ongoing existential challenges due to the fluxes of the North Sea in past, present and future are important for everyone. Shores can be perceived as thresholds of liminality. In time and space, the narratives of pre-human nature meet the narratives of humanity. To spark our imagination for an unforeseen future we are challenged to enhance professional and public climate-consciousness.

The Dutch artists collective, Satellietgroep (The Hague, 2006), redefined the Sand Motor as a cultural phenomenon (Satellietgroep 2007, 2008, 2013a, 2013b). With the Sand Motor, all issues around climate change, relative sea level rise, the future of coastal safety, and the role of humanity in these processes come together. The transdisciplinary collective creates conditions for artists, designers and students to work on-site during artist-in-residency programs, collaborate with the extensive network of locals and scientists - including the researchers of the NatureCoast program - and develop new works and insights that are shared with wider audiences during public programs, often beyond the realm of the arts. (Satellietgroep & Heerema, J., 2019)

In retrospect, these reciprocal encounters revealed unforeseen values of the Sand Motor. It did not exist, and it will dissolve. We may argue that the ephemeral nature of the Sand Motor itself challenged a polyphonic discourse for the co-creation of experiential knowledge. In that sense, the Sand Motor evolved from a non-place (Augé, 1992) into a vital learning environment for the cross-pollination of ideas and experimentations to rethink culture and nature.

Sixteen Public Expeditions, a growing Sand Motor Collection, and an exhibition program called 'Climate as Artifact' (Satellietgroep, 2018) demonstrate how an explorational artist-in-residency program and an inclusive public program can create alternative ways of perceiving and being at the Sand Motor. This essay draws from pioneering *with* the Sand Motor and beyond, from tasting Fossils Soup to designing an educational Sand Motor visitor centre. Without judgement, without a preconceived idea, Satellietgroep is curious to see the opportunities that climate (change) can offer us.

Figure 1. Sand Motor, 'The Dutch are masters in disguising a cultural landscape as a natural one. We tend to design, construct, reconstruct nature to fit our needs', quote and photo Jacqueline Heerema.

2. Public climate-consciousness

Now that people all around the world are slowly starting to rethink how humanity and the planet are interrelated, new questions arise around the understanding of time and the perception of place. It's not merely a technical or a political challenge that we are facing, it is a *cultural* one. People cherish the idea of what nature is and what the world should look like; our environment is adjusted to fit that image. Are we aware of this ongoing representation of nature? We manipulate biotopes and interfere with living and non-living ecosystems. We design parks, zoos, and aquariums. Do we still have a choice of how natural our human habitats can be?

In an insightful range of paleogeographic maps, Peter Vos reconstructs 'The Origin of the Dutch Coastal Landscape' since the Holocene, 11.000 years ago with the fluxes of the North Sea and the genesis of the coastal landscape, including the interactions between natural and anthropogenic (human-induced) processes. (Vos, 2015)

Geology meets archaeology on the shores of the oldest dune landscape in the Netherlands along the seashore, called Solleveld. Historical geographer, Jan Neefjes describes in the 'Landscape biography of National Park Hollandse

Duinen': *"In prehistory and early Middle Ages, the coastal landscape was one of the most densely populated areas of the Netherlands. In the design and development of the area, people used the complex of beach barriers and plains. Although this undeveloped dune area looks natural and natural processes are given space, people have left their mark on the dune landscape through deforestation, planting of helm grasses, agricultural use or for hunting." (Neefjes, 2018)*

With the innovative construction of the Sand Motor on the foreshore of Solleveld, millennia of building with nature transformed into Building with Nature (written with capitals). The Sand Motor uses the forces of the wind and waves as active agencies of change, but can it also be valued as a driving force for humanity to change?

Before the public opening up of the Sand Motor on November 24 in 2011, Satellietgroep proposed to the main stakeholders of the Sand Motor (Province of South Holland and the Ministry of Infrastructure and Environment) to develop a consistent public cultural education program on and about the Sand Motor: *"The Sand Motor is not only a unique example of Dutch innovative coastal management, but is also important for a wider audience. The upcoming public opening is an excellent moment to start to investigate what impact this coastal transition will have on people, communities, and the changing environment. The accessibility of the learning process of the Sand Motor is of public interest, for now and for the future, when the Sand Motor is added to the history books of school children."*

This cultural vision requires that we tell the whole story. The Sand Motor is a pilot project to generate knowledge for future coastal protection, instigated by ongoing coastal erosion. Despite what most people think, the Sand Motor itself is not built to protect the Dutch coastline, it is an open-air, publicly accessible research site. Meanwhile, it is mostly promoted by the main stakeholders as a place where people *"can experience and enjoy nature"*. The man-made aspect was more or less ignored as soon as the Sand Motor was built. Thus, people are excluded from what is actually happening in public space. With ongoing climate change, interventions in the coastal landscape will increasingly influence choices for a safe and healthy living environment. As Stephen Mintern wrote in 'The Sand Engine as a Productive Void. Discussing the Spatial Value and Public Appropriation of the Sand Engine' (Mintern, 2011), the Sand Motor is *"the first of its kind (...), (which) means that the public have no pre-existing idea of how to occupy the space, it is a space void of any memory, therefore allowing for new more singular interactions with the space."* If we follow this line of thought, we can conclude that we have to find new ways of interacting with our environment, thus creating new narratives.

Public Expedition Zandmotor#2 Cultural Geology, March 2015

"Through a nebulous sandstorm in which the entire surface of the landscape seemed to be on the move, a group of determined travellers slowly became visible. They have set out on an arduous journey leaving the mainland behind. Like the early travellers moving north after the receding ice of the last glacial maximum or 'ice-age', they were moving into new territory. Our group was stepping onto the same sand that formed an area called Doggerland that once connected Holland and the UK but disappeared beneath the waves of the North Sea thousands of years ago. Some 21,5 million cubic meters of sand have now been brought up mechanically, to shape a temporary landscape: The Sand Motor." In his publication 'Next Doggerland', artist-in-residence Theun Karelse *"contemplates the parallels and differences between the last climate change event and the current one, in terms of ecology and culture and explores what a positive agenda for the future could mean. How can humans contribute to a healthy and functioning landscape, that includes us? How can people, their technologies, and infrastructures become symbiotic partners in the landscape? What is this post-natural landscape?"*

Karelse offers the audience 'Fossils Soup', a culinary experiment that seeks to connect with the ice-age relicts through a direct sensory experience.

Figure 2. Public Expedition Zandmotor#2 Cultural Geology, March 2015, photo Theun Karelse.

3. The becoming of Sand Motor

In January 2006, awareness that the North Sea may be perceived as a construction site or energy landscape to fit our needs instigated artists collective Satellietgroep to question 'To whom belongs the sea?' The initiative was triggered by the remarkable lack of involvement of arts, culture and heritage in the master plans for coastal transitions in The Netherlands, especially in The

Hague, with top down reconstructions for urban beach resorts in Scheveningen and Kijkduin, and with the prospect of islands in front of the coast. Prospects of innovative engineering that raise questions about modifying public cultural space.

The Dutch word 'kunstwerk' has a double meaning: it can refer to a man-made infrastructure (like a dike, polder, Sand Motor) or to an artistic expression, called a work of art. In the 17th century, painters travelled to The Netherlands, in search of 'Dutch Light'. Pieter-Rim de Kroon and Maarten de Kroon made the international awarded documentary called 'Hollands Licht' (Dutch Light, 2003): *"There's an ancient myth that the light in Holland is different from anywhere else, but it has never been put to the test. It's the light celebrated in paintings – in landscapes by Jan van Goyen and Jacob van Ruisdael, and in interiors and still lifes by Johannes Vermeer, Pieter Saenredam and Willem Claesz Heda. It's also in the works of later artists such as Jan Weissenbruch, Willem Roelofs, Paul Gabriël and Piet Mondriaan. It's the idea that light and observation were the cornerstones of a visual culture dating back to the 17th century. The German artist. Joseph Beuys, however, says that it lost its unique radiance in the 1950s, when the Dutch reclaimed the IJsselmeer (former Zuiderzee), bringing an end to a visual culture that had lasted for centuries."*

Proposals, such as building a dike around the North Sea, reclaiming the Doggerbank or a row of barrier islands in front of the Dutch coast had been circling around for decades. Efforts to deal with clogging infrastructures on the mainland, the promise to conquer 'new land' in the sea appealed to the imagination of generations of policymakers, spatial planners, landscape architects and engineers. An airport in the sea, 90,000 houses, conference centres, hotels and many more economy-driven plans to cope with land-related issues were projected onto imagined reclaimed land in the North Sea. An interesting read is the collection of ideas and plans for coastal development and adaptations to sea level rise on the Public Wiki pages of Deltares. This collection of ideas is divided into six themes: 'create space', 'protection against the sea', 'living and recreation', 'nature and environment', 'fishing and agriculture', 'transport and energy'. Thus, the lack of including the arts, culture and heritage seems manifest.

However, a new dichotomy arose on the Delfland shoreline: New Land as opposed to Existing Land. In 1996, these plans resulted in public protests. 'Laat de kust met rust' (Leave the coast as it is) became the battle slogan, and Wim de Bie, writer and creator of satirical TV programs , danced in honour of his ancestors the 'Dance of the Cananefates' on the beach (De Bie et al, 1975). Public support for economic-driven seaward expansions vanished.

'The sea belongs to everyone and thus to no one' - words that not only define the world's largest public space but also leave it unarticulated. With this concept, Satellietgroep kicked off in 2006 with a fake news article 'Kunst beschermt kust' (Art protects coast). In anticipation of the future coastal expansions, the collective conceptually appropriated one of the artificial islands. In March 2006 the official opening is performed with a construction sign called 'Satellieteiland, where art is the first form of life' on the beach south of Kijkduin, where, years later, the Sand Motor is built. The opening act is performed by prof. dr. Ronald Waterman, esteemed ambassador of nature-based coastal expansions. (Haasnoot, M. (2019)

Around the same time, a tiny booklet called 'Kustboekje' introduced the next stage of coastal development with a so-called sand source, combining safety and spatial quality with a time horizon of fifty years (Adviescommissie Zuid-Hollandse Kust, 2006). Integrated coastal management became the keyword for combining coastal safety in the industrialised urbanisation of the metropolis with upcoming values for nature to achieve social feasibility. Restoring the shoreline of the 17th century and so-called 'nature compensation' for previously lost nature reserves due to the expansion of the Rotterdam harbour, were depicted with images of pristine dunescapes and green shores to frame the coastal expansion as 'nature'. This booklet also promotes the 'Dutch Coast' as a product for the further development of tourism and recreation.

In 2011, the Sand Motor came to be. It was framed as 'nature', but is that what it is?

"I enjoy watching the sea from a distance. There is a double sea. The Laguna. The sea. This artificial beach has two horizons" noticed Yun Ingrid Lee, student of the ArtScience Interfaculty ElementsLab.

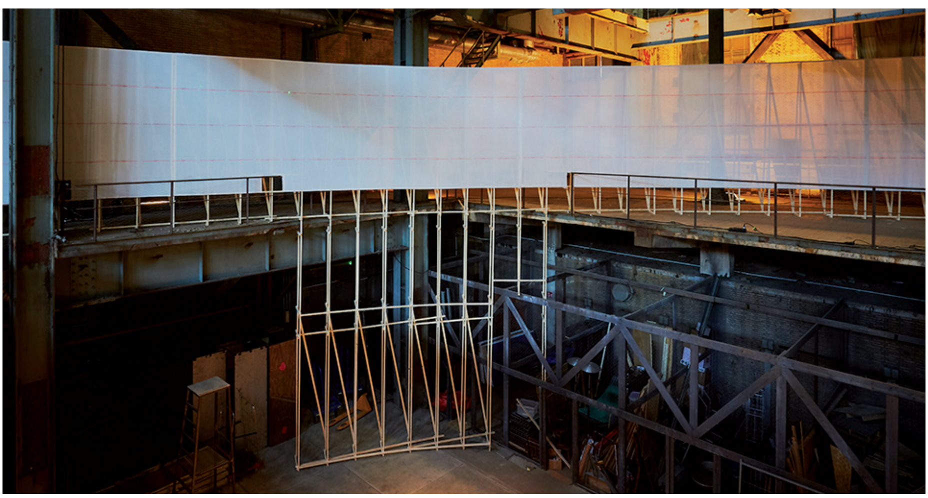

Figure 3. Maurice Bogaert, Wide / White, Climate as Artifact 2018, photo Johan Nieuwenhuize.

In art history, a panorama was a way to imitate or simulate a landscape. The experience of a landscape or so-called 'nature' is not unambiguous, but subject to the spirit of the time. 'Wide / White' by artist Maurice Bogaert, created for the exhibition program Climate as Artifact in 2018, is a spatial intervention, an 'observation machine'. The panoramic installation draws the largest possible circle in space. It crosses open spaces and escapes obstacles along the way. The surface is translucent and white, and thus escapes the romantic illusion of projecting an idea of a landscape onto a pristine canvas. The visitor enters into an undefined film set and is invited to complement the art work with observations and subjective memories.

At the opening of the North Sea Conference 2014, minister Melanie Schultz van Haegen (Ministry of Infrastructure and Environment) stated: *"The Dutch coast is our national heritage"*. At the same conference, Satellietgroep presented the Sand Motor as a cultural phenomenon and initiated the first consistent artist-in-residency and public program with the Sand Motor. Redefining the Sand Motor as a cultural phenomenon, brings the Sand Motor into the realm of art, culture, and heritage. With the Sand Motor, all issues about climate change, sea level rise, the future of coastal safety and the role of humanity in these processes come together. As Jegens & Tevens commented in their online art magazine: *" 'Building with nature' it is called affectionately. From the first moment the natural violence involved in this cooperation between man and nature has proved to be a great source for researchers and scientists, but also for artists. The Satellietgroep Foundation understands this and offers a selection of artists the opportunity in the coming years to work with the Sand Motor through an artist-in-residency program."*

Without judgement, without a preconceived idea, Satellietgroep is curious to see the opportunities that climate (change) can offer us.

4. Sand Motor as ephemeral Land Art

'Land Art' is an important international movement in the arts. The book 'Destination Art' (2006) by art historian Amy Dempsey is a critical guide to a selection of two hundred of the most important modern and contemporary art sites around the world and is regarded worldwide as the 'art lovers travel guide'. It provides an interesting read of how artists, since the sixties, express the interrelations of humanity with nature. The book includes a few famous Land Art works in public space in The Netherlands. One of them is 'Hemels Gewelf' (Celestial Vault, 1996) by American artist James Turrell, created in the artificial dunes of Kijkduin: *"A place where you have the sky to yourself, where you can practice the art of seeing"* Lily van Ginneken, director of Stroom, The Hague Contemporary Art Center, wrote about Celestial Vault.

Working *with*, instead of on the Sand Motor may require all the sensitivity and knowledge we can imagine. In that sense, the Sand Motor can be perceived as a staged landscape, as a stage projected into the North Sea. Built on the foreshore of the oldest dunes in The Netherlands. It provides us with the unique opportunity to stand in the middle of the sea, some twelve meters above the former sea bottom of 2011. To stand and look over the shoulders of our ancestors, who probably last stood there around the year 1600. And while being surrounded by the sea and elements, the Sand Motor provides a look back at the shores to rethink time and space in the past, present and future. It is said to be the first constructed seascape in the Netherlands that is built outside the dikes with the purpose to change and even dissolve into the sea, beach, and dunes. It did not exist, and it will dissolve. But will it really be gone, or has it transformed into something else?

Sixteen Public Expeditions, a growing Sand Motor Collection, and the exhibition program called 'Climate as Artifact' demonstrate how an explorational artist-in-residency program and an inclusive public program can target alternative ways of perceiving and being in the Sand Motor. How does art and redefining the Sand Motor as a cultural phenomenon generate a more essential understanding of the Sand Motor?

"The human desire to understand abstractions leads to new inventions, critical research, and a poetic contemplation of our environment", Heske ten Cate, artistic director of exhibition space Nest The Hague wrote. How can we relate to the abstract dimensions of the Sand Motor? The Sand Motor, as a wide open and seemingly empty stretch of sand positioned just next to one of the most densely populated areas of Europe, offers itself as a blank slate in which experimental works of art engage with open space, the natural elements and the public as pioneers. Can the Sand Motor be perceived as ephemeral Land Art? A time-machine that transports us from the geological era of the Holocene to the Anthropocene, the current era in which humanity affects the earth as a geological force? An unarticulated new wilderness? Or, as urbanist Jan de Graaf questions, is it a suicidal landscape?

Public Expedition Sand Motor #1 Sand Drift, November 2014

Zoro Feigl is the first artist-in-residence of the Sand Motor program in 2014. While roaming the Sand Motor and discussing the moon and stars with coastal morphologist prof.dr.ir. Marcel Stive, Feigl reflects on the Sand Motor in the context of Land Art and the artwork 'Spiral Jetty' (1970) by American artist Robert Smithson: *"As a piece of Land Art, the Sand Motor is of course a wonderful work. The work such as 'Spiral Jetty' was intended. Land Art to give back to nature. Not something that needs to be preserved, but something that is constantly* *changing. Playing with this nature is what I like to work with. A constant dialogue between material and natural laws. Preferably a wild conversation in which the various parties try to convince each other with some force. Often a lost battle for me, nature conquers, it never gives up. In fact, we only give the sea a pile of sand to play with ... to spread it out over the coast. We look at how the sea approaches that, hoping to learn something from it, or to enjoy the beauty it produces."*

Feigl is fascinated by why things work the way they work, why something moves the way it moves: *"On the Sand Motor I had a work in mind, something that could compete with this sand plain, a work that could enter into a conversation. In the many walks there I noticed that the small details in this wild-water desert fascinated me the most. The patterns in the sand, the waves. The drawings that the wind and water make. The size became an obstacle. That's how I started to highlight and isolate the pieces that fascinated me. Playing with these small things eventually became the artwork 'Untangling the tides' with two ropes, the ends of which are attached to small revolving motors, creating a hypnotic effect."*

Figure 4. Zoro Feigl, Untangling the Tides, Public Expedition Sand Motor #1 Sand Drift, Villa Ockenburgh November 2014, photo Thijs Molenaar.

5. Working with the Sand Motor

The idiom of the arts is not language itself, but to evoke our imagination and appeal to individuals and audiences by sensory experiences. One of the conditions for artistic field research is that the public must be able to participate and share in the findings. Being outside, out of your own comfort zone, is one of the experiences the Sand Motor provides as a cultural phenomenon.

Starting in September 2015, Satellietgroep engaged for a year in the ElementsLab with lectors, students, and invited experts to enhance the scope of artistic fieldwork on the Sand Motor as part of the ArtScience Interfaculty program of the Royal Academy of Arts The Hague i.c.w. Leiden University. This interdisciplinary bachelor's and master's program fosters curiosity-driven research as an approach for the making of art: *"The Elements is an outside coastal lab situated along the North Sea at the Sand Motor south of The Hague. What does it mean to work in a dynamic intertidal environment, where the tides are dictating time and seasons are close to our skin? The lab has a phenomenologist approach, stimulates students to play, wander, explore, and focus on elements in their own way, where also their own sensorial body in relation to this dynamic landscape can be considered as an element."*

Aisha Pagnes, student of the ArtScience ElementsLab reflects: "The quintessential purpose of the ElementsLab is to take you out of your element and into the Zandmotor's. At times, a rather discomforting practice, but most importantly, a reminder for how complacent we have become in our planned safety, how we have forgotten to intuitively and respectfully engage with nature and anything that does not fit our scale or schedule. The Sand Motor has a time of its own. Emails and appointments become ludicrous here. Bettering oneself and franticly huffing up the ladder of self-improvement and recognition becomes redundant. You may however, sit and smile, ignorantly and simply."

Public Expedition Sand Motor #6 Climate Experiment, December 2015

Artist-in-residence Esther Kokmeijer explores the scope of human resilience and climate adaptivity. She organised a climate experiment at the Sand Motor during the 2015 Winter Solstice, marking the shortest day and the longest night. Led by several experts, a select group of 15 invitees experienced, embraced, and questioned extreme cold and heat to their bodily limits. Among the experts invited were landscape architect Dirk Sijmons, co-inventor of the Sand Motor, Jurjen Annen, who led a cold training, Mark Hoek, who initiated a heat ritual in a sweat lodge and volunteers of the coastal Rescue Brigade. The experiment is documented with a thermographic camera and an infrared wildcam.

Figure 5. Esther Kokmeijer, Public Expedition Sand Motor #6 Climate Experiment, December 2015, photo Esther Kokmeijer.

The arts can express the spatial, social, and ecological qualities – as well as the problems – of our coastal areas and make them engagingly accessible to the public. These works can transform a destination normally characterised by consumption and recreation into a platform for critical communication and serious reflection. This timely reflection on spatial transition processes may act as a strong catalyst in generating public and professional discussions and connect contemporary research and new works to historic and future works and coastal transitions. Satellietgroep explores the Sand Motor from an artistic perspective and reflects on it in the context of ongoing artistic field research in Scheveningen, polders, the Wadden Sea, Afsluitdijk, and international exchange projects.

Commissioned by the Province of South Holland, Satellietgroep created a cultural vision of the Sand Motor. The collective emphasised that perception, experience, and imagination allow societal access to knowledge and skills, and wrote: *"This can be achieved by positioning the Sand Motor in the middle of society. Transdisciplinary imagination and insights are combined during the public program. The projects place experts and laymen on an equal footing, whereby professional and personal identity shifts to the background and a collective experience arises. The rugged environment of the Sand Motor ensures an adventure with the dynamic concept of man-made nature. It is a space where a public expedition can take place in the middle of a sandstorm, and where people come closer to each other during a cinema event under the moonlight. It is an area where artists, scientists,* *policy makers, visitors and residents, young and old, experience something that they will not soon forget. This creates a personal and sensory connection with the public research area, creating an intimate commitment and strengthening the relationship between people and nature. In short, the public program makes the interconnectivity of people and nature accessible and visible. Laymen and experts are thus part of the discourse on sea, ongoing climate change, and coastal transitions. Societal inclusiveness in these developments increases the resilience of people and/with the coastal landscape."*

Figure 6. Laboratory for Microclimates, Zand Zicht, Public Expedition Sand Motor #5 CineMare at Sand Motor, September 2015, photo Florian Braakman.

Faced with images of suffering polar bears far away, we may wonder if the effects of climate change can be noticed in our daily environment. How close to our bodies is climate change and how we can learn to position ourselves in these transitions for the coming future? One of the conditions humans and other species need to survive is fresh water.

Public Expedition Solleveld & Sand Motor #10 Water Pioneers, December 2016

Satellietgroep i.c.w. Onkruidenier invited the public to join a walk through a time line of 10.000 years coastal landscape history.Together with experts in hydrology, archeology, ecology, Dunea (dune drinking water), and NatureCoast, the public learn from drinking water makers and nature experts, discover old parcelled fields and archaeological traces of coastal civilization in Old and New Dunes, listen at the Duindijk (dune dike) how the watershed was moved during the construction of the Sand Motor, walk on the innovative Sand Motor as a 'Water Maker' due to the growing freshwater bubble underneath, to the North Sea under which fossil water is hidden. Posing as Climate Tour Guides, the artists offered the participants at five locations the taste of the old and new coastal landscape, questioning if we can taste climate change.

Tastings Water Pioneer:

1. Water tower: malted barley bread with a puree of broad beans and Juniper berries from the old layers of Solleveld accompanied with a Pine needle infusion.
2. Before the walk we share little bottles of salty water that corresponds with the salinity of our own body and lies around 4%. This is a saline solution between our body and the sea, in order to prepare ourselves to the tradition of salt cures.
3. Watershed: a schnapps of wild roses from the dunes or a lost green walnut liquor together with a marshmallow made from the marsh-mallow root.
4. Sand Motor: The Water Fountain, with the taste of the freshwater lens from the Sand Motor.
5. Tasting at sea: a fossil bite of diatomaceous earth (compacted earth from diatoms) with a crip layer of seaweed salt.

Figure 7. Walking a time line of 10.000 years coastal landscape history, Public Expedition Solleveld & Sand Motor #10 Water Pioneers, December 2016, photo Theo Mahieu.

6. Climate as Artifact

Following the insights derived from the art program *with* the Sand Motor, in 2018 Satellietgroep posed the question 'Who is nature?' (Satellietgroep et al., 2018) and developed the public exhibition program 'Climate as Artifact'. Materialising ideas through the arts by including scientists and the public, while redefining climate as an artifact (as something we make), helps to increase our sensitivity and to see connections within the natural world and between our actions and our environment.

As an immersive experience of Sand Motor, art student Flora Reznik dug a hole for eight months. 'Hole' became her graduation work of ArtScience Interfaculty and Reznik reflects: *"The work had as a point of departure – a long durational performance in which I dug a hole for eight months in an artificial beach. I followed a strict set of rules: I must go once a week with basic equipment and dig as much as I could during the few hours of light that the Dutch winter provides. I challenged my body at the same time I took measures to care for it: the task became to make a place for myself, a shelter. I engaged in a conversation with the wind: it was clear that we were both the makers-unmakers of the hole. The few passers-by in that far off place saw at a distance a figure at work, and they would approach me. As if they were scripted, everyone asked the same question: 'what are you doing?', although they could clearly see what I was doing. I refused to give reasons. So very interesting, honest and intimate conversations occurred in that isolated location after overcoming the first impulse of people to possess explanations. I realized I had an uninvited audience, that what I was doing wasn't just an action, but a performance."*

Figure 8. Flora Reznik, Hole, ElementsLab ArtScience Interfaculty 2015- 2016, photo kite shot of Hole.

Perception, experience and imagination allow societal access to knowledge and skills. Faced with current and future challenges, the time-depth of landscapes and of ourselves, we need a new visual idiom, other collaborations, and multi-facetted perspectives. In sync with the current global time-frame, we may need to dissolve superimposed differences between sea and land, culture and nature, arts and sciences, professionals and general audiences to learn together where we come from and where we are going. While in the process of expressing unarticulated values, a new visual language is invented, often inspired by the poetic idiom of palaeontologists, geologists, archaeologists, hydrologists, coastal morphologists, oceanographers, climate scientists, ecologists, philosophers, etc., who engage in these adventures and share their insights. Aimed to enhance a deeper professional and public understanding. The network evolved in an extended family that includes the sea, shores, and the Sand Motor as valued non-human entities.

One of the most challenging aspects of the arts is the ability to pose different questions. In January 2006, Satellietgroep kicked off with the question 'To whom belongs the sea?' To celebrate over 12 years of pioneering and to prepare for an unforeseen and challenging future, in January 2018 they started to rethink our perceptions of culture and nature with the question 'Who is nature?' Satellietgroep invited seventeen artists and designers – all previous artist-in-residents - to jointly create a public program based on shared fascinations. This developed into an exceptional project, namely the exhibition program called 'Climate as Artifact'. For the first time, climate is emphatically positioned in the cultural domain. In the run-up to the autumn exhibition, monthly informal meetings took place with the participating artists and special guests from different domains. In addition, a supporting program evolved, where artists in smaller group presentations tested their artistic research with the public and entered into dialogue with scientists, philosophers and each other. Following the practice of Satellietgroep as an alternative academy and appreciating the sea and shores as vital learning environments of time and space, the visitors had the opportunity to engage with the artists who worked on-site, contribute to the ongoing process of artistic research, share their insights, and discover, through the arts, a multitude of fields of knowledge. Experts in the fields of nature, climate, geology, archaeology, oceanography, philosophy, zoology, botany, and spatial planning - as well as a canoe builder from the Marshall Islands - actively contributed to the making of new artworks and public dialogues. This method also led to an exhibition program that differs from more traditional exhibitions. It is closer to a sensorial knowledge lab; a space for experimentation, discussion and wonder; a workshop, learning centre and meeting place, where all your senses are claimed.

Climate as Artifact, 2018

'Eighteen Coffee Breaks - Eight Working Hours' is a triptych composed by artist Maurice Meewisse. He explores the relationship between the landscape, the local, and social history of the Sand Motor. The work is inspired by the creation of this hybrid landscape and aims to bring it back to a human scale. The Sand Motor is, in a way, an accomplishment of industry, the result of human endeavour even though it is experienced as nature. Meewisse introduced the coffee break, a very important daily ritual.

Figure 9. Maurice Meewisse, Eighteen Coffee Breaks - Eight Working Hours, Climate as Artifact 2018, photo Jacqueline Heerema.

7. Destination Coast: Kijkduin

Nowadays, two travellers from around the world seek the shores of Kijkduin: the one in search of art visits the famous Land Art work by American artist James Turrell, called 'Celestial Vault'; the other in search of coastal innovation visits Sand Motor. Sometimes they merge, in search of what the collective calls 'Destination Coast'.

Building on three years of experience as a nomadic arts initiative (Satellieteiland, 2006-2008), in the summer of 2009 Satellietgroep built Badgast. In the middle of a temporary urban surfing village called F.A.S.T (Free Architecture Surf Terrain, Scheveningen), the collective initiated an artist-in-residency and public program (Badgast, 2009-2015) in one-and-a-half stacked re-used shipping containers, designed by Refunc Recycle Architects. During five successful years of exploring the scope of the sea with this international artist-in-residency program, cinema at sea and talks at Badgast, and an international exchange program called 'Now Wakes The Sea' (since 2012) Satellietgroep built an extensive network and expertise of interconnecting arts, science and society on coastal transitions and climate change, in The Netherlands and abroad.

Meanwhile, construction plans for the Sand Motor evolved, thus providing a new opportunity to create an inclusive program to enhance climate-consciousness. Though local public protest against the construction of the Sand Motor prevailed in 2011, with the building of the Argusmast observation tower in 2012 in the middle of Sand Motor, public protest arose against building in 'our nature area', thus showing a remarkable shift in public opinion. Dutch artist-architect John Körmerling designed the Argusmast with a public viewpoint. But Rijkswaterstaat never allowed the public to visit the Argusmast. Abe Veenstra, Advisor of Spatial Quality for the Province of South Holland (2013-2016) reflects, in 2013, on the Argusmast: *"It underlines the laboratory character of the place; playing with sand and water elevated to science. However, it is only the Argus eyes of the scientists who are allowed to view the (undoubtedly) beautiful view. I consider it a missed opportunity that the placement of such an object has not been used for a combination with a public viewing point where it can literally be illustrated how the fascinating game of sand, wind and water is played here."*

Students of the Sand Motor ElementsLab comment on the Argusmast: *"During the time we spent on site we discovered that in certain weather conditions, the mast becomes an elements-driven sound instrument – an aeolian harp of sorts."*

"The Dutch are masters in disguising a cultural landscape as a natural one. We tend to design, construct, reconstruct nature to fit our need" reflected Satellietgroep. This ongoing friction between the top-down framing of the Sand Motor as 'nature' and the societal challenges of sharing insights of human-induced coastal interventions is expressed by Ronald van den Hoek (et al., 2014) in 'Uncovering the origin of ambiguity in nature-inclusive flood infrastructure projects, Ecology and society': *"Our main finding was that ambiguity in Building with Nature projects seems to originate from a contradiction between the beliefs held by different actors. Furthermore, our results suggest that in the current practice of Building with Nature projects, the scientific knowledge of experts is perceived as more legitimate than the local knowledge and experiences of lay actors, which implies that experts have a more powerful position in multi-actor decision making. Thus, our research underlines the difficulty of bringing local knowledge and past experiences of lay actors into collective decision making."*

Figure 10. Sand Motor as learning experience for public climate-consciousness, Public Expedition Sand Motor #14 Timescale of Landscape, April 2018, photo Florian Braakman.

"Dears, storm today: so great for filming, and possible some rain; no worries, I made a shelter for us this morning and prepared another experiment. See you there at 14:00" as Cocky Eek, artist-tutor of ArtScience Interfaculty texted to the students of the ElementsLab. Challenged by the ongoing artistic field research and public expeditions program, the need for a modest, sustainable and inclusive Sand Motor 'shelter' arose. A space to explore, collect, share and learn on-site from the ongoing outdoor artistic and scientific experiences, with the Sand Motor and with the public.

Commissioned by the Province of South Holland and together with public and professional stakeholders, Satellietgroep worked in 2014 and 2015 to develop Zandgast, the proposed new educational Sand Motor visitor centre, with an artist-in-residency and public program on and about the Sand Motor. A modest but visionary space, with the aim to collectively share all works and insights on location with a wider public audience to enhance climate-consciousness. Overtreders W, Rob Sweere and RAAAF (Rietveld Architecture-Art-Affordances i.c.w. Atelier de Lyon, Deltares, TU-Delft, Volker Wessels) were selected for the first designs of Zandgast. During several stakeholder meetings, the proposed designs for Zandgast achieved general support.

The proposal by RAAAF involves a next innovation of building with sand. With locally-sourced sand and the use of biological methods (Beach Rock, TU Delft et al.), this contemporary architecture will, in time, erode, as the Sand Motor does, thus bringing the sand back in the environment.

Henk Ovink, 1st Dutch Water Envoy commented on the design proposal of RAAAF: *"The pavilion is the first real experimental upscaling of building with sand that RAAAF | Atelier de Lyon performs i.c.w. Deltares, TU-Delft, Volker Wessels. The quality of our country and landscape, of our cities, starts with the right match between safety and quality and it is that match that RAAAF | Atelier de Lyon embraces and is committed to a future perspective: temporary and adaptive, robust and natural, innovative and inspiring. The imagination speaks and makes the safety of our country really tangible in this sand pavilion." Eric Luiten, Advisor of Spatial Quality for the Province of South Holland (2009-2012) added: "Sustainably manufactured, explicitly architectonic, merges with the harsh environment. Very delightful. Robust, manageable, tenable in harsh conditions and at the same time understandable as temporary. Uncommon, stubborn, interesting."*

Figure 11. RAAAF, Rietveld Architecture-Art-Affordances i.c.w. Atelier de Lyon, Deltares, TU-Delft, Volker Wessels, proposed design Zandgast, 2015.

However, in December 2015 minister Melanie Schultz van Haegen (Ministry of Infrastructure and Environment) stated that the safety of the Dutch coast is in order, and it is now time to start building on the shores for economic and tourist growth. Again, societal protest as 'Laat de kust met rust' arose, and a 'Kustpact' was developed. While commercial exploitations with rows of holiday houses on the beaches continues, the only cultural initiative called Zandgast became collateral damage.

Although the physical materiality of the Sand Motor is impressive, the experiences of art will survive in the collective public memory, after the Sand Motor has dissolved. In 2015, artist-in-residence Theun Karelse offered the audience 'Fossils Soup'. On September 6, 2019 world famous artist Olafur Eliasson (Iceland, Denmark) re-posted on Instagram - in the context of his solo exhibition called 'In real life' (Tate Modern, London 2019-2020) - to his 407.000 followers:

Public Expedition Zandmotor#2 Cultural Geology, March 2015

"K is for Kitchen. When eating a bowl of fossil soup, one might ask oneself, is this a vegetarian dish? Are fossils considered animal remains, or geological objects? A few years ago, Dutch artist Theun Karelse was invited by the Hague-based Satellietgroep as an artist-in-residence on the Sand Motor – a giant artificial sandbank running along the coast of the Netherlands. Quite unexpectedly, he ended up gathering a sizeable collection of fossils, which had been deposited along with the sand from the North Sea floor. Theun wrote: 'Some of these fossils are rather spectacular, like a mammoth rib or the tooth of a woolly rhino. These date back to the last glacial maximum (Ice Age) and are between 40,000 and 20,000 years old. There are also some less spectacular bone fragments.

It is pretty amazing to find these objects and hold them in your hand. It made me wonder if they grant access in some way back to the ancient past. Can anything from those times be experienced through these bones? Would they perhaps still have a taste? This became an experiment to see if we could become the first people in many thousands of years to taste mammoth!' He decided to approach experts in prehistoric food and archaeological cuisine to experiment in making a fossil broth, first by simply mixing the bone fragments with water and stewing them. This was then developed into a recipe for 'mammoth soup': assorted Sand Motor fossils, water, freshly picked ramson (daslook, or Allium ursinum), birchwine (berk, Betula), fermented cornel (kornoelje, Cornus mas), raw reindeer meat (rendier, Rangifer tarandus). Archeological experts confirmed that because fossils of this age still can contain traces of cartilage, marrow, and certainly DNA, the soup is not, in fact, vegetarian."

#Karelse #theunkarelse @satellietgroep #EliassonAlphabet

Figure 12. Theun Karelse, Fossils Soup, Public Expedition Zandmotor#2 Cultural Geology, March 2015, photo Florian Braakman.

8. Conclusion

The Sand Motor did not exist and, due to the predesigned ephemeral character, it will dissolve. But will it really be gone or has it transformed into something else? As the first of its kind, and with the transformation of building with nature into Building with Nature (written in capitals), some unforeseen lessons are learned with the Sand Motor. What are the lessons learned so far?

With ongoing climate change, anthropogenic interventions in the coastal landscape will increasingly influence choices for a safe and healthy living environment. With the construction of Sand Motor, a new opportunity emerged to create an inclusive cultural program to enhance professional and public climate-consciousness.

The Sand Motor is a man-made coastal intervention in public space, an open-air and publicly-accessible research site. It uses the forces of the wind and waves as active agencies of change. This essay argues, that as cultural phenomenon, the Sand Motor is a driving force for humanity to change.

The ephemeral nature of the Sand Motor itself challenges a polyphonic discourse for the co-creation of experiential knowledge. It evolved from a non-place into a vital learning environment for the cross-pollination of ideas and experimentations to rethink the reciprocal relations of humanity and nature in past, present, and future. The projects by Satellietgroep instigated a public dialogue on the unforeseen values of Sand Motor and the relationship between nature and people. However, the missed opportunity of the Sand Motor is an on-site space, to explore, collect, share and learn from the ongoing outdoor artistic and scientific experiences, *with* the Sand Motor and *with* the public. In that sense and for the future, it is essential to solve the ongoing friction of top-down framing of the Sand Motor as so-called 'nature' and target the societal challenges of sharing insights of human-induced coastal modifications in cultural public space.

We conclude that, for the evolution of Building with Nature as challenge to rethink culture and nature in coastal landscapes, it is vital not only to include nature, but also culture. Therefore, pioneering *with* the Sand Motor should also include pioneering *with* the social and cultural values, to enhance not only public and professional climate-consciousness, but also to adopt it as a *human-inclusive* landscape. This may well be the most important lesson learned for a more inclusive societal embedding of the concept of Building with Nature in general.

Acknowledgements

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ECOLOGY

Odum's dark bottle and an ecosystem approach

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Abstract

Eugene Odum was an ecological pioneer, writing the discipline's first textbook, Fundamentals of Ecology, in 1953. Although his work is almost 70 years old, it laid the groundwork for contemporary landscape systems thinking. Since Odum's time, a lineage of ecological research and theory has helped to define concepts pertaining to ecology, ecosystems, and nature. With these terms in peril of becoming ambiguous, especially in the design arts, this chapter revisits the origins and development of ecologic thinking in order to construct a more critical understanding of nature, and the role of the designer for Building with Nature.

One particular experiment by Odum is used as the foundation of concept development. A pond is his reference site and he 'dissects' it, using dark and light bottes to illustrate its nuances and the overall ecosystem idea. Three important principles can be derived. First, the ecologist, or the designer, should understand the 'nature' of the system, or site, where they are working. Second, nature is formed through functional interactions over extended periods of time. Lastly, through an ecosystem approach, it is shown that systems involve indirect effects. In ecological networks, sites are impacted by forces beyond their immediate boundaries, as well as through other social and cultural systems. Case studies located along the Florida Gulf Coast are used to explain Odum's and others' concepts. Florida has developed in parallel with human's capacity to manipulate their environment. For this reason, it is a useful reference site, illustrating trajectories in ecological thinking.

KEYWORDS

Environmental design, ecological design, Build with Nature, ecosystem approach, landscape architecture, ecological planning

1. Introduction

In the field of ecology, the term ecosystem has been synonymous with nature for almost 100 years (Tansley, 1935; Odum, 1953; Egerton, 2017). When first introduced, it marked a radical shift in the environmental sciences. Prior, concepts of nature were influenced by those in fields like biology, zoology, or in natural history (Benson, 2000). Flora and fauna were studied as objects, independent from their surroundings, each with unique attributes and behaviors. However, in 1935, British botanist Sir Arthur Tansley proposed a term that would reframe the ecologic perspective. An ecosystem, he wrote, provided a more holistic and interconnected model. *"Our natural human prejudices force us to consider the organisms … as the most important parts of these systems, but certainly the inorganic 'factors' are also parts – there could be no systems without them,"* he wrote (Tansley, 1935). He suggested moving beyond an object-based mode of inquiry, to one where object, humans and environment are studied together, and that elements be put into a multi-scalar context, *"from the universe to the atom."* (Tansley, 1935; Golley, 1993; Egerton, 2017). Although the term ecology had been used before in the sciences, Tansley and those after him thoroughly transformed it and gave it a dynamic new direction (Benson, 2000).

At the center of this development was a young professor at the University of Georgia who would change the broad understanding of ecology, and of nature, for all future generations, so much so that he is now considered "The Father of Modern Ecology" (Craige, 2001). Dr. Eugene Odum received his PhD in zoology with a major in ecology in 1939. At first, he was mostly fascinated with birds, but that path of study led him to a job researching plant succession at a biological research station. While performing those duties he began a transition, one that put his attention towards the dynamic nature of a site, and how it functioned as a system. *"Only by knowing the nature, extent, and speed of changes as well as factors causing them can man intelligently control his environment in the future,"* he wrote in a report (Craige, 2001; Odum, 1940). He was also greatly influenced by his father, a prolific sociologist that believed in holism and recognized the influence of context on communities (Craige, 2001; Eagerton, 2017). Odum picked up on Tansley's and others' ideas and brought ecology and ecosystems to the masses, producing the discipline's first textbook *Fundamentals of Ecology* in 1953. His book described experiments and explained natural processes so that students could understand ecosystem thinking. Through real-world case studies, he provided new imagination as to the interconnected nature of our world. He also discussed the value of operating at, and becoming familiar with, various scales. *"When someone is taking too narrow of a view, we may remark that he cannot see the forest through the trees,"* he writes. *"Perhaps a better way to illustrate the point is to say that to understand a* *tree, it is necessary to study both the forest of which it is a part as well as the cells and tissues that are part of the tree."* (Odum, 1963).

This chapter will return focus to the origins of ecology and to the ecosystem approach, not only in Odum's work but also in others' development of these concepts. This is important since, in recent years, terms like ecology and ecosystem have become somewhat ambiguous, often referencing definitions more closely associated to historic concepts in the sciences (Benson, 2000; Reed & Lister, 2014; Craige, 2001). Chris Reed and Nina-Marie Lister, a landscape architect and ecologist, recently wrote that, *"Today 'ecology' has been co-opted to refer to almost any set of generalized ideas about environment or process, rendering the term essentially meaningless."* (Reed & Lister, 2014). For design fields like architecture, landscape architecture and engineering, this has had significant impact, affecting overall approach and project outcomes (Reed & Lister, 2014).

By revisiting the ecosystem approach, in both its origins and development, it may be possible to better situate humans within their world, and to suggest new potentialities and responsibilities for Building with Nature. This chapter will identify examples from various stages in ecological thinking in the Florida Gulf Coast, to correlate theory with real-world implementation and environmental response. Florida has been inhabited in parallel with humans' significant ability to alter their environment but also with change in ecological perspective. The landscape itself shows evidence of a graduated development in ecological thinking (see Spirn, 1998).

2. The Pond, Dissecting Tools and the Dark Bottle

Odum liked to use a pond as his reference site. For him, it beautifully illustrated many fundamental ecologic principles (Odum, 1971, Willis, 1997). *"Let us consider the pond as a whole as an ecosystem…"* Odum began. *"The inseparability of living organisms and the nonliving environment is at once apparent with the first sample collected. Not only is the pond a place where plants and animals live, but plants and animals make the pond what it is. Thus, a bottle full of the pond water or a scoop full of bottom mud is a mixture of living organisms, both plant and animal, and inorganic and organic compounds."* (Odum, 1971) Odum's pond is a system, an infinite macrocosm of parts relating across and through multiple scales, each element necessary and affecting each other. This, he would write, was nature (Odum, 1971).

In order to conceptualize this further, Odum conducted an experiment using pond water and multiple glass bottles, appropriately called his *"dissection tools"* (Odum, 1971). He filled the bottles with water from varying depths, wrapping a few of them with foil, which darkened them from sunlight. The light and dark bottles were suspended in the pond at the same depth where the water came from and after 24 hours they were removed and processed to measure oxygen content. In the dark bottles, oxygen levels had decreased. It was consumed but not produced. Phytoplankton, which is responsible for oxygen production, was subjugated by the foil and not able to do its work. Conversely, in the clear bottles oxygen was produced in excess. This is representative of the upper levels of the pond. There, phytoplankton supplies enough oxygen to sustain itself, but also the bottom dwellers. There, at the bottom, soil and nutrient is created through decomposition and consumption of detritus by saprotrophic organisms, an important aspect of total system health. Each element acts individually but also as a system, perpetuated by unit adaptation to place. The relationships are co-dependent and are supported by each other's function. Odum explains the importance of recognizing these hidden members of the community: *"Although we regard microorganisms as 'primitive,' man and other 'higher' organisms cannot live without ... the 'friendly microbes'; they synthesize necessary organics and provide the 'fine tuning' in the ecosystem since they can adjust quickly to changing conditions"* (Odum, 1971). He goes to great length to discuss the importance of detritus and pond functionality at the bottom, as well as the functions at the pond edge, in the middle, and in gradients in-between (Odum, 1971). Light and dark zones, top and bottom levels of the pond, they each have a functional relationship in the production and processing of nutrients and in perpetuating the existing environment (Odum, 1971; Odum, 1963). They support each other. With this in mind, we can begin to visualize the pond in a different way. It is not comprised of isolated components but is rather the cumulative set of agents that aggregate to make up its ecosystem, to form its nature (Holling, 1973; Pyne, 2010).

Odum also discussed, for the pond specifically, how the synergy of parts within the pond developed over time (Odum, 1971). Through competition, adaptation, and by finding the right fit, the components create a complex web of interconnected functionality (Odum, 1963; Benson, 2000; Hutchinson, 1957; McHarg, 1969; Henderson, 1913). This occurs through constant exchange, with things impacting other things within the system. Elements co-evolve to meet criteria related to specific attributes of place and context, in order to produce a dynamic that perpetuates existence (Pyne, 2010; Holling, 1973). This process occurs over time. In an attempt to create a definition, one could say that something's nature, or nature in general, is *the resultant of a process where elements within a system interact with each other over time*.

Lastly, Odum described the concept of a watershed. He acknowledged that the pond is often falsely perceived as a self-contained unit, defined by a geographic boundary, and that the success and failure of its system is often evaluated in a limited manner. *"It is the whole drainage basin, not just the body of water, that must be considered as the minimum ecosystem unit...,"* he wrote

(Odum, 1971). He went on to suggest that the cause of and solutions for water pollution are not to be found by looking only into the water. *"It is usually the bad management of the watershed that is destroying our water resources"* (Odum, 1971). He emphasized the importance of a holistic, systems-based perspective. *"Since the ecosystem is primarily a unit of function, just where one draws a line between one part of the gradient and another is not particularly important"* (Odum, 1971). His focus was wholly on how the system worked, its inter-relationships, and in defining site by functional rather than locational connections.

There have certainly been many advancements in ecological studies since Odum's time, and these will be discussed, but a critical analysis of his experiments can help to derive a main set of principles to guide future work in environmental design and for Building with Nature. A larger framework is also developed through this text. If nature is the result of relationships, and humans are part of the milieu, then we must consider nature not as something to build with, as a thing apart, but as something that we are within (Gunderson & Holling, eds., 1995, as cited in Reed, C. & Lister, N. -M., 2014). If we are within the system, as a productive agent, intertwined and in relation, then we must also acknowledge the productive role of humans, especially now in the Anthropocene: we Build our Nature (Jordan III, 1994; Vitousek, 1997).

3. Principle #1: Identify and Incorporate Landscape Systems

The question of "Building with Nature" points to a question of cognition. What is it that is being worked *with*? What nature is being engaged and perpetuated by the project? In the transition from pre- to post- ecosystem thinking, Odum, Tansley and others helped to visualize an interconnected world. Odum's textbook drew upon an accumulating body of research, by authors like Henry Cowles, Frederic Clements, Henry Gleason, Victor Shelford and Evelyn Hutchinson, who had already written about functional interrelationships between things in the environment (Egerton, 2017). At the time, these researchers were also developing new forms of representation. Drawings of landscapes began to depict systems, not just objects. This was new science, and a new approach. The first food web diagram had been published by Lorenzo Camerano, in 1880, (figure 1) (Bersier, 2007; Egerton, 2007), however it was not until 30 years later that a steady stream of food web diagrams were produced. Pierce, Cushman and Hood constructed the next example in 1912. Another, by Victor Shelford (figure 2), continued the trend in 1913 (Bersier, 2007; Egerton, 2007). From there, a new form of landscape depiction developed to more holistically describe sites and their ecosystems.

Mapping Functional Relationships

Odum takes something familiar, the pond, and reveals a world of functionality and interrelationships that lurk beneath the immediate and obvious. He guides his readers beyond visual perception to one of function, range and scale. It provides a change of optics. Through the discussion of his experiment, he is able to re-map a person to place, giving them a new foundation from which to go forward, and to guide future decision-making.

Upon first encounter, the pond is a water body. It is clear, or not, has fish, or not, and often has plants around the edges. With a more detailed analysis, the pond is also comprised of smaller elements responsible for its physical characteristics.

Phytoplankton, as an example, is found in the upper levels of the pond where light is able to penetrate and it provides oxygen and food for fish and plants. Odum points out that *"these producers are not visible to the casual observer and their presence is not suspected by the layman. Yet, in large, deep ponds and lakes phytoplankton is much more important than is [the more visible] rooted vegetation in the production of basic food for the ecosystem."* (Odum, 1971). Bacteria and fungi are also working within the pond, as are insects, their larvae, and a host of living and non-living elements that make up its total set of components. Odum, and others, go further, however, to point out that it is not their singularity that makes up their nature, but rather the functional relationships between them, as an ecosystem (Odum, 1971; Lister, 2008; Holling, 1973). These elements are doing things to or for or against each other and this exchange produces ecological effects.

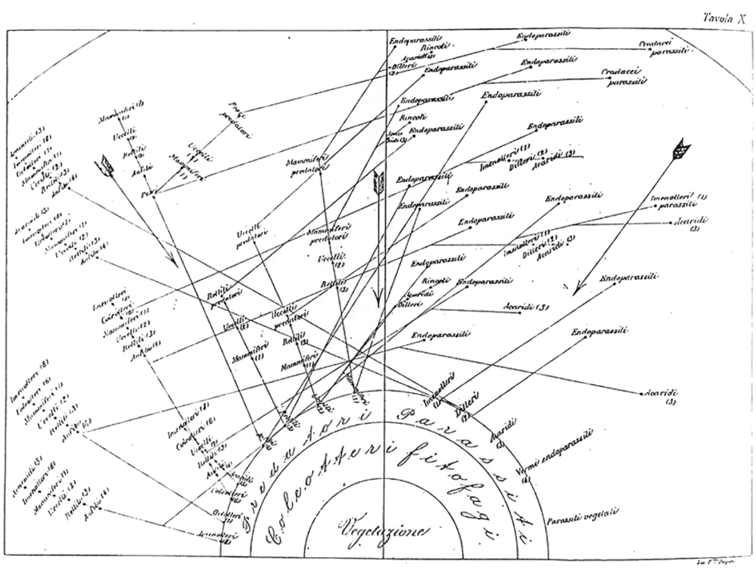


Figure 1. The first known documented food web diagram, by Lorenzo Camerano in 1880.

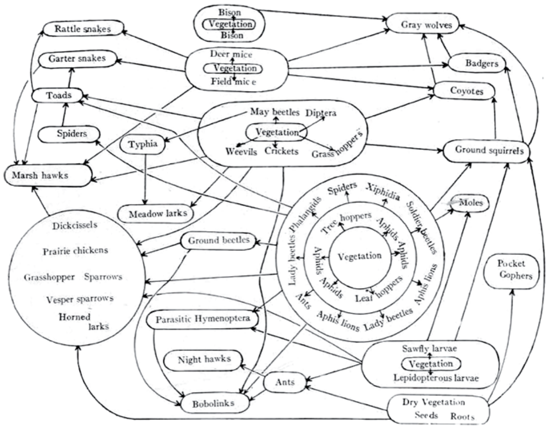


Figure 2 Victor Shelford's diagram from 1913, showing food relations of land animals.

To transpose Odum's understandings to design, it is important to consider the complete system, and not just appearances. He suggests that we are not able to understand something's nature through vision. It takes science and experimentation to dig into what can be considered an infinite world, or eco-system, comprised of a network of interconnected elements. The complexity involved in an ecosystem approach is certainly one of its difficulties and is recognized as a reason why reductive models are more prevalent (Craige, 2001; Bersier, 2007). This has been found true in the sciences but also in the design professions (Brown & Corry, 2011; Reed & Lister; Steiner, 2002; Weins, 1992). It is more common for practitioners to analyze their sites formally or aesthetically, or to select a few prioritized attributes despite an awareness that others may exist (Carpenter et al., 2009; Brown & Corry, 2011). However, a return to Odum's experiment can provide a useful perspective and approach for ascertaining a more complete understanding of site (figures 3 and 4).

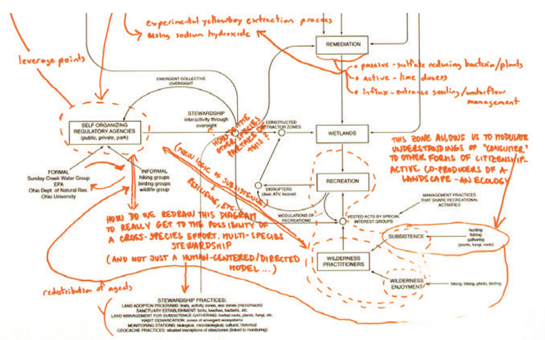


Figure 3 (left). Ecology diagram by Spurse, a contemporary environmental design office that consistently uses diagram in their projects to engage the ecosystem of the project. Image courtesy of Spurse.
Figure 4 (right). Diagram by Spurse. Enlarged detail. Image courtesy of Spurse.

The Effects of Cultural Bias

When regarding the Gulf Coast of Florida, these same principles can be understood through a trajectory of projects and manifestations of environmental design. The peak of development in Florida occurred with the advent of modern technologies in the 1950's and 1960's (Smith, 2005). Also, at that time, the population was comprised of people from many other places, from within and outside of the United States (Smith, 2005). This largely foreign population was working within a new territory. Developers had quick profits in mind and were focused on cultural considerations such as finances and views to the sea. With little regard as to the ecological underpinning of coastal environments they began to reshape their surroundings. The government supported this by passing the Riparian Act (1856) and the Butler Act (1921), which allowed land owners to *"obtain title to submerged lands adjacent to their uplands by bulkheading, filling or permanently improving submerged lands"* (Steinmeyer, 1999). This prompted removal and displacement of existing mangroves, wetlands and marshes and filled lands for ownership. After a surge of development, many thousands of acres of coastal water had been transformed in places like Boca Ciega Bay in St. Petersburg (1953), Cape Coral near Fort Myers (1957) and Marco Island near Naples (1960's) (figures 5 and 6).

Figure 5 (left). Aerial view of the construction of islands in Boca Ciega Bay, near St. Petersburg, Florida. With permission from Archives and Library, Heritage Village.
Figure 6 (right). Aerial view of St. Petersburg development. Image by Brian Cook.

Sea walls separated property from the waters, allowing property ownership to assume use to the edges (Parsons, 2015). Many miles of coastal gradient were lost and ditching, canals, rip rap and boat wakes ultimately have caused multiple scales of anthropogenic change (Peterson & Lowe, 2009). Similar to the darkened bottle, the system shifted and existing functional relationships were displaced while others were allowed to become more dominant within the ecosystem. Without the incorporation of landscape function into the region's development, a new nature formed. There have been major impacts such as algal blooms, marsh and mangrove loss and a reduction in fisheries production (Peterson & Lowe, 2009).

Similarly, in the City of Tampa, intense building within the floodplain created a situation where urban environments were increasingly flooding. When Hurricane Donna passed through in 1960, neighborhoods flooded and people demanded protection from the United States Army Corp of Engineers (Foley, 2007). The Corp's approach was focused. The directive was to simply move water to the bay, bypassing the city and provide relief from flooding. With this approach and bias, they developed a project and trenched 22.5 kilometers (14 miles) from an inland point around the city, constructing a bypass into McKay Bay (figure 7).

Figure 7. Aerial view of the City of Tampa. The Hillsborough River crosses the north end of the image from east to west, and connects to the bay. The Bypass Canal (named C-135) extends from the northeast of the city southward, bending west into McKay Bay and the port. Map data from Google ©2019.

With control structures and monitoring, this route eliminated all threats of severe inland flooding for the region (Foley, 2007). It has also functioned as a reservoir to supply drinking water. One can critique, however, using Odum's perspective, whether the engineers took an ecosystem approach, and can evaluate what elements they prioritized in the system. Their decisions enabled new opportunities for people, including safety. But with cultural successes, the landscape systems were not well represented, and have since diminished. The waterway did not incorporate attributes of the existing biotic functionality or the scalar landscape relationships, and now are a different projection of nature in that place (PBS&J, 2010). One could say that the Army Corp, in their design efficiency, was focused solely on the cultural aspects of the project. The final construction provided a corridor for water movement but not all of the complexities and ecologies associated with the historic riverine ecosystem, the one that so many other regional elements were built upon[1].

1 Readers should also reference David Fletcher's Flood Control Freakology (2008), which highlights other potential river ecologies, beyond those that are typically identified. This article suggests an expanded perspective for the nature of rivers.

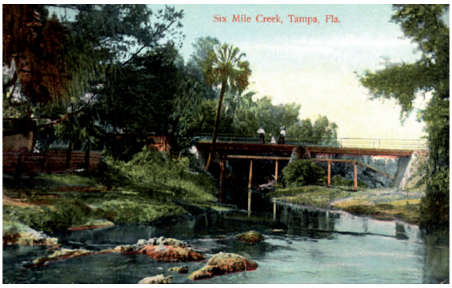


Figure 8 (left). Historic postcard of Six Mile Creek, in Tampa, which extended northward from the Palm River. This area was displaced by the construction of the Tampa Bay Bypass Canal (C-135).
Figure 9 (right). Historic postcard of Six Mile Creek, showing the overall dimension and depth of the area.

In addition to cutting through upland areas, the Bypass Canal displaced the shallow Palm River (figures 8 and 9). Within the new configuration, depth and breadth were spatially maximized. River bank slopes were built as steep as allowable, and riprap was used to prevent erosion. An offset distance from the water's edge has been maintained by mowing and spraying of vegetation, to keep it in control, and to prevent vegetative growth (figure 10).

Figure 10. The Tampa Bay Bypass Canal (C-135), in the location that was once Six Mile Creek. Image by Brian Cook.

More importantly, the functionality of this new ecosystem has shifted the nature of the region. In 2002 reports noted that *"the canal bottom is virtually devoid of life,"* despite its situation in a highly productive estuary environment (PBS&J, 2010).

In 1997, scientists said that the *"Palm River has the worst quality of any system in Tampa Bay,"* that it has *"algae blooms all year round,"* and that it was a *"killing field."* (Foley, 1997). A 2010 report by the Tampa Bay Estuary Program explained that *"the historical riparian emergent tidal wetland habitats in the Palm River were completely altered by dredging and filling. There are virtually no submerged habitats in the [Bypass Canal] due to steep channel side slopes.*

Therefore, the existing habitat values and functions in the tidal portion of the [Canal] are very poor," with *"high salinity levels"* and *"oyster mortality," "hypoxic (low oxygen) and periodic anoxic conditions that result in depauperate benthic communities"* (PBS&J, 2010).

During this history in Tampa Bay, there was a focus on the immediate, the cultural and the surficial aspects of environment. A holistic vision of landscape systems and interrelationships was not part of the construction, either in process or implementation. Because of this, similar to the darkened bottle, there have been severe consequences and a resultant change to the nature of the region.

4. Principle #2: Construct Relationships Over Time

In his texts, Odum repeatedly expressed that an ecosystem is comprised of functional relationships, and that these functions occur over time (Odum, 1971). For instance, in his representation of the pond, he spoke of its "metabolism" and described processes that were occurring within the water, such as production, consumption and decomposition (1971). The foil, darkening the bottle, was inserted as an actor, which induced change by altering the functionality of the system. The system adapted, filling itself with components that are capable of surviving within the given milieu (Odum, 1971, Holling, 1973).

Whereas Odum's example occurs in a relatively short amount of time, this type of exchange and adaptation also occurs over millennia. For example, a forest ecosystem may require fire for reproduction (seed dispersal) or for soil building, but fire is also a factor of geographic context, induced by heat, lightning or levels of precipitation (Pyne, 2010). Plants and animals in a region such as this have developed over evolutionary time to be resilient to the functional factors within the system. These become part of their characteristics, prolonging their existence (Pyne, 2010; Holling, 1973).

Robert E. Cook, in his article "Do Landscapes Learn? Ecology's 'New Paradigm' and Design in Landscape Architecture," (2000) investigated how the viola plant migrates so that it can continually find an appropriate place to live. It positions itself, over generations, by dispersing its offspring in order to find nutrients and light as forest conditions change around them. In this process, many succeed, but others do not. Trial and error perpetuate a dynamic and responsive process of engaging context, so that the species can continue to succeed from within their system, over time. Charles Darwin described this framework eloquently:

"It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us."

– Darwin, Origin of Species (1839)

In Florida, these laws, or factors of context, became apparent after a canal was dredged for shipping in Tampa Bay. The spoil was set aside, creating a new pair of islands. Over time, vegetation colonized the island, and so did extreme quantities of birds, including many that are rare. It has become one of the most valued avian habitats in the Gulf (Audubon Florida, 2020b; Davis, 2017). The material and design fit within a nature that is highly regarded, both for human and landscape systems, so much so that organizations have proactively maintained the islands to perpetuate it in the face of erosion and sea level rise. In 1977, on one side of the island, an oversized sand pile was deposited (Dial & Deis, 1986). It has since used the sea current forces, migrating to create a lagoon rich with avian habitat (figures 11 and 12).

More recently, on the other side of the island the shoreline has been protected with oyster domes and wave attenuating devices (figures 12 and 13).

As stewards, those involved have become part of the system, and will monitor this relationship into the future to guide an approach toward building within this (and future) nature(s).

Figure 11 (left). Sand pile site, which has been allowed to curve around the island using existing flow patterns. It has created a lagoon and new habitat for avian life and waterfowl. Image by Brian Cook.
Figure 12 (right). The sand pile site can be seen on the upper side of this image. On the bottom side, which faces north and the port channel, the island is protected by wave attenuation devices. Image by John Landon, courtesy of the Audubon Society.

Figure 13. Wave attenuation devices on the north side of the island. Image by Brian Cook.

Physical Exchanges, and Working Within

These examples help to realize the importance of context, and time, which is connected to existing relationships and functionality of site. Like in the pond, or in the forest, projects operate within an ecosystem comprised of deeply connected and contingent relationships. These relationships extend, as does the systems functionality, to support a complex web of components, sometimes so complex it is beyond cognition (as pointed out in Principle #1; also Carpenter et al., 2009). Displacing these functions can have calamitous results, like in the darkened bottle. For designers, Odum's study exhibits the importance of recognizing, and working with(in), the existent forces that comprise the nature of the site, over time. To build with time is an acknowledgement of context, of working *within* nature. It is a perspective as much as an operative procedure. If a design's success or failure depends on time spent within an ecosystem, this assumes useful participation and impact from the already established functionality of a site.

This concept of working within processes can also be considered in design, as a practice. It has been demonstrated that functional connections are built upon an exchange over time, as a physical conception. However, this also applies to project work and its relationship to the environment. Each project should be seen as part of an ongoing exchange. Through multiple and iterative exchanges at a site, humans and their constructions are able to fit their constructions to be more finely tuned to work with(in) context. Robert Cook suggests that landscape architects might consider a new paradigm in practice, acknowledging that the ecological idea is defined by processes, as "an engagement" over time (Cook, 2000). This suggests that the design project be considered in series, that each intervention is one of many in the trajectory of constructing (the nature of) a site.

Social Exchanges, and Making Amends

In more recent ecological theory, a social-ecological dimension has been recognized as highly influential to our built environments (Folke et al., 2005). In this capacity, social-ecological thinking suggests the importance of involving the public in the landscape-making, nature-building enterprise. Not only should experts be involved in projects, but also the broad public as a political agent within (their) nature (Westley et al, 2013; Folke et al, 2005; Lister, 2008). William Jordan III discusses restoration efforts and community participation as a key human act that forms bonds and positions humans within their ecosystem. He suggests that it integrates them into *"biotic citizenship,"* and that ultimately it induces an *"ecological relationship with these systems"* (Jordan III, 1994). In this manner, humans find themselves an active participant within their nature, involved in an ongoing pursuit of adaptation and exchange.

In order to address some of the aforementioned problems in Florida Gulf Coast Communities, recent social-ecological projects have operated in locations where landscape capacities were diminished by anthropogenic change. These projects ameliorate landscape ecosystem infrastructures while also introducing local populations to their environment, and environmental process. One such project occurred at MacDill Airforce Base, at the south end of the Tampa Peninsula. As part of a multi-year installation, the organization Tampa Bay Watch installed precast concrete domes and bags of oyster shells with assistance from local community members. The team placed materials slightly offshore to establish a hardened substructure with the correct texture and porosity to promote oyster growth. Behind the domes, marsh grasses were planted, extending the overall shoreline and stabilizing it through the use of biotic mechanisms (Tampa Bay Watch, 2020) (figure 14).

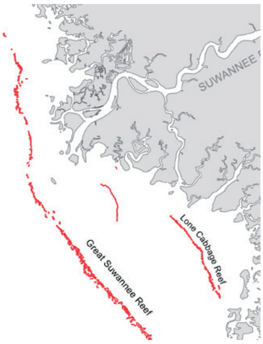
Figure 14. Volunteers place oyster bags at the MacDill Airforce Base project site. Image by Airman st Class Sarah Hall-Kirchner.

Besides the benefits of water filtration, plant growth and benthic activity, this program has developed a human population that are working within their regional landscape system. Through the project they are able to recognize their integral role in both the making and degradation of landscape while learning about its functions and characteristics through shared experience over time.

Another project further north in Florida has accomplished similar goals but at a much larger scale. The Big Bend area is in the top portion of the Gulf on Florida's peninsula. In this flat and largely uninhabited region, freshwater seeps and flows from inland creeks and springs, mixing with the Gulf's salt water to create extremely rich estuarine environments. Human communities in the region are highly dependent on these ecosystems. They are recognized as part of human ecology, both environmentally and economically. Historically this landscape has been rich in oysters, which filter water and dissipate storm energy, protecting coastal homes and habitats (University of Florida, 2018). However in the 1970's local fisherman noticed diminished productivity. The system was changing.

A study (Seavey et. al) in 2011 found that from 1982 to 2001 there was indeed loss of oyster habitat; 66% of reefs had disappeared in general, with 100% collapse at offshore reefs. (University of Florida, 2018) Whereas overharvest is a leading threat to oysters worldwide (Beck et al. 2011), it was not found to be the problem in this instance. Instead, they found a correlation between oyster decline and low flows in the river. Their conclusion: *"The usage and retention or redistribution of freshwater by human users is the main driver of the reduced discharge of the Suwannee [River]."* (Seavey et al, 2011) With this knowledge, they were able to take a multi-pronged approach to promote the existing deep-time relationships in the system while accounting for, and even inducing, human influence.

A large-scale project was developed to construct a durable media for oysters to colonize. The team followed historic patterns and built linear chains of oyster bars parallel to the coast. In this location they act like a "leaky dam" and hold non-saline water close to shore while also increasing oyster productivity (figures 15, 16 and 17).The reef was raised 30-60 centimeters (1-2 feet) above its current height to account for sea level rise. Limestone rock, the same rock that forms the substrate of the coastal geography, was brought to the site and installed by local contractors. In total, approximately 5 kilometers (3 miles) of reef were constructed at 10 meters (30 feet) wide (University of Florida, 2018).



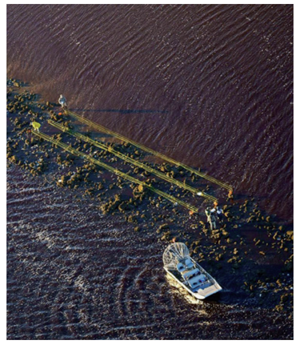


Figure 15 (left). Mapping of historic oyster reefs outside of the Suwannee River area. Map by Krystan Wilkinson, University of Florida.

Figure 16 (middle). Aerial view of installed oyster bars at Lone Cabbage Reef. Image courtesy of Carlton Ward, Jr. / Florida Wild.

Figure 17 (right). Crews take transect samples at oyster bars. Image courtesy of Carlton Ward, Jr.

So far, test sites built prior to the full-scale oyster reef project found that the design promotes more and successive growth of oyster populations. They create *"ideal habitat for juvenile blue crabs and many other oyster reef-dependent animals,"* and are more durable substrate than found in recent conditions (University of Florida, 2018).

In these projects, time is essential, both for working within existing processes and for the participation of communities in constructing their nature. The latter projects reveal a social-ecological approach and a more iterative perspective toward Building with(in) Nature. As Nina-Marie Lister (2008) points out, *"In the absence of certainty and predictability the implication for decision making is that greater participation in the process is necessary – decisions must be discussed, debated, negotiated, and ultimately learned rather than predetermined by rational choice."* This negotiation occurs in a site, in situating an implemented project within its context, as well as in the planning phases. If we are to acknowledge that we work within ecosystems, both socially and physically, these processes are critical for building functional relationships (nature), which takes time.

Considering how much time it has taken for landscape systems to develop, humans are a relatively new participant. Maybe this is why we keep ourselves out of the equation and are still positioned as outsiders. This brings up a few questions: Have we positioned ourselves within the landscape system, in an exchange, over time, whereby we are perpetuating each other's existence? Are we part of that system, within and adapted to it? Or is it possible that we have been constructing an alternative nature, or ecosystem, one that is not intertwined with deep time landscape processes? If that is the case, what is our territory, and what are we adapted to?

5. Principle #3: Consider Indirect Effects

"A very important aspect in the study of ecological networks is the concept of indirect effects, that is, effects between two species that are not directly interacting, and which are mediated by other interacting species in the network. Such indirect effects can have profound influence on community dynamics." This summary by Louis-Felix Bersier (2007) helps capture the significance of the ecosystem approach. One of the most important developments and understandings from Odum's study, and his discussion of the pond, is that objects, as traditionally depicted by our ocular vision, are not sufficiently represented. In fact, their presence is the result of a web of interrelationships, contingent functionality, and interdependencies, and not all of them reside within a fixed geographic boundary of site (Bersier, 2007; Odum, 1971; Brose et al., 2005).

For example, in Southern Florida, near Fort Myers and Cape Coral, there have recently been infestations of blue-green algae, a loss of sea grass and harmful effects to coastal sea life, for both humans and non-humans. Although some portion of this is directly connected to local landscape changes, it is also influenced by hydrologic change hundreds of kilometers away.

The Kissimmee River flows from near Orlando, in central Florida, to Lake Okeechobee. From there it is discharged through the Caloosahatchee River toward the Gulf. In the 1940's severe flooding in newly urbanized areas prompted the Army Corp of Engineers to take the bends out of the 215 kilometer (134 mile) Kissimmee River and establish a 9 meter (30 foot) deep by 100 meters (300 foot) wide flood control canal with six major structures. Wetlands were filled in and cattle and housing took the place of historic meanders and marshes. As designed, the Kissimmee River Canal had much less function in the processing of nutrients than did the Kissimmee River. The water filled Lake Okeechobee more rapidly, and management of the lake included pulse flows during rainy months that pushed fresh water from the estuary into the Gulf of Mexico. This eroded sea grasses and oyster beds at the bay, impacting key components of the marine food chain. Without them, further degradation occurred since nutrients and other pollutants were not filtered out of the water (Gillis, 2018). To re-claim the functionality of this ecosystem, the Kissimmee River Restoration Project was authorized in 1992. When complete, 35 kilometers (22 miles) of channel will be backfilled and 71 kilometers (44 miles) of historic river channel will be restored, including 8,100 hectares (20,000 acres) of wetlands and 10,360 hectares (40 square miles) of river-floodplain ecosystem (figures 18 and 19). To accomplish this, 41,302 hectares (102,061 acres) of land were acquired. In some cases, residents were engaged to either relocate or to modify their property, but this was not possible in all stretches of the canal. In the end, total cost will approximate $1 billion USD (USACE, 2020; SFWMD, 2010; Koebel Jr. & Bousquin 2014).

Figure 18 (left). Aerial view of the Kissimmee River Restoration Project, with backfilled channel and newly restored river corridor. Image by South Florida Water Management District.
Figure 19 (right). Flooded portion between the historic Kissimmee River Channel and the newly restored river corridor. Image by South Florida Water Management District.

After project completion in 2020, *"Lake Kissimmee will rise 1.5 feet deeper each year, storing water to feed the river during the dry season and rehydrating another 30 square miles of dried marshes around it"* (Audubon Florida, 2020a). Already, impacts have been seen in the uplands. One report (Audubon Florida, 2020b) says that, *"Wading bird numbers have surpassed restoration goals, waterfowl and shorebirds are seasonally abundant, bass and sunfish have increased, and the green, blue, and flowery beauty of the river marshes has returned."* These upstream benefits will be monitored as to their effectiveness in altering the coastal ecosystem.

As in Odum's watershed description, the functionality of a site cannot be addressed locationally. As a system, its interacting components are linked by bonds of functional influence, which extend both physically and socially.

As shown in Florida, the functionality of a site cannot be determined by visual determinants but instead by an analytic investigation of contingent relationships, which cross geographic boundaries. To address the functionality of site, one cannot simply draw a boundary around it. A site is a system and should be accounted for as such.

6. Conclusion: Towards and Ecosystem Approach

The principles described in this chapter present a foundation from which to go forward, and to address the topic of Building with(in) Nature through a more critical lens. Key concepts from Odum, his successors, and in the Gulf Coast include:

1. Identification of and perpetuation of non-human systems within human-focused projects,
2. Working with the element of time, within existing physical and social systems, and by acting as stewards of our nature
3. The importance of working through scales, considering extended and indirect networks of impact upon a site.

This involves a concerned and compassioned perspective, working to incorporate the complexity of our environment within built projects, and a hermeneutic process whereby humans make informed decisions and then revisit them to learn from the dynamic relationship and response from landscape, as context (see Corner, 1991). Through this exchange, relationships are constructed. In Florida, this has become first-hand experience. The ecosystem has begun to shift, providing perspective as to the response of human action, similar to the darkening of the bottle when foil was applied. However, at this time, great efforts are underway to make amends.

Odum's experiments were about opening up perception, making known the importance of all system components and their functional interrelationships, and doing this with intent, through science. His main point is to be holistic, and to consider the complexity of landscape spaces. Also, embedded in this discussion is an understanding that we are one of many forces to operate on a site. Nature is not something apart from us, but rather something that we are within. Odum cautions against a resourcist approach, and provides a useful analogy: *"Man thrives best when he functions as a part of nature rather than as a separate unit that strives only to exploit nature for his immediate needs or temporary gain (as might a newly acquired parasite). Since man is a dependent heterotroph, he must learn to live in mutualism with nature; otherwise, like the 'unwise' parasite, he may so exploit his 'host' that he destroys himself"* (Odum, 1963).

C.S. Holling, in his article *Resilience and Stability of Ecological Systems* (1973), says that *"evolution is like a game, but a distinctive one in which the only payoff is to stay in the game. Therefore, a major strategy selected is not one maximizing either efficiency or a particular reward, but one which allows persistence by maintaining flexibility above all else."* To do so, we must build for humans, but we must also build for our context, the one that we are dependent upon. As shown, Building with(in) Nature is a difficult and complex endeavor. It takes work and resources. But those are the stakes in the game.

Dr. Odum, an ecologist, was technical when explaining our role within nature. Martin Buber, however, as a philosopher, offers a more poetic description. He says of "life with nature":

> *I contemplate a tree.*
>
> *I can accept it as a picture: a rigid pillar in a flood of light, or splashes of green traversed by the gentleness of the blue silver ground.*
>
> *I can feel it as movement: the flowing veins around the sturdy, striving core, the sucking of the roots, the breathing of the leaves, the infinite commerce with earth and air – and the growing itself in its darkness.*

I can assign it to a species and observe it as an instance, with an eye to its construction and its way of life.

I can overcome its uniqueness and form so rigorously that I recognize it only as an expression of the law – those laws according to which a constant opposition of forces is continually adjusted, or those laws according to which the elements mix and separate.

I can dissolve it into a number, into a pure relation between numbers, and eternalize it.

Throughout all of this the tree remains my object and has its place and its time span, its kind and condition.

But it can also happen, if will and grace are joined, that as I contemplate the tree I am drawn into a relation, and the tree ceases to be an It. The power of exclusiveness has seized me.

(Buber, 1937)

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Building with Nature in landscape practice

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Abstract

In a world where increased prosperity has created a number of novel, ecosystem-related threats to people's health and the economy, designing with nature offers a promising outlook to mute the potential negative impacts of our actions and to keep improving the quality of life worldwide. It also provides an alternative to an attitude that has been largely negligent towards our non-human fellow beings.

Drawing from the experience of DS landscape architects, four actualized projects and two student master theses illustrate the challenges, opportunities and benefits that building with nature presents. These cases highlight four important lessons for designing with nature in rural and urban landscapes.

First, considering the surrounding landscape as a starting point creates a deeper understanding of the situation at hand. This allows for better planning with the ecosystem and enhances the richness of its biodiversity once a project is delivered. Secondly, planning with nature creates the opportunity to let nature do some of the work. This can include water purification, drainage, and cooling. The third lesson is that designing with nature requires a long-term plan. Maintenance might be necessary, and the public may need to be patient to watch the ecosystem slowly flourish through the decades. Finally, creating a new kind of wilderness-imbued beauty to inspire public acceptance and to motivate stewardship is a promising method for establishing a successful long-term nature-inclusive design project. These and other lessons contribute to a field of design where incorporating nature is the status quo.

KEYWORDS

Landscape, nature inclusive design, landscape architecture, aesthetics, ecosystem services

1. Beautiful new landscapes for all that lives

We live in increasing prosperity, while the distance from that which lives with us on earth is growing. Because of our actions, biodiversity is in decline, the climate is changing and we are creating new health risks for people and other beings (Franco, 2020). Of the 17 sustainable development goals defined by the United Nations (UN, 2015), seven are directly connected to the proper functioning of the global ecosystem. These are Zero hunger, Good Health and well-being, Clean water and sanitation, Sustainable cities and communities, Life below water, Climate action and Life on land. Ecosystem services (Millennium Ecosystem Assessment, 2005) are therefore expected to play a major role in reaching these goals.

The investment in people's nests and the work of landscape architects is mainly concentrated in urban areas. Many people, and with them, animals, leave the countryside to create their livelihood in urban areas (Ritchie and Roser, 2018). In the Netherlands, the cities and villages grow steadily (CBS 2019) while a lack of nature in our cities has a negative effect on our quality of life. Neighbourhoods experience heat stress, water problems, animal plagues and more. Furthermore, building projects often contribute to the decline of populations and ultimately push species to the brink of extinction. This blatant disregard for our fellow beings is not sustainable, and also unnecessary.

The earth can no longer be ignored as a powerful autonomous, living force in human affairs, says Bruno Latour in "Down to Earth" (Latour, 2018). We have to land on earth. It is a serious political factor today. Those who advance at the expense of the earth, he names them the 'globals', will have to reconsider their way of living. The locals, long seen as the losers, he says, are in fact the experts of how the earth works. The globals have to join hands with the locals, to find a new way of living. Building with nature makes us terrestrials and improves our relationship with the earth. Amongst recent building projects, some do involve nature as a serious partner. They are designed with a nature-inclusive approach, which proves promising for multiple reasons.

Instead of devouring space, the investment in human 'nests' unlocks living space for many living creatures other than humans. To achieve this, one can reshape the existing ecosystem into a new landscape with a sustainable equilibrium. Buildings are part of the ecosystem; they are rocks in the landscape, a welcome habitat for humans as well as for some bees, bats, and birds. They are placed to complete the ecosystem, much in the same way as a clump of trees is the finishing touch in a traditional English landscape park. Building with nature refines the practice of landscape architecture in a novel way, offering new opportunities for future development of rural and urban areas.

Figure 1. Achter 't Holthuis, Twello.
Figure 2. Park Brederode, Bloemendaal, 2003-2019.

While nature has always played an important role in aesthetics (Parsons, 2008) nature-inclusive design creates new kinds of aesthetics, in which wilderness and culture find a beautiful new balance.

The benefits of building with nature in spatial planning will be illustrated with four actualized DS landscape architects designs in the landscape of the Netherlands. These projects have put the principles of building with nature in practice, and some of the ecosystems have been growing further for several decades. These interventions serve a wider range of societal goals using the force of nature. To further illustrate this approach, we also look at two student's projects (Nieuwenhuijs, 2018; Van der Woude, 2019). They have the same nature-inclusive outlook as the projects by DS landscape architects. As purely theoretical projects, their content is not polished by reality, but this increases their illustrative power.

In four chapters and a discussion, a reflection is made on the landscape design practice of DS landscape architects. The design of an actualized landscape transformation is often related to a housing project. The aim of the transformation is to design a robust landscape where urbanisation can take place with the inclusion of nature. In retrospect, four important lessons are drawn for the design of nature in urban landscapes. These are: start with the landscape, let nature do the hard work, give the landscape time, and use beauty to inspire stewardship.

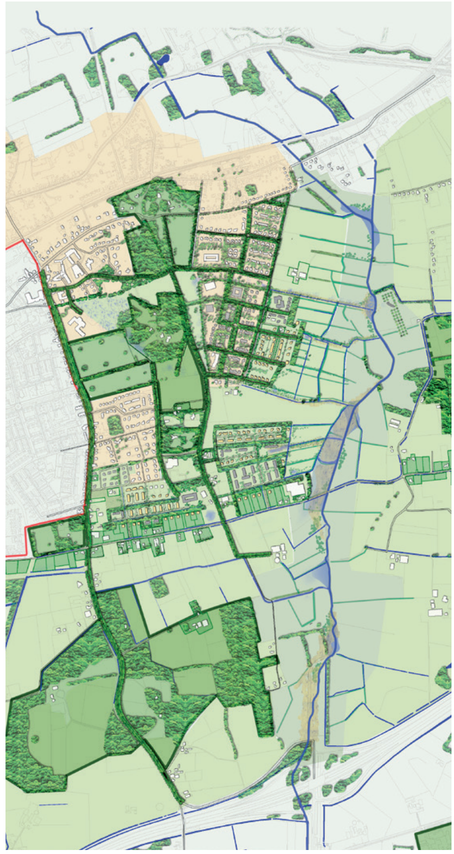

Figure 3. Landscape park Poelgeest, Oegstgeest, 1997 – 2005.
Figure 4. Fliertdal, Twello, 2014.

2. Landscape first

In situations where an existing landscape needs to undergo a transformation, DS landscape architects designs the landscape for all that lives with us. The result should be a rich landscape in addition to the fulfilment of the human program. To achieve this, DS designs the landscape first, to encourage the ecosystem towards a new, sustainable equilibrium. Afterwards, a housing program is rolled out. This is illustrated by two projects: Achter 't Holthuis (figure 1) and Park Brederode (figure 2).

In Achter 't Holthuis in Twello, a former sports complex is turned into a landscape of woodlands and open spaces, laced with lanes. The new function unlocks the possibility to create a vast new estate, encompassing two existing estates. The lanes and plant species tie into the existing ecosystem and the water network is linked with the Fliert brook valley (figure 4). This defragmentation makes the ecosystem more robust.


Figure 5. landscape built for the neighbourhood Achter 't Holthuis.
Figure 6. A stretched lane of Achter 't Holthuis.

The estate landscape is known for its bats. The straight, stretched lanes connect the mansions, providing beautiful sightlines towards the valley and the mansions. They also offer hunting space for the bats around the estates. Furthermore, these lanes benefit the drainage of the area, opening up the flow towards the open spaces. These spaces are local floodplains where the common spadefoot toad finds its breeding ground. The woodlands benefit a range of local species at all levels of the food web. The buildings are part of the ecosystem as well, they are rocks in the landscape, a welcome habitat for humans as well as for some bee, bat and bird species.

In Brederode Park the site has been inhabited by humans since the Middle Ages. For the last one hundred years it was a psychiatric hospital with well-maintained lawns and borders. The remnants of small estates, the traces of lanes, mixed with design elements of former parks were placed in a new landscape setting. The central area is transformed into a brook and inundation fields. The historic bleachfields are now meadows with wild grasses. The view of the dunes is opened up (figure 7).

The presence of good quality water is a vital part of the ecosystem. The common frog, amongst others, is given more space. In spring, the frogs migrate from Kennemerduinen National Park to the site to breed in the ditches and ponds. The water for the brook is tapped from the dunes to fill a new brook and the inundation fields. The calcareous water also creates a unique habitat for endangered orchids.

On both sides of the valley the landscape absorbs human nests. On the west side, the landscape looks like an expansion of the local national park. The new sand hills are fixed with the endemic forest vegetation while local fauna arrives from the dunes, including deer, rabbits, finches and crickets. The villas are placed in vegetation, partially sunk into the terrain (figure 8).

The landscape on the east side has the spatial and natural qualities of a garden city. This area is ideal for hedgehogs, tits, and different species of butterflies. It reinterprets the park designed by the famous landscape architect, L.A. Springer.

Figure 7. The new dune valley of Park Brederode (image by Walter Herfst).
Figure 8. The villas in Park Brederode partially sunken in the landscape.

The remaining tree groups, rich planting schemes, sight lines and path alignment are placed in a new landscape setting. More trees are planted and thick hedges line the fringe of the parcels (figure 9). In both projects, nature-inclusive design uses the surrounding landscape as a starting point to integrate human living spaces with a biodiverse ecosystem which has brought more endemic biodiversity to the site. The monotonous biotope of the sports fields was replaced by diverse, richer biotopes, such as a woodland, wild meadows and gardens that fit well into the ecosystem. The well-maintained hospital park biotope was changed into a fine grain mix of culture and nature. By studying the landscape to design and build with nature, the areas are now robust and accessible living environments for many species.

Figure 9. The neightbourhood Park Brederode on the east side.

3. Let nature do the work

Quality of life remains a central development theme in the 21st century, and ecosystem services will play an indispensable role in providing it (Millennium Ecosystem Assessment, 2005). In the neighbourhoods described in this chapter, quality of life is improved due to the role that nature plays in the living environment especially when the landscape is made into a rich and robust ecosystem. A public space with lots of vegetation alleviates peak temperatures during heat waves. It also has the capacity to store and evaporate excess water during heavy rainfall and store moisture during periods of drought. The neighbourhood has cleaner air, stores CO_2 and their inhabitants have reduced stress. Nature is at work for us.

The community living around the Fliertdal profits (in both a technical and cultural way) from this new, natural landscape of the Fliert brook. Dealing with the challenges of climate change, the water authority was in search of space for water retention, so the watercourse of the Fliert now includes space for the brook to meander. It allows for a rich ecosystem to develop on the site. The speed of the water flow is reduced, letting water infiltrate into the soil, creating a buffer for dry periods. The brook landscape, with an enlarged water surface, mitigates high surface temperatures during heat waves, while the abundant vegetation can absorb even more CO_2 and produces more oxygen to breathe. The cultural contribution is that it allows people to be in nature while at and around their homes.

In Poelgeest the desire to clean local stormwater in a natural way motivated an approach of designing with nature. As a result, water drained from the urban area is diverted into the smallest polder. This polder has a labyrinth of ditches in a field of reeds. The clean water from this polder is pumped into the next polder for storage in order to gradually return it to the neighbourhood (figure 3). To enjoy nature at its best, the landscape can be entered by paths on the polder dykes. Here you also find birdwatchers using the dyke as a viewing platform. To step into the polder landscape boots are needed to take the small paths and planks bridge the ditches.

Anne Nieuwenhuijs (2018) uses the tidal flows of the Westerschelde in her conceptual project to filter the water and harvest toxic sludge. By means of small interventions, such as a dyke placed sensitively where the water flows, harvesting sites are designed for the removal of toxic sludge (figure 10). During high tide, the current in the estuary naturally deposits the toxic sludge in the basin. Low tide is used to harvest the sludge out of the Westerschelde, releasing cleaner water back into the sea. Toxic sludge is then compressed into harmless rocks. This makes it possible to turn a local nature-abusing substance into material to support the local ecology. The building blocks are used in small projects for landscape development along the Westerschelde.

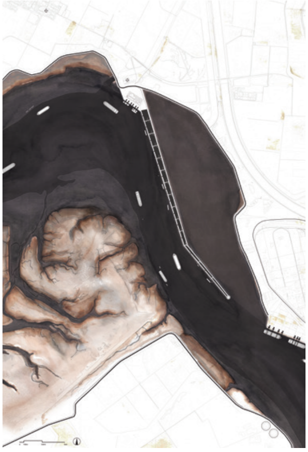
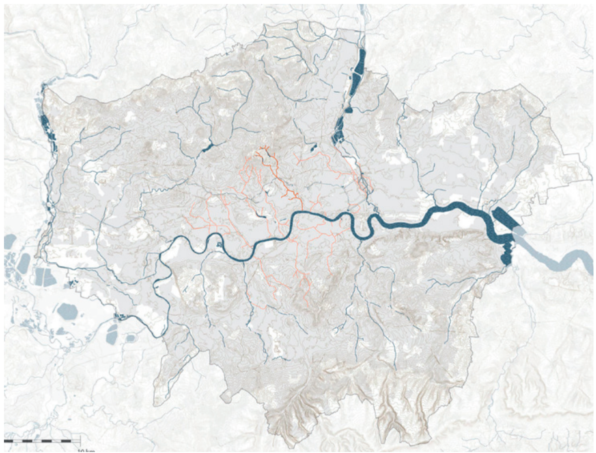

Figure 10. A dyke placed on the waterflow in the Westerschelde.
Figure 11. Tight network of natural brooks under London.

With these blocks, a landscape can be made, offering new opportunities for ecology, spatial quality and landscape dynamics.

The employment of natural processes, both technically and aesthetically, is not limited to rural areas. With nature's help, Charlotte van der Woude (2019) projects a future for the city centre of London (figure 11). This city is built on a tight network of natural brooks, currently in use as sewers. In this design project, nature ventilates the densely-built city by opening up windows to the original waterways of London. The openings work as an air conditioner, cooling the city on a hot summer day. The openings absorb rainwater in the event of big storms. They also restore access to the landscape below the city, where previously absent life forms thrive quietly. By letting nature back in, the quality of life of the inhabitants is improved with ecosystem services. These interventions provide excellent recreational sites, combined with climate adaptive solutions. Unrealised and realised, these projects propose a new symbiosis between nature and occupation, delivering unexpected and beautiful landscapes.

4. Cultivation in time

When building with nature, it takes time for ecosystems to develop into a natural, resilient ecosystem. The desired population of species needs a chance to establish and determine their natural interactions with other species in motion. It requires patience to let an ecosystem grow in a neighbourhood. Residents need to suppress their inclination to interfere prematurely. To increase the overall biodiversity in time we need rules and policies, good management, and education for inhabitants.

Figure 12. Woodlands in the neighbourhood Achter 't Holthuis.
Figure 13. The Woodland garden manual , DS 2005.

In the neighbourhood Achter 't Holthuis, the houses stand in woodlands which are part of the public space (figure 12). Maintenance activities are organised by the communal gardening service as they have specific local knowledge of their own landscape. The woodlands cast a shadow over the gardens, something Dutch residents usually complain about. It is very common and, in such cases, inhabitants ask the community to cut down the trees. The "Woodland garden manual" was made to increase respect for the surrounding woodland and thus the tolerance to let it grow. Providing many examples of compatible plant and animal species, it also inspires newcomers to adapt their gardens to the surrounding ecosystem (figure 13). It lists beautiful, indigenous shade-loving plants that can be bought at the local nurseries and garden centres. To envision the look of a woodland garden, show gardens were made together with students from the nearby school of horticulture. The stewardship for the woodlands is an ongoing effort and it is crucial to give the landscape of woodlands, open spaces and lanes time to develop into a sustainable ecosystem.

The Fliertdal is owned by nature foundations and private landowners so the success of the development of a sustainable ecosystem and beautiful valley depends on their cooperation. The Fliertdal toolbox is provided to guide them and consists of 20 sheets of paper that each depicts a landscape element for the valley. The appearance, the planting plan and the maintenance of each element are described on the sheet (figure 14). The landowners can apply for subsidies for the elements from the toolbox. However, if they decide to plant conifers, they will not get financial support. The toolbox system increases the chance that the landscape will evolve into the desired type of ecosystem.

In Poelgeest, the landscape park was sold to Het Zuid-Hollands Landschap, a non-profit firm specialised in the management of small nature areas. With their management, the long-term development of nature is in good hands. They organise working events for volunteers in the landscape to increase stewardship. Many inhabitants join these days to stay in touch with the unique natural elements found in their living environment.

Vlechtheggen
beekdal

Heggen geven het dal van de Fliert een ander meer kleinschalig karakter. Heggen worden zo veel mogelijk aangeplant op plaatsen waar ze vroeger ook hebben gestaan, meestal op de vochtigere delen van het dal. De vlechtheg is een speciaal soort heg die veel langs de Fliert voorkwam. Bij de vlechtheg wordt het te snoeien hout niet afgeknipt of gezaagd maar ingehakt. De half doormidden gehakte takken worden omgebogen en vervlochten met andere takken en stammen. Vlechtheggen zijn lage, tot maximaal 2 meter hoge randbeplanting bestaande uit een gering (1 tot 5) aantal soorten, inheemse struiken. Vlechtheggen worden jaarlijks gesnoeid en gevlochten.

sortiment

hoofdsoort 90%

Crataegus monogyna	meidoorn

bijsoort 10%

Acer campestre	veldesdoorn
Cornus sanguinea	kornoelje
Prunus spinosa	sleedoorn

aanplant en verwerking

plantwijze	driehoeksverband
plantafstand in de rij	0,50 m
plantafstand tussen de rijen	0,50 m
plantrijen	2 of 3

eerste vervlechting na 6 tot 8 jaar na aanplant door stammen half in te hakken en om te buigen

beheer	vanaf 6 tot 8 jaar na aanplant		**uur / jaar**	**tijdstip uitvoering**
uitlopers half inhakken en opnieuw invlechten		1 x / jaar 100 %	20 / 100 m1	november - februari
overstaanders handhaven ongeveer 1 per 100m1				
onderbegroeiing selectief maaien		1 x / jaar 100 %	0,5 / 100 m1	juni - september

natuur

natuurdoeltype	struweel/mantel/zoombegroeiing	
doelsoorten	zoogdieren	boommarter, das, franjestaart (vleermuis)
	vogels	blauwe kiekendief, groene specht, steenuil, wielewaal
	reptielen	hazelworm, ringslang
	amfibieën	kamsalamander, knoflookpad

subsidie

aanleg per 100m1
beheer per 100m1

Figure 14. Sheet from the Toolbox Fliertdal.

During the opening of the park in 2011, expert excursions were organised, and 50 fishing nets were dealt out for the local children to play with in the landscape (figure 15).

The conditions for a rich, biodiverse ecosystem that was established in Brederode Park are expected to develop together with the new inhabitants. We educated the developers, architects, and brokers to respect the aim of the landscape design and to convey the ambition for nature to the new owners.


Figure 15. Fishing nets for the local children at the opening of Poelgeest landscape park.
Figure 16. The root vole, protected species in Poelgeest (image by Marte Holten Jørgensen).

This legislation will help the landscape to develop in time. A part of Brederode Park is designated as wilderness. For gardens in the dunes, a special regulation is applied, aiming to create conditions for wild animals to live there. It is called 'NLT- natuurlandschappelijke tuin'.

Finally, a maintenance plan is written to gradually reach the goals for nature and the landscape. The advice to choose in Brederode Park for an experienced nature organisation like 'Het Zuid-Hollands landschap' was not followed. The community did choose an organisation employing people with disabilities to do the work, because of their cost-efficiency. These people are not particularly knowledgeable in the environmental realm. The missed opportunity here, is the fact that untrained workers cannot increase stewardship by sharing their expertise with the inhabitants while working on site.

Another way to support the cultivation of the landscape in time is through alliances with other organisations, such as a water authority. This is the case for Fliertdal, Poelgeest, London and the Westerschelde. Flora and fauna legislation sometimes demands relocation or protection of species habitat in development sites (Brederode Park, Achter 't Holthuis, Poelgeest). Such legislation can be an important driving force in the establishment of new ecosystems (figure 16).

The average budget for green maintenance in public space is extremely low. Nature organisations often have to work with underqualified volunteers while horticultural firms work with people with disabilities to keep costs low. Maintenance professionals tend to maintain the natural elements that already exist, but have limited resources to expand and improve that which is designed by the landscape architect. It is therefore often wise to design landscapes in which the ecosystem takes care of itself as much as possible and allow time run its course.

 

Figure 17. View on estate 'Hunderen' in Twello.
Figure 18. The new brook in Park Brederode (image by Walter Herfst).

5. Beauty for stewardship

How can we reach the next level in planning? It is through winning hearts that we win minds. While nature is an important inspiration for aesthetics (Parsons, 2008), people generally are more engaged with wilderness that is conformed to the human scale and shape (Gobster et al. 2007). The landscape architect is trained to improve the aesthetics in the landscape on a human scale. In nature-inclusive designs, it is the ability to make beauty with wilderness that helps to create acceptance of nature in people's living environments. To create an aesthetic nature-inclusive landscape, DS landscape architects considers three aspects of beauty in every project. These are the composition, the cultural beauty, and the extent to which a landscape is expected to create beauty in experiences. Increasing the beauty of a landscape inspires better stewardship and is an underestimated tool for increasing biodiversity.

In Achter 't Holthuis, it is the historical estate landscape that seduces. The composition of mansions, lanes, woodlands, and fields offers the passengers memorable visits (figure 17). Walking in Brederode Park, along the brook in the buzzing fields, with the high dunes on the horizon, and the historic remnants around, is like experiencing sublime beauty (figure 18). The composition of landscapes works to create a sense of beauty and in the best case, belonging.

Beauty is also a goal in the toolbox strategy in the Fliertdal. One of the subsidised elements in the toolbox is the hawthorn hedge. If many residents plant this species, the synchronous white blossoming of a large number of these bushes in early spring will be an attraction for both hikers and residents.

The beauty of Poelgeest lies in its concept. It fulfils its new job simply with the planted reed. In the reedscape, the water is purified while the 'Waterwheel' art piece gently rotates. The habitat of the protected tundra vole is saved and the landscape park is now a hotspot for birds and bird watchers. A colony of spoonbills is the finishing touch to make this area an attractive place to be and to care for.

Figure 19. The working of the needle landscape expressed in crossection, Westerschelde.

In Anne's design, an eerie needle landscape of 500ha is envisioned (Nieuwenhuijs, 2018). The tall pointy pillars have a perforated base. Through it, they suck up the contaminated sludge (figure 19). That is then pumped into a nearby sludge depot. The pumping landscape is a sublime minimalistic machine providing its own kind of beauty.

In the London project (Van der Woude, 2019), six interventions are proposed throughout the underground landscape of brooks. This will create new microclimates for new biotopes in the public space. The sites with windows to the underworld infuse the public spaces in London with a new, unexpected kind of beauty, provided by the mysterious, Victorian, brick sewage network. It is designed to invoke a unique aesthetical experience.

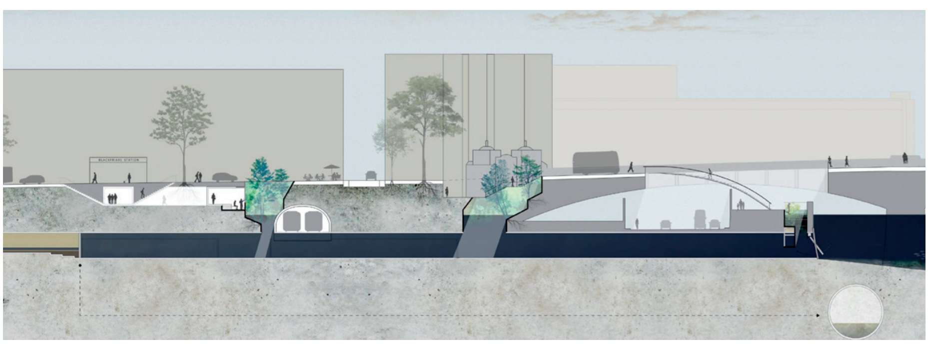

Figure 20. Windows above waterways subjected to ebb and flow, London.

One of these windows is particularly interesting. The Thames is a tidal estuary, and Charlotte proposes to open one of the windows above waterways subject to ebb and flow (figure 20). The pathways are drawn on a height that allows visitors to touch the water during high tide.

To design for a beautiful, nature-inclusive landscape inspires greater acceptance of a project. Combining wild, natural elements with cultural preferences creates a new aesthetic that is appreciated by the public. DS landscape architects therefore always use it as an important guiding principle for building with nature.

Towards a broader practice of designing with nature

Nature-inclusive landscape design, as a conscious way of employing ecosystem services in urban settings, potentially offers an important contribution to reaching the millennium development goals.

From the perspective of the designer at DS landscape architects, four main principles provide important lessons to the field of building and designing with nature. Together, they illustrate that nature-inclusive design may require some extra work and thoughtfulness, particularly in the planning phase, but it also yields benefits that could well outweigh the investment. These cases do not bring forth a detailed cost-benefit analysis, but they certainly do draw the attention to values and yields that have not always been included in the equation. The quality of life of our human and non-human companions being a prominent example, the provision of ecosystem services another.

Figure 21. Building the new landscape of the Fliertdal (image by M. Hirschler).

Figure 22. Nature nearby, Poelgeest.
Figure 23. The reed field in the smallest polder of Poelgeest.

The first principle, landscape first, illustrates that by paying careful attention to the landscape and its surrounding ecosystem, nature-inclusive designers can arrive at innovative solutions that work with, rather than against, nature. This is what Bruno Latour refers to when expressing that we can no longer design our 'nests' without incorporating the habitats of what lives with us. We are part of the earth and expressing that in our design work is a viable option. Biodiversity can and will increase if we remain sensitive to it.

In a time where lives accelerate and maintaining the status quo requires increasing effort, it is all the more comforting to know that we can design in such a way that nature takes over some of the work. Ecosystem services are not just a benefit we receive from our natural environments, they are concepts that can be planned and designed for (figure 22). Why build expensive high-tech water-cleaning filters if something as simple as a bed of reeds can achieve a similar effect, such as in Poelgeest? Why create intricate drainage systems to pump water up, if you can let it flow down and create a habitat for spadefoot toads, as was done in the Fliertdal? Letting nature do the work means looking at a site for just a little longer, to find the opportunities that ecosystems have in store for us.

Working with nature - not in spite of nature - requires a certain amount of patience, long-term commitment and maintenance. Results will not always appear within a year or even a decade. It requires cultivation over time, the third principle, to allow the development of an ecosystem. That applies to all actors, meaning that education and awareness-raising may be needed for residents, as was done in Achter 't Holthuis and Fliertdal. That requires expertise and a common understanding, which, as in the case of Brederode Park, will not always be funded the way it was planned for by the designers. While a collaborative effort between the stakeholders may be reached with incentives, maintenance laws and policies can be required to guarantee continuity, as was done with designated wilderness areas in Poelgeest. In sum, it may be wise to plan for a situation where a resilient ecosystem maintains itself as much as possible.

Figure 24. The waterwheel bringing the clean water back to the neighbourhood.
Figure 25. Nature in the neighbourhood Poelgeest.

Aesthetics and beauty should be a vital part of any nature-inclusive design, increasing biodiversity and building with nature. Nature-inclusive design is a new way of controlling wilderness and perceptively working with wild biodiversity creates a new kind of aesthetics. In a situation where stewardship over the land is required, such as drawing in volunteers for maintenance activities or to create political will for conservation of an area or execution of an idea, the element of beauty is often highly underestimated. DS landscape architects sees this quest as the next challenge for building with nature: to develop a new landscape architecture language that is able to connect the technique of building with nature with new aesthetic experiences for all beings involved.

Robust landscapes with rich and diverse ecosystems protect species, regulate and clean water, provide fresh air, reduce temperature extremes, stabilize water tables, and are generally healthier. Despite increasing environmental risks, let us be hopeful for the future of neighbourhoods for humans, plants and animals. Wild nature is an increasingly accepted part of our living environment. Nature is no longer to be seen as a threat or as something dirty, but more and more as a partner for confronting the changes ahead. It can be functional and beautiful at the same time. The provided examples of nature-inclusive design demonstrate that these qualities can and should be brought into reality.

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MODELLING

A novel coastal landscape model for sandy systems

Community base for interdisciplinary research on coastal evolution

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Abstract

A common measure to mitigate erosion along sandy beaches is the implementation of sand nourishments. The design and societal acceptance of such a soft mitigation measure demands information on the expected evolution at various time scales ranging from a storm event to multiple decades. Process-based morphodynamic models are increasingly applied to obtain detailed information on temporal behaviour. This paper discusses the process-based morphodynamic model applied to the Sand Motor and how the morphodynamic forecasts have benefitted from the findings of an interdisciplinary research program called NatureCoast. The starting point is the morphodynamic prediction of the Sand Motor made for an Environmental Impact Assessment in 2008 before construction began. After the construction, the model computations were optimized using the first-year field measurements and insights by applying advanced model features. Next, an integrated model was developed that seamlessly predicts the morphodynamics in both the subaqueous and subaerial domains of the Sand Motor. Decadal predictions illustrate the need to be able to resolve the marine and aeolian processes simultaneously in one modelling framework in the case of dynamic coastal landscapes. Finally, a novel morphodynamic acceleration technique was developed that allows for predicting the morphodynamics for multiple decades while incorporating storm events in one simulation. Combining the above-mentioned developments has led to a unique, open-source, process-based landscape tool for (complex) coastal sandy systems, which can stimulate further collaboration between research communities. Moreover, this work demonstrates the evolution from mono- to interdisciplinary forecasts of coastal evolution.

KEYWORDS

Sand Motor, morphodynamic modelling, decadal forecasts, interdisciplinary research, NatureCoast research program

1. Introduction[1]

Climate change is an intense challenge that our ever-increasing world population faces, and it poses special problems for those living near coasts. People have always been attracted to the coast, as a place to live and work, and to relax. By 2050, around half of the world's population is expected to live near the coast, the vast majority in developing countries. How will we cope with rapidly rising sea levels and more intense and frequent storm surges? Although retreating from coastal areas is a solution, this is an unlikely option for most coastal settlements. This means that active protection of urban areas and infrastructure against flooding will remain our primary focus. Artificial protective barriers, such as concrete dikes, dams and breakwaters have traditionally been the go-to way to deal with coastal protection. However, such hard structures have always had the single aim of providing coastal protection, without considering their impact on the coastal ecosystem. In other words, traditional coastal management solutions were treating symptoms; building coastal protection structures in nature often created new problems or moved existing problems to other nearby areas.

Throughout history, the fate of the Netherlands has always been intimately linked to the sea. Without our coastline protection and inland water management, two-thirds of the country would be under water. However, we have also realized that simply treating symptoms is no longer sufficient. Protecting people and infrastructure will always remain the primary aim of coastal management, but the impact on the environment must also be considered, as well as the wider societal context. This means that we need to fully understand how coastal ecosystems function and what their societal context is. This knowledge is crucial if we are to create integrated multifunctional coastal protection solutions that have minimal environmental impacts and are widely appreciated. The shift away from treating symptoms towards integrated, multifunctional designs requires a new approach. Throughout the Netherlands, the Building with Nature approach has been adopted. The key to this innovative approach is using prototype pilots to develop new knowledge and insights.

Building with Nature

Building with Nature (BwN) means proactively maximising the use of natural processes to improve life in delta regions. The proactive BwN approach advocates an integrated approach that harmonizes coastal management solutions with the requirements of ecosystems (de Vriend, 2015). Decisions must be made regarding desired societal and ecological functions, which means that the state and the functioning of the ecosystem must be studied and un-

1 This section is partly revised from Luijendijk and Van Oudenhoven (2019a).

derstood before a design can become a plan. The BwN approach maintains that this knowledge is crucial if environmental and nature concerns are to be integrated into coastal infrastructure projects. By considering how the local ecosystem can become part of the solution, project managers anticipate legal opposition and avoid having to create alternative nature areas. This is almost directly opposite to mainstream infrastructure approaches, which tend to focus on the current situation rather than the future and build in nature, rather than with nature. Besides being proactive, the BwN philosophy attempts to maximize the use of natural processes in infrastructure projects. The Sand Motor is one of the first large-scale applications of the BwN approach.

Figure 1. Aerial photo of the Sand Motor just after construction in July 2011.

The Sand Motor

The Sand Motor is a large sandy peninsula, constructed in 2011 on the Dutch North Sea coast near The Hague (see Figure 1). This unprecedented pilot project involved placing 21.5 million m^3 of sand on and in front of the beach with the aim that it would spread along the coast (Stive et al., 2013). Sand nourishment itself is not a new method to prevent coastline erosion. In fact, the Netherlands has had a structural nourishment program since the early 1990s. However, the Sand Motor is a unique beach nourishment project due to its size, the design philosophy behind it, and its multifunctionality. The volume of sand used for the Sand Motor is about five times that of an average nourishment. The Sand Motor is intended to feed the adjacent coasts by using the natural forces of tides, waves and wind; in a way, it is built to "disappear". Another unique aspect of the Sand Motor is that it combines the primary function of coastal protection with the creation of a new natural landscape that also provides new nature and leisure opportunities. From the outset, "learning by doing" has been a crucial part of the project (Luijendijk and Van Oudenhoven, 2019). Because of its innovations, the Sand Motor has triggered considerable political and scientific interest from all over the world. Large research consortia such as the NatureCoast program were formed to conduct interdisciplinary research on the Sand Motor.

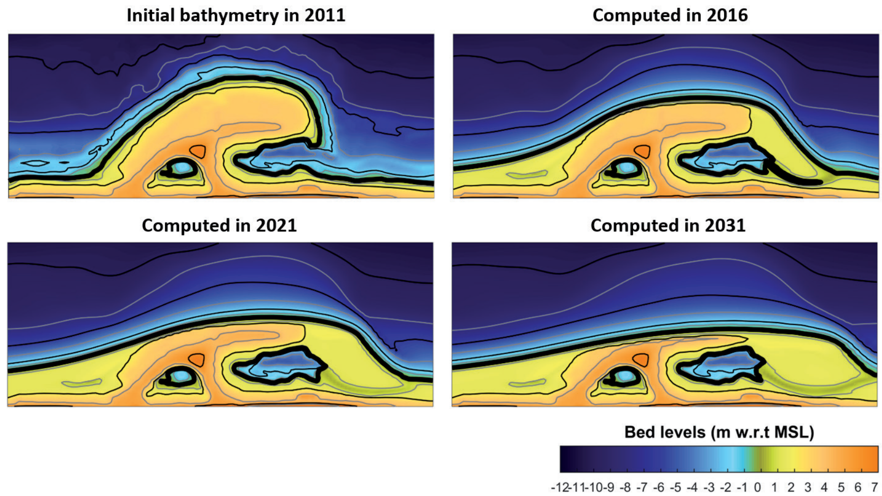

Figure 2. Predicted bed level evolution in the EIA phase for a period of 20 years (Stive et al. 2013).

As part of the Environmental Impact Assessment (EIA) in 2009, morphodynamic simulations were set up to predict the expected morphological evolution for a period of 20 years (Tonnon et al., 2009). These simulations were made for three alternative designs: a hook shape, an offshore island, and a foreshore nourishment (fully submerged). The predicted bed levels played a key role in the evaluation of the different designs and associated functions of flood protection, recreation, and nature area development. The selected hook shape design and location best fulfilled the multidisciplinary and multi-stakeholder requirements of safety in combination with recreation, development of nature, and scientific innovation. Although the results after 10 years of the three alternatives show quite similar development, the simulations with the hook shape design revealed the most heterogeneity in landscape features and ecotopes. The predicted bed levels for the selected alternatives are presented in Figure 2 up to 2031.

The Dutch Ministry for Infrastructure and Environment commissioned an extensive monitoring and evaluation project since the construction of the Sand Motor. The project evaluated the performance of the Sand Motor in terms of the three original project aims: stimulating dune growth in the project area, developing additional recreation and nature areas, and knowledge development through "learning by doing". The study was always intended to be a monitoring project, focusing on gathering data and answering the question of whether the Sand Motor works. Hence, it does not answer fundamental scientific questions regarding the Sand Motor, such as how and why the Sand Motor works. This task was left to the research programs, of which NatureCoast was the most extensive.

Measurements showed that the models overpredicted growth of the dune area by 500% after four years (Taal et al., 2016). Furthermore, the observed erosion volume in the first years after completion is significantly higher than predicted upfront. The high resolution and frequency of the measurements facilitated a unique 'numerical living lab' where the relevance of a range of environmental forcing conditions and processes can be analysed in detail. The Sand Motor provides a unique case study due to its size, resulting in a large signal-to-noise ratio and due to the comprehensive monitoring campaign, to further advance coastal morphodynamic modelling. The goal of this paper is to share the highlights of the interdisciplinary research program NatureCoast and its benefits on future model forecasts. Section 2 presents the observed behaviour of the Sand Motor in the first 6 years after construction. Findings of the NatureCoast program, relevant for the focus of this paper, are discussed in Section 3. A novel coastal landscape tool is presented in Section 4 highlighting the recent advancements made in coastal morphodynamic modelling. The overall findings are presented in Section 5.

2. The observed behaviour of the Sand Motor

This section describes the construction and observed behaviour of the evolution and dune formation at the Sand Motor.

Construction

The selected alternative was constructed with a cross-shore slope at the peninsula of 1:50, so that the toe of the nourishment reached -8 m NAP and ~1500 m from the original coastline. The northern tip of the peninsula created a sheltered area that nurtures different biotic species. A small lake of about 8 hectares was designed to prevent the freshwater lens in the dunes from migrating seaward, which would endanger groundwater extraction from the existing dune area. Sediment for the nourishment was mined offshore at two sites just beyond the 20 m depth contour at about 9 km. The sand was mined by Trailing Hopper Suction Dredgers and placed at the Sand Motor location

(Luijendijk and Van Oudenhoven, 2019). The Sand Motor was constructed in only three months between March and July 2011. Grain size analysis revealed the mean sediment diameter D50 was approx. 280 µm, which is slightly larger than the mean sediment sizes found at the natural coast here (250 µm).

Observed bed level behaviour

Monthly bed level measurements showed a rapid, predominantly alongshore redistribution of sediment in the first year after construction. The head of the peninsula eroded rapidly, leading to accretion both to the north and south. In the first half year after implementation, a spit developed from the northern tip of the peninsula, pinching the lagoon entrance. The maximum elevation of the spit and shoal were slightly below the high-water level, so they flooded during high tide (and storms). The channel landward of the shoal discharged the flow into and from the lagoon. This resulted in strong flow velocities of over 1 m/s during rising and falling tide in the spring of 2012, causing hazardous situations for swimmers. In the first three years, the coastline developed into a Gaussian bell-shaped curve. The curve widened over time, although after 2015 no further widening of the shoreline position was observed (see Figure 3). Since 2016, the shoreline has developed an asymmetrical shape (de Schipper et al., 2016).

Figure 3. Aerial photographs of the Sand Motor between July 2011 and July 2017.

After construction no sub-tidal bars were present, but these sand bars started to develop after about a year. The subtidal bars and coastline position seem to have been linked since 2013 (see Figure 4). Storms can sometimes cause a large-scale reset of the bar system. By 2018, about 3.5 million m^3 of sand had left the initial peninsula area. The erosion of the peninsula is predominantly caused by wave action, where both daily conditions and high wave events matter. In the first year after construction, the Sand Motor changed shape faster than expected based on long-term model calculations performed as part of the environmental impact assessment. Conversely, subsequent changes were slower than predicted. In 2018, the head of the Sand Motor had retreated about 300 meters since its creation in 2011 (Luijendijk, 2019b). At the same time, the Sand Motor extended up to 6 km alongshore. This shows that the intended feeder function works well. The adjacent beaches are gradually fed by the Sand Motor as the sand is spread by natural forces.

Observed dune development

The beach and the dunes are important for nature and leisure activities along the entire Delfland coast, which includes various strictly protected Natura 2000 areas. This means that the dune area landward of the Sand Motor, called Solleveld, is protected from interventions in the area. Solleveld consists mostly of “old” dunes which were deposited by the sea starting in 3000 B.C. There is a relatively narrow strip of young dunes at the seaward part of Solleveld. For decades the Delfland dunes have been growing steadily, both in height and width, mainly due to coastline maintenance activities.

Since the construction of the Sand Motor this process has continued but not as quickly in the monitoring area as before its construction. The new dune forms are highly dynamic and therefore extremely appealing in landscape terms. The area of new dunes is increasing slightly, but much slower than predicted. Only about one hectare of dune area was formed in the monitoring area in the first five years (Taal et al., 2016), which is surprisingly much smaller than predicted (23-27 hectares after 20 years). This can be partly explained by the fact that the dune lake and the lagoon capture large amounts of drifting sand and delay dune growth. The dunes are expected to continue to grow and this process should accelerate in the future, particularly once the lagoon and the dune lake have filled with sand. Furthermore, the crest of the Sand Motor has developed into a bare sandflat where lots of shells have emerged at the surface, limiting the erosion by wind. Another reason for the limited growth of the dunes is the intensive shared use of the beach. The formation of a new row of dunes in front of the old one is slowed by traffic on the Sand Motor, particularly vehicles driven by supervisors, surveyors, and researchers. The cleaning of the beach performed by the city authority of The Hague also prevents dune formation.

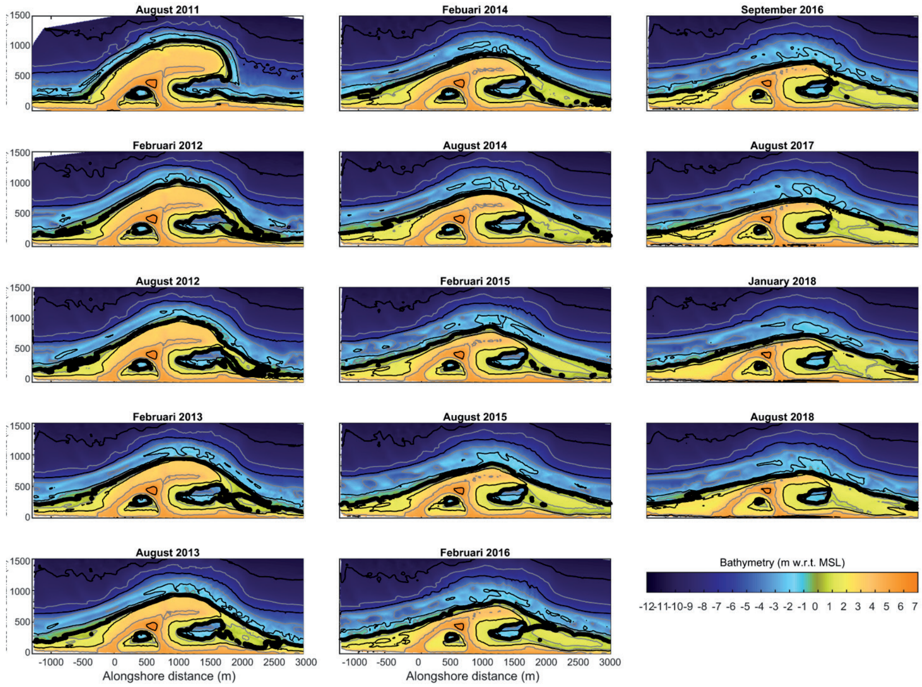

Figure 4. Measured bed levels between August 2011 to August 2018 (Luijendijk and Van Oudenhoven, 2019).

Lidar measurements show that the average dune growth of 14 m^3 per meter longshore per year in the Sand Motor domain is slightly lower than the dune growth rates along the adjacent beach stretches, while this stretch has a much wider beach compared to the other stretches. Observations after five years show that a large volume of 400,000 m^3 of sand has been blown into the dunes, lake and lagoon, which confirms the relevance of the aeolian transport in the morphological behaviour of the Sand Motor. From a sediment budget analysis of the Sand Motor it can be concluded that 58% of all sediments deposited in the dunes originate from the low-lying beach zone that is regularly reworked by waves (Hoonhout and Vries, 2017). For these reasons a model is needed that takes the interaction between both the aeolian and hydrodynamic and morphodynamic processes into account.

3. Relevant NatureCoast findings for model forecasting[2]

NatureCoast has been the largest research program focusing on the Sand Motor. The NatureCoast program was carried out by a consortium of knowl-

2 This section is a summary of and partly revised from Luijendijk and Van Oudenhoven (2019)

edge institutes and universities, and the research was conducted in cooperation with end-users from private companies, research institutes and governmental organizations. The Dutch Technology Foundation (NWO-TTW) provided the largest share of the project funds. The research in NatureCoast focused on six themes: coastal safety, dune formation, marine ecology, terrestrial ecology, hydrology and geochemistry, and governance (Luijendijk and van Oudenhoven, 2019). In this paper only the relevant findings of the first two themes are discussed.

Coastal safety

The dunes landward of the Sand Motor need to grow to increase coastal safety from flooding. Sediment composition will determine how effective this process is; this involves the mean sediment diameter, the sediment grading, and the presence of shells (see Figure 5). Simulations have suggested that if shells had not been present in the nourished sand, much more sand would have been transported from the crest of the Sand Motor. In addition, at the crest an armour layer developed which resulted in relatively limited windblown transport activity. This was largely due to its height. If the Sand Motor had been lower and the dry beach had experienced more frequent flooding, the development of the armour layer might have been limited, thus stimulating aeolian activity. Similarly, the dune lake and lagoon intercepted much of the sand transported from the low-lying beaches, limiting the possibilities for embryonic dunes to form. If these water bodies had been smaller or in different locations, local dune growth might have been stimulated. The long-term effects of the trapping remain to be seen, because at some point these reservoirs of fine, windblown sand will become available, as the waves and currents continue to erode the Sand Motor. Another important finding is that analysis showed that the 12 largest wave events of the first year resulted in about 60% of the total erosion observed in that year (Luijendijk et al., 2017b). Milder wave conditions, which occur more often, are thus almost as important to the erosion of the Sand Motor as storm conditions and should therefore be explicitly incorporated in the long-term (decadal) morphodynamic predictions.

Dune formation

Research on new dune development away from the existing dunes showed that the high, barren plain of sea bed material hampered perennial plants from colonizing, because root stalks transported by storms could not reach the higher elevations (van Puijenbroek et al., 2017). Wind-blown seeds that could reach these elevations found conditions that were too dry to germinate, and the steadily lowering bed level due to wind erosion did not help either. Without perennial vegetation, it was hard for permanent dunes to form on the dry beach. Thus, the sediment composition and crest height are two important factors that affected the development of vegetation at the Sand Motor. Hence, to realistically predict windblown transports, the sediment composition, crest height, and the ever-changing shape of the Sand Motor should all be included in such computations.

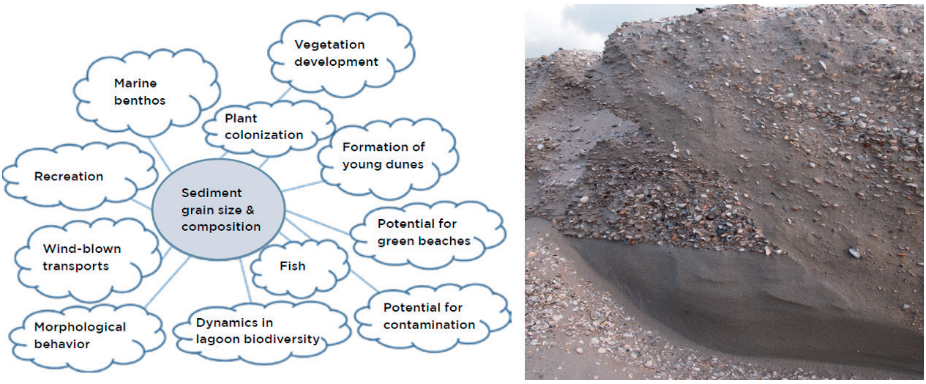

Figure 5. Left: the many relations of the sediment grain size and composition to other processes and aspects at the Sand Motor. Right: photo of the variation in grain size diameter of the nourished sand taken at the cliff (photo by Iris Pit).

The NatureCoast research has clearly illustrated the complexity of the Sand Motor's behaviour in space and time. Many interrelations were found that could only have been identified by combining knowledge across various disciplines. The most telling example is how sediment size and composition has influenced the Sand Motor's morphology and ecology and thus the ecosystem services. The driving mechanisms of the tides, waves and wind cause sediment sorting processes to act upon the nourished sand. The sediment size and composition were found to influence everything from the communities of marine benthos, fish, plant colonization, wind-blown transports, the formation of embryo dunes, development of vegetation, the dynamics in biodiversity in the lagoon, the potential for green beaches in the lagoon, the potential for contamination, morphological behaviour, and even recreation (Luijendijk and van Oudenhoven, 2019).

The next section will discuss in detail on how the abovementioned findings have influenced the numerical model approaches and computations.

4. A novel coastal landscape model

This section presents the technical advancements in coastal morphodynamic modelling and the decadal predictions of large-scale sandy interventions.

Technical advances

A process-based model has been used to hindcast the initial response of the Sand Motor. The Delft3D hydrodynamic model reproduces measured water levels, velocities and nearshore waves well (Luijendijk et al., 2017a). Applying the morphological model with its default formulations and parameter settings results, however, in a morphological evolution that is quite far from observed. The following four technical improvements have been applied to the Delft3D hindcasts and have resulted in greatly improved morphodynamic simulations for the Sand Motor.

Model features

Three key model features were found to be crucial to achieve a good agreement between the model and data (Luijendijk et al., 2017a): the erosion of dry cells, sediment transport formulation, and the formulation for nearshore wave energy distribution. Resolving the erosion of dry cells by distribution, the erosion volumes with neighbouring (dry) cells led to a better reproduction of the observed shoreline retreat. Applying a complex sediment transport formulation, including a roughness predictor, resulted in a better representation of the erosion in the shallow parts of the cross-shore profile. Explicitly resolving the roller forces of a wave, in addition to the wave forces, provided an improved distribution of the wave energy and hence the wave-driven currents. Applying the three features results in a computed morphological evolution which is consistent with the observed evolution during the study period; Brier Skill Scores in the ’Excellent’ range were achieved following the classification of Sutherland et al. (2004). Model results clearly showed that sand, eroded from the main peninsular section of the Sand Motor, is deposited along adjacent north and south coastlines, accreting up to 6 km of coastline in total during just the first year of the Sand Motor.

Grid alignment

Applying the above model settings in model simulations beyond two years revealed increasing deviations with observed behaviour. The observed symmetrical, gaussian shape of the Sand Motorafter three years was not reproduced while using these settings. The deposition of the sand, eroded from the head of the peninsula, was not correctly reproduced by the model. It turned out that the alignment of the computational grid dominated the accretion patterns. Applying a curvature in the grid solved this problem and resulted in comparable Gaussian shapes between the model and the observations.

Coupling wet and dry beach models

To realistically predict windblown transport, the water levels, waves, sediment composition, and the ever-changing shape of the Sand Motor should all be included in such computations. For this reason, two morphodynamic models, being Delft3D Flexible Mesh (FM) and AeoLiS, have been seamlessly integrated and applied to the Sand Engine (Luijendijk et al., 2019a). The integrated morphodynamic simulation is capable of reproducing the observed changes between 2011 and 2016 for both the subaqueous and subaerial domain. Regarding dune growth, the simulated results of the integrated model compare well with the measured dune growth between 2012 - 2015; the measured yearly-averaged dune growth rates vary between 14 - 19 m^3/m/yr, while the simulated yearly-average dune growth rate is 18 m^3/m/yr.

When incorporating the prediction of subaqueous morphodynamic changes by a seamless coupling of AeoLiS with FM, three additional processes are explicitly resolved: 1) the reworking of sand in the intertidal zone by waves breaking up the armoured layer, 2) the erosion of the dry beach area by waves, surges and currents resulting in new beach areas exposed to aeolian transport, and 3) the widening of beaches adjacent to the Sand Motor due to alongshore dispersion.

Morphodynamic acceleration technique

A new acceleration technique for morphodynamic predictions ('brute force merged') was developed, which incorporates the full temporal variability of the wave directions and heights in the wave climate (Luijendijk et al., 2019a). This method is an attractive and flexible approach providing a combination of phenomenological accuracy and computational efficiency (factor 20 faster than the benchmark brute force technique) at both the short-medium (storm time scales) and long-time scales (20-30 years).

Impact of advancements on decadal projections of the Sand Motor

The improvement in morphodynamic modelling since 2009 (EIA phase) and notably the abovementioned technical advancements have resulted in an increase in skill of the predictions (see Figure 6). Original forecasts in 2009 (see Figure 6, EIA at second row) show the sand dispersion to both sides of the Sand Motor, while overestimating the development of a spit on the northern side of the peninsula. First year calibration improved the model results for 2016 significantly (Stive et al., 2013; see third row). The new morphological acceleration technique improved the results further both quantitative and qualitative (see fourth row). The dynamics and dimensions of the lagoon are better reproduced. Incorporating aeolian transport (see Figure 6, FMAL at lowest row) has significantly improved the skill of the dry beach, dunes, dune lake and lagoon. Incorporating these processes is not only paramount for realistic predictions of coastal dune development but also for the decadal morphological behaviour of the subaqueous domain (Luijendijk, 2019b).

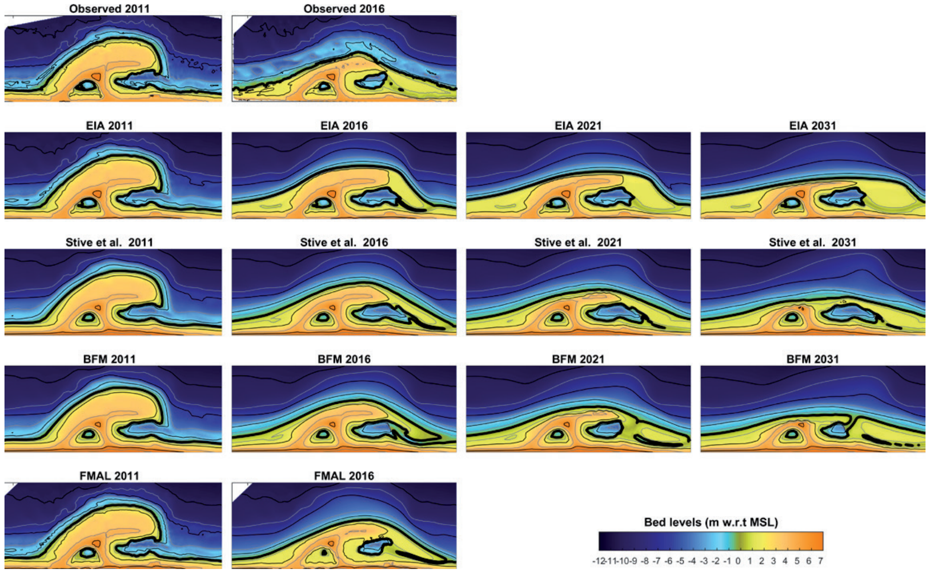

Figure 6. Advances in multi-scale morphodynamic predictions of the Sand Engine (from Luijendijk, 2019b). The four columns represent the years 2011, 2016, 2021 and 2031. The first row shows the observed bed levels, while the subsequent rows show the predicted bed levels presented in EIA, Stive et al., 2013, Brute Force techniques, and the coupled model, resp. FMAL refers to the FM coupled model with AeoLiS. The FMAL results for 2021 and beyond are not yet generated.

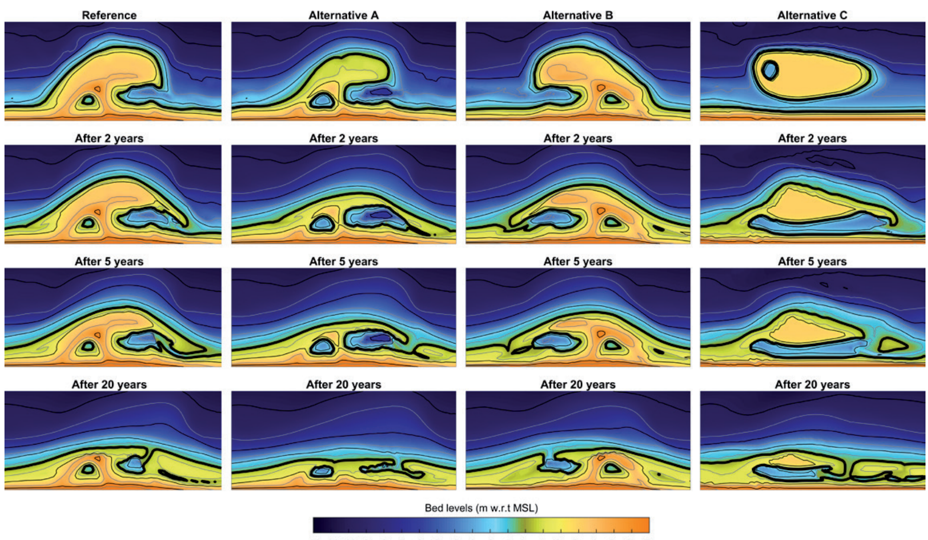

Figure 7. Predicted bathymetries for the reference case (the Sand Motor as constructed in 2011) and three alternative designs using the model discussed in Luijendijk et al. (2019a); Alternative A - the lowered Sand Motor, Alternative B - the mirror-image version of the Sand Motor, and Alternative C - the wing-shaped island.

Decadal projections of large-scale interventions

In the numerical models, many parameters can be varied when designing a sandy solution, for example, the volume, size, shape, orientation, elevation, slopes, grain size, sediment composition, chemistry of the sand, groundwater table, and features like the dune lake, lagoon, and intertidal flats. To demonstrate the impact of a few of these design parameters, the predicted 20-year evolutions of different alternative designs are presented (see Figure 7) by applying a Delft3D model as discussed in Luijendijk et al. (2019a). It is important to realise that the hook shape is just one of the possible shapes and designs. A Sand Motor is not per se a hook-shaped beach nourishment, but a concentrated nourishment that feeds the adjacent beaches at a rate that is in pace with the natural dynamics.

5. Findings

This paper discusses the process-based morphodynamic model applied to the Sand Motor and what the morphodynamic forecasts have gained from the findings of the interdisciplinary research program NatureCoast. An example of a relevant finding is that milder wave conditions, which occur more often, are almost as important to the erosion of the Sand Motor as storm conditions and should therefore be explicitly incorporated in the long-term (decadal) morphodynamic predictions. Another example is related to aeolian transport relevant for dune formation. To realistically predict windblown transports, the water levels, waves, sediment composition, and the ever-changing shape of the Sand Motor should all be included in such computations. These and other findings have triggered new developments which led to a new coastal landscape model, which integrates all relevant processes in a seamless manner (i.e. the FMAL model; the FM model coupled with AeoLiS).

The coastal landscape model was developed to seamlessly predict the morphodynamics in both the subaqueous and subaerial domains of the Sand Motor. Decadal predictions illustrate the need to be able to resolve the marine and aeolian processes simultaneously in one modelling framework; especially when dynamics of coastal landscapes and the resulting dune formation as part of the coastal flood defence are subject of interest. The coastal landscape model also incorporates a novel morphodynamic acceleration technique that allows for resolving the morphodynamics from storm to decadal time scales in one simulation.

Combining the above-mentioned developments has led to a unique, open-source, process-based landscape model for (complex) coastal sandy systems, which can stimulate further collaboration between research communities; extensions into dune dynamics and vegetation development are already planned. Moreover, this work demonstrates the evolution from mono- to interdisciplinary forecasts of coastal evolution. It is only these integrated models that can further optimize the spatial design of larger scale adaptive coastal interventions and allow for quantification of the various ecosystem services in space and over time.

Acknowledgements

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Beach-dune modelling in support of Building with Nature for an integrated spatial design of urbanized sandy shores

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Abstract

The long-term physical existence of sandy shores critically depends on a balanced sediment budget. From the principles of Building with Nature it follows that a sustainable protection of sandy shores should employ some form of shore nourishment. In the spatial design process of urbanized sandy shores, where multiple functions must be integrated, the knowledge and the prediction of sediment dynamics and beach-dune morphology thus play an essential role. This expertise typically resides with coastal scientists who have condensed their knowledge in various types of morphological models that serve different purposes and rely on different assumptions, thus have their specific strengths and limitations. This paper identifies morphological information needs for the integrated spatial design of urbanized sandy shores using BwN principles, outlines capabilities of different types of morphological models to support this and identifies current gaps between the two. A clear mismatch arises from the absence of buildings and accompanying human activities in current numerical models simulating morphological developments in beach-dune environments.

KEYWORDS

beach-dune modelling, urbanized shore, coastal spatial design, building with nature, wind-driven sediment dynamics

1. Introduction

Coastal dunes on sandy shores provide multiple ecosystem services to urbanized coastal areas: they protect against flooding by offering a buffer against storms and a higher ground to live on (a regulating ecosystem service), provide drinking water by collecting and filtering water in the coastal freshwater lens (production service) and provide an attractive environment for leisure and beach tourism (cultural service). A good spatial design for an urbanized beach-dune area takes the full spectrum of these functions into account. However, these desired ecosystem services can only exist by the grace of the *supporting* ecosystem services. Therefore, a truly *integrated spatial design* not only combines all desired functions into a favourable spatial arrangement, it must also explicitly take into account and use the supporting ecosystem services.

In the case of dynamic landscapes like sandy shores, the prime supporting ecosystem service is the sediment cycle. The long-term physical existence of sandy shores depends critically on a balanced sediment budget, which is closely connected to sea level rise. Therefore, sediment budgets and -dynamics are essential in any sustainable spatial design of urbanized sandy shores. This leads to our definition of *Building with Nature* (BwN) for sandy shores: using natural forces (waves, tides, wind) and morphodynamics to redistribute sediment to desired locations in order to achieve integrated spatial design goals.

Solutions for coastal protection are needed most where shores are urbanized. Developing such solutions in urbanized coastal landscapes following BwN principles requires an integrated spatial design, which not only introduces additional, and possibly contrasting, functional demands, but also adds the new challenge of how different functions will interact morphologically. On many urbanized shores, the built environment encroaches onto the beach in the form of beach restaurants or series of beach huts in front of the dune, and related infrastructure such as board walks and concrete pathways (*figure.1*). Such structures interact with wind-driven flows of sediment that are an inherent part of BwN solutions to protect the shore. Therefore, making an integrated spatial design to solve these conflicts – or more likely prioritize and optimize accordingly – requires knowledge of both functional demands of the services and of morphological interactions between them.

The essential role of sediment *dynamics* in BwN design makes morphologic modelling a crucial part of the design process. The challenge for spatial designers is to develop spatial designs in a beach-dune environment that must remain dynamic because of its BwN functionality.

Figure 1. Example of urbanized shore with 'Building with Nature' intervention; Kijkduin, Sand Motor mega-nourishment, The Netherlands. (Source: Zandmotor, 2017)

This implies they not only need to understand how static structures interact with the wind-driven sediment flow but, as part of the spatial design process, also need to actively use such interactions. This way a true BwN design solution is achieved where presence and location of structures become part of a dynamic spatial design for urbanized shores. To do so, morphological models are needed to evaluate the impact of different possible spatial designs and design principles. (See Van Bergen et al., 2020, for actual examples of such design principles).

Numerous coastal morphological models have been developed by coastal scientists and coastal engineers for various purposes. However, it is often unclear for spatial designers what can be expected from these models with respect to level of detail of the simulation, accuracy, temporal and spatial scales of problems for which models are suitable. Furthermore, models describe certain aspects more accurately than others because modelers develop their models with a certain purpose in mind.

To our knowledge, modelers so far have never specifically considered the information needs of spatial designers when developing *beach-dune models*. Therefore, this paper identifies morphological information requirements in the spatial design process of urbanized sandy shores using BwN principles. It also outlines the capabilities and limitations of different types of morphological models to simulate impacts of constructions on beach-dune development. To bridge the 'language gap' between spatial designers and morphological modelers, we have attempted to avoid jargon, or explain it, and illustrate different approaches through examples from the ShoreScape[1] project. Hereby, we aim to match the morphological information requirements of spatial designers and morphological model capabilities to identify knowledge gaps where current models do not match information needs for integrated spatial design of urbanized shores.

2. Morphological information needs for integrated spatial design of urbanized shores

An integrated spatial design of urbanized sandy shores requires understanding and prediction of sediment dynamics and morphological change in interaction with a (possibly) dynamic built environment (Van Bergen et al, 2020). The specific morphological information needs vary during the different phases of the design process, as outlined below.

In the '**inquiry and analysis**' phase of the design process, design requirements and context are explored to grasp the parameters of the urban and eco-morphological spatial systems involved. In the case of a BwN approach, this requires information on the *dynamic* context. That is not just spatial characteristics of the system at a given time, as can be represented in a Geographical Information System (GIS), but of the full system's behaviour. For instance, considering a specific nourishment scheme, which beach width variation over time, or which combinations of dune height and width can be expected to develop in areas of a planned waterfront design? What are characteristic bed level profiles across the beach-dune zone during this development? Which morphodynamic mechanisms exist to direct the location and amount of erosion and deposition using buildings placed at the beach (such as already present on *Fig. 1* for recreational use)? Additionally, in this phase of the design process rules of thumb are desired that summarize interactions of buildings with wind-driven sediment flows. For instance, a simple formula describing the relation between inter-building spacing and the amount of blockage of wind-driven sediment flow. Similarly, what would be the sediment blockage factor of raised buildings as a function of their vertical distance above the beach?

The above type of information is important for understanding landscape and urban processes and to identify parameters for the exploration of possible futures. Integrated spatial designs for urbanized shores with wide beaches, rapidly eroding shorelines and large spatial variations therein, such as at

1 ShoreScape is a research project that aims to develop knowledge, tools and design principles for the sustainable co-evolution of the natural and built environment along sandy shores.

the Sand Motor (*figure 1*), will most likely differ from those with more gradual advancing shoreline positions and slowly seaward advancing dune fronts.

In the subsequent phase of '**design feasibility**', different spatial arrangements are tested and combined into one design. Interactions of urban design and morphological development are studied by so called 'rapid prototyping'. For example, when planning for beach housing in a dune formation zone, various layouts are explored by systematically varying the types and configurations of buildings and the timing of their placement. A combination of several design aspects will lead to variants and plausible solutions, ready to fit the dynamic context and urban program.

Finally, in the phase of '**design optimization**', interactions between different design aspects are studied in detail and optimized. Now decisions have to be made that have financial consequences and thus require a higher level of accuracy and precision of morphological information. For example, when considering sea level rise, a proposed nourishment scheme and arrangement of beach houses should guarantee natural growth of the dunes, such that flood safety levels and natural values provided by the dunes will be maintained. This requires detailed information about, amongst others, the amount of sand in the dunes over time, including a prediction of its topographic evolution, to enable the application of models that test flood safety levels through time. This optimization process will lead to a favourable solution, underpinned by quantitative tests based on the output of morphological modelling.

3. Model types for evaluating morphodynamics of the beach-dune system on urbanized sandy shores

In the context of simulating topographic changes (related to sand transport by wind and water) in a beach-dune environment, the term 'model' or 'morphodynamic model' refers to a simplified version of reality that, in its very essence, incorporates topography (bed elevation) and the sediment transport processes that change it. Models differ in how they incorporate sediment transport processes. Broadly, we can identify three types of models, differing in their simplification approach: conceptual models, physical models ((scaled) lab experiments), and numerical simulation models. For a beach dune environment, numerical simulation models can be split into process-scale models and rule-based behavioural models. In the following, we will explain these different modelling approaches, what type of information they can provide as well as their present, or inherent, limitations.

Conceptual models

In the context of morphodynamic modelling, a conceptual model refers to a schematization of the beach dune systems in a qualitative manner. It describes, in words, how beach-dune topography changes under the influence of one or more factors (such as wind, waves, or sediment surplus), often with the help of diagrams and sketches. Relations between factors and bed level changes are often described in terms of positive or negative feedback. Conceptual models can be based on a combination of phenomenological knowledge, derived from field observations, and theory (first principle physics, analogies). For example, Psuty (2004) describes how various dune typologies develop on accreting and eroding beaches and links these with a diagram of sediment budget curves for beach and foredune (*figure.2*).

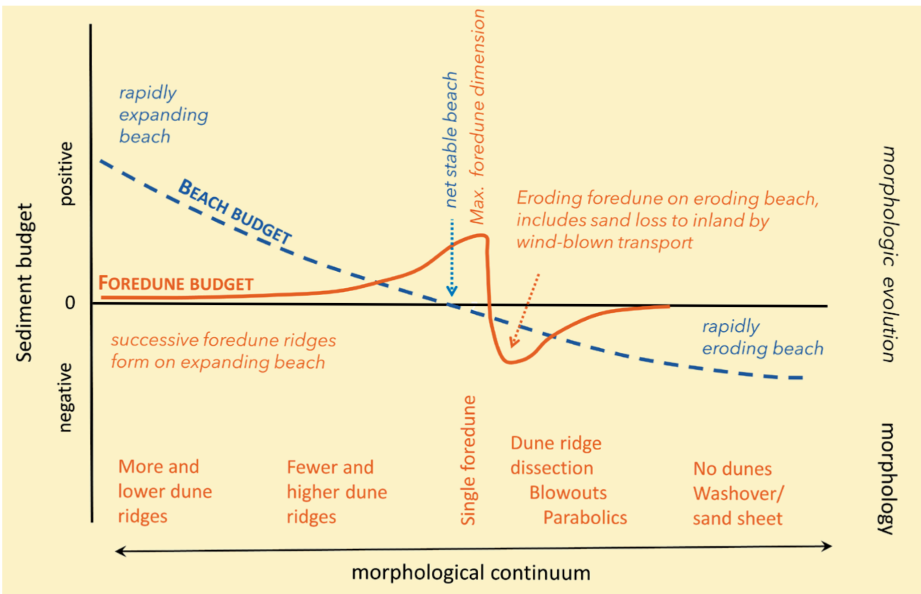

Figure 2. Example of a conceptual model, showing the relationship between the sediment budget of the beach and the resulting sediment budget of the foredune with related topographies of this sand-sharing system. Note that for the situation of a slightly negative sediment budget of the beach, maximum sand storage in the foredune (max. foredune dimension) and maximum inland sand transport expressed through parabolic dune development, are closely positioned and may even occur simultaneously along a given coastline (modified after Psuty, 2004).

Rules of thumb also are conceptual models and have a quantitative element to them. For example, in a given region, initiation of sand-drift dikes[2]

2 A sand-drift dike (stuifdijk) is an artificially created linear dune ridge, initiated by erecting long lines of reed bundles and willow on coastal sandflats to capture windblown sand, often accompanied by planting marram grass at a later stage. Traditional Dutch coastal maintenance practice (see Boeschoten, 1954).

will be unsuccessful when the sandflat is less than 1.3 m above mean sea level (Boeschoten, 1954). Rules of thumb are often based on empirical relations that may be derived from field monitoring or lab experiments (physical models), although they may as well form a way of schematizing insights derived from numerical simulation models. Empirically derived, as well as process-scale modelling-derived rules of thumb can form input for rule-based morphodynamic simulation models.

A conceptual model generally forms the basis for developing a numerical simulation model by providing the elements that may be quantified in numerical simulation models. Conceptual morphological models themselves do not provide quantitative information on rates of change, sediment volumes, or specific complications that could arise from interventions. Morphological experts may use conceptual morphological models to provide:

- a fast overview of possible, first order impacts on morphology of interventions/designs or objects
- rules of thumb for indicating types of natural topographic evolution to be expected in different zones of the beach dune system.

Physical models – scaled lab experiments

A physical model is a tangible representation of a natural system, simplified, but still faithfully reflecting important relationships between relevant processes. Observations and measurements in a physical model can be used to infer information about the behaviour of the natural system itself. As physical models are often built on a reduced spatial and temporal scale, they are also called scale models.

In coastal studies, physical models are mostly used to examine hydrodynamics and morphodynamics and are generally developed in a laboratory setting. For instance, Boers et al. (2009) used a wave basin to study storm erosion of a scaled dike-and-dune system; wind flow around buildings or over dunes can be studied in wind tunnels (e.g. Fackrell, 1984; Wiggs et al., 1996). Occasionally, physical experiments are located in a field setting. For example, Visser et al. (1991) conducted a full-scale dike breach experiment at Het Zwin. Other examples are scale experiments at the beach examining effects of building geometry on sedimentation and erosion patterns in their surroundings (Poppema et al, 2019).

The reduced complexity and scale of physical models, in comparison to the full-scale, real world setting, makes them flexible, relatively cheap and easy to adapt, and suitable to:

- Investigate *archetypical situations* and underlying principles (e.g. Fackrell (1984) and Martinuzzi and Tropea (1993) on the flow structure around a

cube);
- Systematically *vary a specific variable* to investigate its effects (e.g. gradually increasing wind speed to examine deposition patterns around houses like Liu et al. (2018) did for snow accumulation);
- Answer *explorative design questions* (e.g. 'can a funnel-shaped configuration of a series of beach huts, located seaward of the dunes, induce locally increased sediment supply towards the dunes?');
- Evaluate *design performance* (e.g. 'Does beach house configuration X lead to the desired sedimentation pattern?').

Physical models also have drawbacks and limitations. As for all types of models, processes not included in the model can be an issue (e.g. growing vegetation). On top of this, a basic problem of physical models is scaling. If the geometry is scaled (e.g. using a 1:20 scale model of a beach house in a wind tunnel experiment), a faithful representation of real world conditions regarding wind and sediment requires other properties (such as weights, forces, velocities, and time scale) to be scaled as well. This scaling involves physical scaling laws that may pose conflicting constraints on how scaling should occur. As a result, scaling cannot be perfect, and the model maker has to decide which processes are chosen and scaled properly.

An example application of physical models in the context of urbanized beach modelling, is to examine effects of building size and shape on size and location of deposition and erosion patterns. In the ShoreScape project, we placed cuboid scale models of buildings with various dimensions on the beach (see *Fig. 3*) in order to derive general rules for the effects of building dimensions that can be used in rule-based morphological computer models (see section 14.3.4). We placed the scale models on the beach instead of in a wind tunnel to reduce some of the scaling issues and remove limitations of the physical size of a wind tunnel. By using scale models, instead of full-scale objects, one can more easily vary test configurations. Other advantages of field deployment are that longer-term effects with changing wind conditions can be examined and that inherent natural wind and sand transport variations are automatically captured. This simultaneously brings a clear disadvantage of field deployment: one cannot control weather conditions, hence experiments performed on different days will experience different wind conditions, complicating a comparison of results on different days and requiring careful interpretation. The latter can be supported by developing complementary numerical modelling experiments using CFD (see Section 14.3.3) where the influence of different wind speeds can be systematically studied and understood.

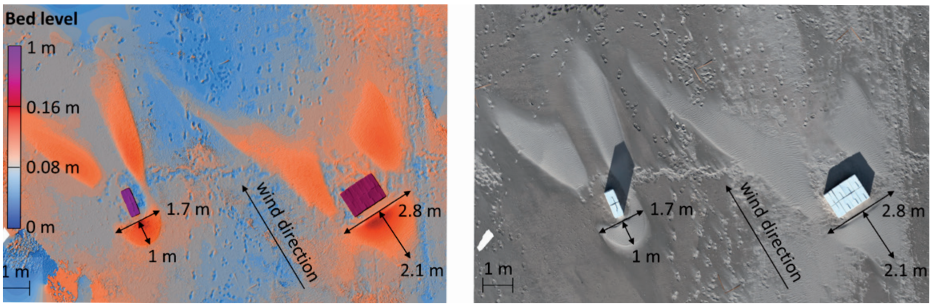

Figure 3. An elevation map (left) and orthophoto (right), showing the erosion and deposition around the same set-up with two scale models of buildings that differ in width. As an example, the measured dimensions indicate that both the width and length of the deposition upwind of the models increase with increasing scale model width.

Process-scale numerical simulation models using CFD

Computational Fluid Dynamics (CFD) is a method enabling computers to solve problems of flow in liquids as well as gasses. In fluid dynamics, flow is described by fundamental physical laws, which include continuity of mass, momentum and energy. These laws describe how these quantities change in time and space due to physical processes. This means that flow properties like density, velocity, pressure and temperature are described through these equations. In practice, the model equations are not easy to solve. Numerical techniques can be used to find approximate solutions for these equations, as the continuous model equations cannot be solved directly. Therefore, the model equations are discretized into a set of algebraic equations. This can be achieved by subdividing the computational domain into a finite number of small cells. These discrete equations can then be solved to find approximate solutions of flow properties.

Sediment transport depends on flow conditions, so CFD can be used to obtain the forcing of sediment transport models. Spatial variations in the fluid flow near the sand surface result in spatially variable sediment transport rates, which causes bed level changes through erosion at one location, and deposition at another. In return, these bed level changes again affect the flow field, closing the feedback loop, also known as a morphological loop.

Using CFD to solve flow problems has advantages but also limitations. By increasing the number of cells, the numerical solution converges toward the exact solution. Therefore, this solution method can be very powerful for finding flow properties in high resolution in time and space. However, increasing the number of cells also increases the computational time required. Therefore, in CFD simulations, there is always a balance between computational cost and resolution. In comparison with field experiments, where all variables are constantly changing, CFD simulations allow a systematic investigation of the impact of specific variables of interest. Numerical modelling can be a powerful tool for providing insight into physical processes. Model results are often simplifications of reality and will therefore not replace experimental research, but rather be complementary to experiments.

This makes CFD models suitable to:

- Systematically *vary the value of a specific variable* to investigate its effects. Parameter values can be precisely specified, or certain processes can be eliminated to focus on processes of interest. (e.g. gradually increasing wind speed to examine influence on size of erosion and deposition patterns around houses)
- Focus on specific aspects of the problem of interest by *turning processes on and off* in simulations. Processes that could be investigated are for instance: does soil moisture affect wind driven sediment transport.
- Compute *detailed flow and sediment transport estimates around a single design* for very short timescales (up to minutes) and a limited number of conditions. Solving airflow equations around buildings requires solutions for a wide range of spatial scales; from the large-scale flow around the building to small-scale flow structures in the turbulent wake behind the building. Even though the small-scale flow structures will be parameterized, the wide range of spatial scales limits the simulated time to several minutes. Computational times typically take hours or days.
- *Obtain system knowledge* through CFD, which can result in rules of thumb.

Even though computers become increasingly powerful, solving turbulent wind flow at the required level of detail and fast enough for a long-term morphological evolution of quantitative accuracy, is not yet realistic. Average flow simulations can be used but result in a lack of physics on smaller scales. Note that most morphological models used in coastal engineering applications are hydro-morphodynamic models that use a more schematized way of CFD modelling, with cell sizes of tens to hundreds of meters and often only depth-averaged fluid flow instead of the full 3D flow field. These models can be applied to simulate the development of the submerged nearshore seabed and can be used, for instance, to evaluate the longer-term shoreline evolution of mega-nourishments due to waves and currents.

A preliminary result of the use of CFD modelling in the ShoreScape project is shown in *Fig. 4*. CFD can provide detailed airflow patterns around various geometries and arrangements of beach houses. Aeolian sediment transport can then be computed by using sediment transport equations that are dependent on bed shear stress and near bed flow velocities, which are calculated for each cell in the computational domain of the CFD model. The morphologic change is derived from the conservation of sediment. Simulations can be made for full scale beach houses, but also at the scale of the physical model experiments at the beach by Poppema et al (2019) to support interpretation of observed sedimentation patterns in terms of underlying mechanisms and test for possible scaling effects.

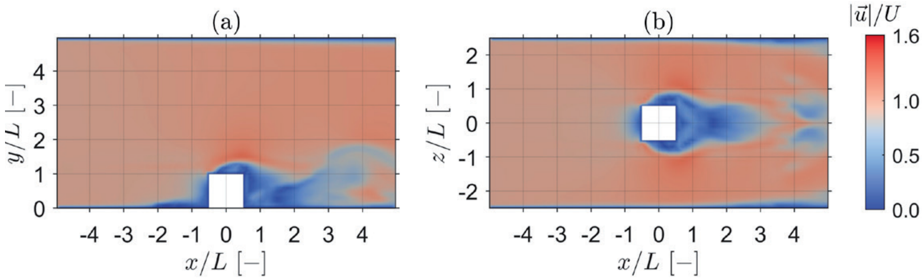

Figure 4. Example snapshot of calculated flow field around a cube-shaped building using CFD modelling: a) side view, slice along centre line z/L=0, b) top view, slice along y/L=0.5. Fluid flow from left to right. Blue to red colours indicate low to high flow velocities.

Rule-based coastal morphodynamic models

Like CFD models, rule-based morphodynamic models describe the beach-dune topography using a large number of cells on a regular grid, usually a two-dimensional surface. The difference lies in the rules that describe the behaviour of these cells. Discrete numbers represent the state of each grid cell (e.g. its elevation, density and type of vegetation in the cell, depth of groundwater). Cell states can change according to transition rules that define how the current state of a cell depends on the previous state of this cell and of its surrounding cells. For example, the probability of sediment deposition in a cell depends on the presence of vegetation *within* the cell (which would trap sediment) and on the presence of a higher elevation in an upwind cell (a dune creates a shadow zone with decelerated wind and increased deposition behind it). This type of model, with grid cells and discrete cell states governed by transition rules, is most commonly referred to as Cellular Automata (CA) model (Fonstad, 2013).

The evolution of the beach-dune topography is calculated by applying these transition rules multiple times to all grid cells, where each iteration (i.e. application of the rules to all grid cells in the model) represents a time step. The mathematical functions that control cell state transitions can be as simple, or complicated, as desired to achieve the aim of the model. To create a meaningful CA model of a natural system, a physical rationale for the mathematical functions of each transition rule is essential. Transitions should be based on general rules or on empirical estimates derived from measurements and must account for all necessary processes required for the desired pattern/phenomena.

So far, the DUBEVEG (Dune, Beach and VEGetation) model (Keijsers et al., 2016, Galiforni-Silva et al., 2018, 2019) is the only attempt to simulate beach-dune development solely using a CA approach. It includes the main processes involved in the dynamics of the beach-dune system, such as wind-driven sediment transport, vegetation growth and decay, hydrodynamic erosion and supply, and groundwater depth. Model rules are applied with a weekly time step, under the assumption of a given long-term average wind-driven sand transport. This results in short computing times, making the model suitable for long-term morphodynamic studies over tens of years.

The main advantages of CA modelling are its flexibility and range of modelling possibilities with a relatively low computational effort. Rules can be simple and are usually easily adaptable. For instance, DUBEVEG only needs sediment transport rules without separate rules for fluid flow (air or water), contrary to CFD models where repeated fluid flow computations are an essential and computationally intensive component.

A limitation of the beach-dune CA model is that total aeolian sediment supply is user-specified, either derived from other models or from long-term monitoring data. This implies that the total wind-driven sediment volume increase, totalled over the simulated period, is imposed by the user and *not* an outcome of the interacting processes in the model. Also, because CA models focus on interactions *at* a certain location (e.g. *changes* in sand transport around a dune), rather than the movement of objects *through* space (e.g. the transport of sand grains), the model does not simulate sand fluxes as required for commonly used model validation methods (e.g. comparison to a measured sand flux). CA model outcomes can therefore only be validated at a higher level of aggregation, such as overall trends and spatial patterns in morphology. Hence model outcomes cannot be used as a quantitatively accurate prediction or reproduction of beach-dune topography at a given time.

Following from all advantages and limitations, CA models for beach-dune dynamics are currently useful as exploratory rather than predictive tools. Their characteristics make them suitable for:

- Investigating underlying principles of *archetypical situations* (e.g. can dune formation be explained solely from shadow zone effects and avalanching when slopes become too steep?).
- Investigating *process interactions* ('How do seasonally present houses in front of a dune affect this dune?')
- *'Rapid prototyping' to answer explorative design questions* (e.g. 'can strategic, time-varying placement of beach houses help build up a dune?')
- Qualitatively c*omparing designs* ('will a design with larger distances between houses result in a higher dune? ')

An example of the output of a CA model simulating the impact of beach houses on dune development is shown in *Fig. 5*. Here, a series of beach houses are implemented in the CA model DUBEVEG by defining non-erodible cells and adding a rule that states a zero probability for sand deposition on top of a house. The nine houses are 2.5 m high, 4 m wide, and 10 m long, and have a 4 m spacing. As we used the DUBEVEG version described in Galiforni-Silva et al (2018), *specific rules for the impact of rectangular objects* on *sedimentation/erosion patterns have not yet been implemented.*

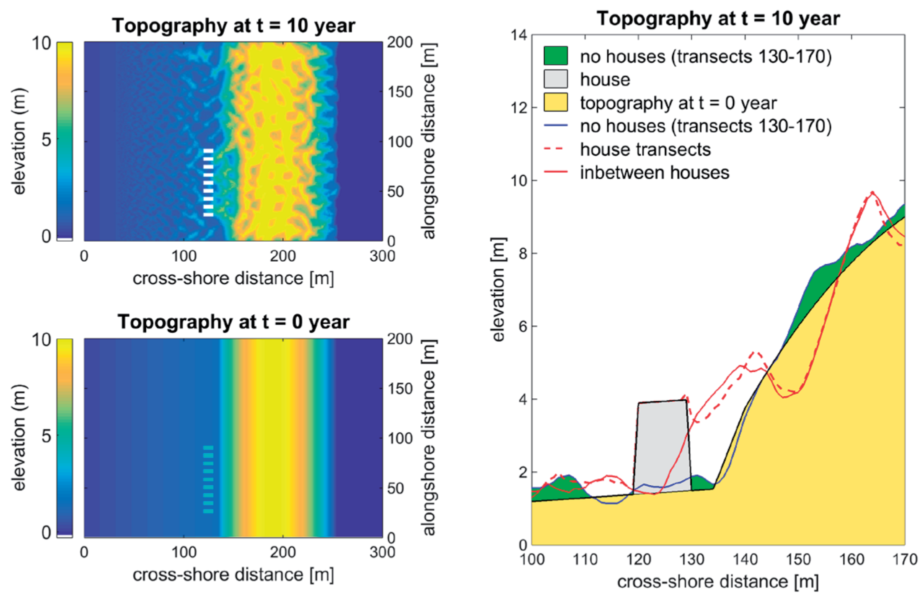

Figure 5. Example illustrating a possible outcome of implementing beach houses in a CA model, where it should be noted that the CA model used does not yet include rules that specify the impact of bluff-body objects, such as beach houses, on local sedimentation-erosion patterns. a) Top view of beach-dune topography after 10 years simulation, white rectangles represent beach houses; b) top view of beach-dune topography at start of simulation, rectangles represent beach houses; c) average topography along transects crossing the middle of a beach house (red dashed), transects in between beach houses (red solid), transects without beach houses (black solid, where green infill indicates sedimentation).

4. Matching morphological information needs and morphological model capabilities

A BwN approach for developing integrated spatial designs for urbanized sandy shores requires morphological modelling at both small and large scales. It requires models to predict the larger scale evolution of the coastline under different nourishment strategies as well as the evolving topography of beach and dunes on smaller scales. For the latter, understanding shorter term interactions of wind-driven sediment transport, vegetation growth, dune development, human use and the built environment are essential to simulate the long-term consequences for the upper beach and dune evolution. Understanding and modelling these complex interactions, where sediment has to move from the submerged domain to the subaerial domain and interact there with the biotic system and the socio-economic system is at the frontiers of coastal modelling (Lazarus et al, 2016).

In the 'inquiry and analysis' phase of spatial design, conceptual models, physical scale models, and CFD models all contribute to meeting identified morphological information needs. In this context, CFD modelling serves two main purposes. Firstly, detailed 3D airflow simulations combined with sediment transport calculations may enhance insight into underlying mechanisms of building impacts on erosion/sedimentation patterns, leading to rules of thumb. Secondly, coarse grid CFD models (grid size of tens to hundreds of meters) with highly reduced complexity fluid flow equations or surrogate modelling techniques (e.g. Berends et al., 2019), can be used to provide morphological information on the approximate effects of nourishment schemes on the coastal profile or shoreline position over many years to a few decades. Regarding modelling of wind-driven sedimentation and erosion around buildings, many studies exist that model airflow around buildings (e.g. Ozmen et al., 2016), but none have calculated related sediment transport patterns. A few modelling studies exist where zones of acceleration and deceleration of the wind near the sand surface, induced by the building, were interpreted as zones of erosion and deposition (e.g. Van Onselen, 2018). Note that the process-scale numerical modelling of wave- and current-driven sedimentation and erosion around hard coastal protection structures at urbanized shores, such as seawalls, is much more advanced (e.g. Smallegan et al., 2016; Muller et al, 2018)

In the phase of 'design feasibility', it is 'rapid prototyping' that puts high demands on the computational time of long-term morphological simulations (covering several years to tens of years). It requires numerical models that can quickly evaluate morphological effects of multiple spatial design alternatives, considering the interaction of buildings and sediment flows, as well as interaction with vegetation development (all of which influence dune formation). This makes CA models currently the most suitable type of model, even though they do not yet include rules for interactions of buildings with wind-driven sand transport. Also, it has been observed that activities related to the recreational use of the beach, such as beach raking or beach traffic, may affect vegetation growth and hence dune development, as does local mechanical removal of aeolian sand deposits by property owners (Jackson and Nordstrom, 2011). Respective relations are still lacking in current beach-dune morphological models.

Regarding the phase of 'design optimization', expressed morphological information requirements seem to be rooted in the tradition of static spatial designs, where the final design can be highly detailed and precise. However, in the case of BwN-based spatial designs, the final design is not a static situation but an inherently dynamic, evolving situation and a static end situation will never exist. Regarding the assessment of flood defence functionality of future dune landscapes, adaptive approaches may be needed (cf. Vuik et al, 2018). Moreover, the assessment of the safety level of a dune with hard objects in or on top of it, is still a difficult issue (e.g. Boers et al., 2009). Apart from the difficulties of knowing details of future beach-dune topography, even predicting the total amount of sand in a dune area is still a major challenge. No models are available yet for accurate prediction of long-term sediment supply to the dunes. Recent efforts in coupling subaqueous and subaerial domains in numerical model studies (e.g. Roelvink and Costas, 2019; Hallin, 2019) help to obtain quantitative insight in the time-varying amount of sand supply that is delivered by the waves and tides and can be picked up by wind for continued onshore transport. In short, present-day capabilities of morphological models to support design optimization are still limited.

5. Conclusion

Using 'Building with Nature' principles in the spatial design of urbanized sandy shores asks for a new design approach. A recognition of the interconnectedness between urban and morphological spatial systems implies the need for dynamic and adaptive, instead of static, designs. Combining the demand for multi-functionality – flood protection, nature, recreation and economy – while at the same time explicitly considering and utilizing sediment dynamics, requires truly integrated spatial design. This poses new challenges to morphological models supporting it.

Numerical models (computer models) able to accurately predict the morphological effects of interaction between wind-driven sediment dynamics and buildings are currently lacking. This is most severely felt in the phases of 'design feasibility' and 'design optimization', where alternatives like conceptual and physical models – particularly useful in the 'inquiry and analysis' phase – are less suitable. In the 'design optimization' phase, a gap exists between model capabilities and morphological information needs as it is difficult to accurately predict the long-term sediment supply to dunes with numerical models. Finally, the observed influence of human activities on urban beaches on vegetation development is currently absent in all morphological models. Hence predicted location and/or rate of new dune formation will be inaccurate for urbanized beaches.

To conclude, arriving at integrated spatial designs for the sustainable protection of urbanized sandy shores using BwN principles requires morphological models that can go beyond the hydro-morphological simulation of nourishment behaviour alone and can include interactions with how humans use the beach.

Acknowledgements

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Natural solutions versus technical solutions

How ecosystem benefits can make a difference in public decisions

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Abstract

'Building with Nature' solutions seem like a logical alternative to technical solutions. Working with nature instead of against it might save civil engineering costs. But will it also generate additional civil engineering benefits? Typical engineering benefits are related to flood prevention, transportation and sand mining. Both technical and natural solutions can produce these benefits. Natural solutions, however, may produce additional ecosystem benefits. These are rarely accounted for in investment decisions about engineering projects.

This is not surprising as there are no rules stating that and how these benefits should be calculated. The Netherlands is the first country in Europe to install a national guideline for monetising ecosystem benefits within cost-benefit analyses in the public sector. This article shows how this guideline provides a systematic approach to prevent both over- and under-estimations of ecosystem benefits. The key to this approach is to make a distinction between goods and services that directly generate welfare while linking those to conditional functions that indirectly generate welfare.

This approach is applied to flood defence in the Scheldt estuary in Belgium. It resulted in benefit estimates that were large enough to compensate for the extra cost of natural solutions. Taking ecosystem benefits into account influenced the flood protection decision of the national government: the natural 'inundation areas'-solution was preferred to the technical solution of 'dyke heightening'.

KEYWORDS

ecosystem valuation, national guideline, cost benefit analysis, goods and services, inundation area, estuary, functions of nature

1. Introduction

In civil engineering, natural solutions are gaining popularity as an alternative to technical solutions. When natural solutions save costs, they are -of course- welcomed. For example, making use of water currents to reduce the cost of dredging. When a natural solution turns out to be more costly than its technical compeer, the technical solution is usually favoured. For example, creating natural inundation areas is more expensive than dyke heightening, because the creation of inundation areas requires giving up valuable agricultural land.

But is it fair to compare two types of solutions merely on the basis of cost, when they might also differ in terms of benefits? If designed for a specific purpose (e.g. flood protection) both natural and technical solutions have similar key benefits (e.g. prevented flood damage) for society. The natural solution may, however, have ecosystem benefits, that the technical solution does not, such as recreational or carbon fixation benefits.

The key to promoting natural solutions thus lies in scientists' ability to determine ecosystem benefits. Both ecologists and economists have carried out studies to calculate ecosystem benefits in monetary terms. Once a price tag is put on ecosystems benefits, they can be included in the cost-benefit analyses that investment decisions are based on (Pearce and Turner, 1990; Layard and Glaister, 1994; Hanley and Spash, 1993).

The extent to which ecosystem benefits are accounted for in cost benefit analyses differs per country. In Belgium and in the Netherlands, the values of ecosystems were not included in cost-benefit analyses for actual political decisions until the year 2004. In that year, a national guideline for determining ecosystems' benefits was endorsed by the Dutch government (Ruijgrok et.al., 2004).

An interesting feature of this guideline is the way in which it tries to prevent possible over and under estimation of ecosystem benefits. The few valuation studies that had been conducted in the past seemed to produce results that either completely overruled the costs of the appraised project or were absolutely negligible compared to the project costs. On the one hand, policy makers felt that studies concluding that ecosystems are much more valuable than any economic activity, could not be right and were not helpful to make decisions on planned economic activities or civil engineering projects. On the other hand, they felt that studies concluding that ecosystems' values are negligible were not really helpful either.

It thus seemed that the results of valuation studies were perceived as either too high or too low to play a role in the costbenefit analysis for concrete investment decisions on civil engineering projects[1]. In this chapter, it is shown how the Dutch guideline helps to prevent over and under estimations of ecosystem benefits on the basis of a case study in Belgium: flood protection in the Scheldt estuary.

2. The methodology of ecosystem valuation

Definitions

In order to understand the way in which the ecosystem benefits of the Scheldt estuary are determined in this chapter, it is important to note how the term benefit is defined and used. The socioeconomic benefits are defined as the amount of both material and immaterial forms of welfare that nature generates for society. This means that socioeconomic benefits are larger than the cash flows derived from nature. These cash flows, which can be rather limited for unexploited, pristine natural areas, form the financial benefits. The broad welfare definition means that the socioeconomic benefits are purely anthropocentric: they pertain strictly to human welfare. Socioeconomic benefits do not encompass the intrinsic value of nature, as the welfare of other organisms, plants and animals is not included[2]. Figure 1 shows the economic, the financial and the intrinsic benefits of ecosystems.

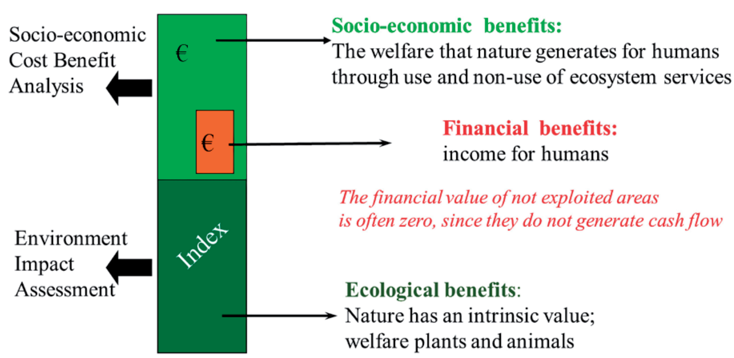

Figure 1. The three benefits of nature

1 Another reason why the results of ecosystem valuation studies are not used in political decision making, is that these studies do not always measure change. E.g. Costanza et.al. (1997) estimate the values the of current natural capital stock to awaken politicians. Of course, this value cannot help a policy makers to decide whether they should give up a part of a nature reserve to build a parking lot. For that decision they need to know the value of the change to the reserve and compare it with the benefits of the parking lot.

2 If humans obtain welfare from the well being of other organisms, this is included in the form of a nonuse value.

Unlike intrinsic benefits (mostly referred to as intrinsic value[3]), the economic benefits of ecosystems can be expressed in monetary terms by means of several economic valuation techniques (Taylor, 2001; Ward and Beal, 2000; Mitchell and Carson, 1989). Expressed in monetary terms, the benefits can be included in socioeconomic cost-benefit analyses which are also in monetary terms. In order to do that with the ecosystem benefits of the Scheldt estuary, the various ways in which these ecosystems generate welfare flows were investigated.

It is noted here that the intrinsic benefits of ecosystems, which are not included in cost-benefit analyses, are usually reported in environmental impact assessments in terms of a score or index. In those assessments, the impacts of civil engineering projects are determined from the perspective of the welfare of species.

Methodology

Ecosystems generate human welfare because they produce goods and services that humans can use and/or simply enjoy without using it- the so-called nonuse function (see e.g. Bateman et.al. (2002), Hanley and Spash (1993), Pearce and Moran (1994)). The use of goods and services can be direct or indirect through the use of other goods or services[4].

Examples of direct forms of use pertain to goods such as wood, clean water, and fish or to services such as recreational opportunities, protection against flooding or climate change. Examples of indirect forms of use are 'nutrient recycling' and 'fish nurseries' which respectively result in 'clean water' and 'fish production'. By using the clean water or the fish, we indirectly use the nutrient recycling service and the nursery service. In other words, the ecosystem´s nutrient recycling and the nursery function are conditional to the production of clean water and fish.

To capture all benefits of an ecosystem, it is important not to omit any goods and services that the ecosystem produces, because that causes an underestimation of the nature value. At the same time, it is also important not to value indirect forms of use in addition to direct forms of use, as this causes overestimations. A way to solve the problem of potential under- and overestimations is to make a distinction between conditional functions that indirectly generate welfare and goods and services that people can directly use or

3 A benefit is comprised of a quantity times a value, e.g. flood protection benefits are the number of houses protected times the avoided damage per house or recreational benefits are the number of recreational visits times the value (i.e. willingness to pay) per visit. Similarly, intrinsic benefits can be expressed in terms of the number of hectares of nature types times the number of (rare) species per hectare.

4 Sometimes the categories 'direct-' and 'indirect-use' are interpreted as respectively tangible and intangible goods and services.

enjoy without using (the socalled nonuse) and to systematically link conditional functions to goods and services. To understand this solution, we shall take one step back and look at the original functions of the nature approach.

The functions of nature approach, which distinguishes production, information, regulation and carrier functions, was originally developed by ecologists to identify the substance and energy flows between the ecosystem and the economic system (e.g. van der Maarel and Dauvellier, 1978). The approach was immediately applied by both ecologists and economist[5] to determine the economic value of ecosystems (van Holst et.al, 1978; Gren et.al, 1994, Barbier, 1993; de Groot, 1992; Costanza et.al, 1997), even though this approach was not developed for this purpose. Later, the approach was further developed by the Millennium Ecosystem Assessment panel, that distinguishes supporting services, i.e. conditional functions and other goods and services (i.e. the other functions[6] (Millennium Ecosystem Assessment, 2005). Figure 2 shows how the different types of functions form a link between the ecosystem and the economic system.

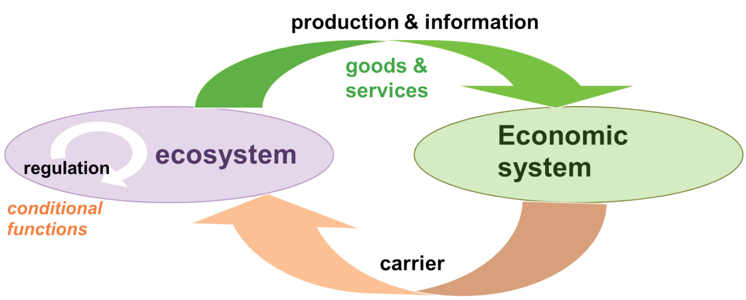

Figure 2. The functions that ecosystems fulfil for the economic system

In figure 2, the different categories of functions are represented by arrows pointing in different directions. The production and information functions reflect a flow from the ecosystem to the economic system. They form the supply of goods (production) and services (information) from which humans directly derive welfare when using or not using it. These are the welfare flows that we are searching for when trying to determine the economic benefits of ecosystems. Carrier functions represent an opposite flow from the economic system to the ecosystems. Humans put houses, waste, roads etc. into

5 It may be noticed here that in studies done by economists, the total economic value concept usually plays a central role, whereas in studies by ecologists, the functions of nature approach is the central focus.

6 This panel uses the terms provisional, regulation and cultural functions. The socalled carrier functions are no longer distinguished.

the ecosystem. Carrier functions should not be included in ecosystem benefit calculations, because they lead to overestimations. In the end, the space that ecosystems provide carries all human activities, rendering the ecosystems´ benefits equal to the benefits of all human activities. In situations where we would like to compare the benefits of ecosystems with the benefits of economic activities, this is not very helpful. For example, suppose we need to decide whether or not to build a road through a natural area. We would like to compare the benefits of the road with the costs of losing the ecosystem in that area. If the benefits of carrying a road are attributed to the natural area, than the costs of losing the ecosystem will always be exactly equal to the benefits of the road, leaving the matter undecided.

Regulation functions are flows inside the ecosystem and are represented by an arrow inside the ecosystem. They are the processes and characteristics that make the carrying of activities and the production of goods and services possible. Originally, they were also called conditional functions (Harms, 1973). Including these conditional functions in addition to goods and services (i.e. production and information functions) is the major cause of overestimates in valuation studies. Conditional functions such as pollination, nutrient recycling, nurseries, carbon sequestration etc. only indirectly generate welfare since they lead to food production, clean water, fish production and protection against the effects of climate change. This means that if both pollination and the food production, or both the nursery and the fish are being calculated and added up to determine the total ecosystem benefits, one and the same welfare flow is counted twice. This is comparable with valuing both the ice cream machine and the ice cream and adding the two values up to determine the socioeconomic benefits of ice cream production.

For the sake of not omitting any important ecosystem benefits, it is useful to identify conditional functions. At the same time, they can be the cause of overestimations, when overlapping with other goods and services (see Box 1). By linking conditional functions to goods and services that directly generate welfare, it becomes easier to carry out an ecosystem benefit study without omissions and without overlap. Table 1 presents a list of wetland ecosystems functions and links the goods and services to conditional functions.

Table 1 shows that nurseries lead to fish production and nutrient recycling to clean water. Since each time there is only one welfare flow, this means that one should either value the nursery or the fish, and either the nutrient recycling or the clean water in order to correctly determine ecosystem benefits[7]. From literature on economic valuation methods, we know that conditional functions such as nutrient recycling cannot be valued in a reliable way with methods that measure people's willingness to pay, such as CVM

7 When there are two or more conditions to one good, one should choose between the good and the most limiting condition.

and TCM, whereas commodity-like goods and services, such as ´clean water´ and ´recreational visits´, can (Freeman, 1986). These conditional functions can, however, be valued quite easily by means of cost-based methods such as abatement cost avoided. Such cost-based estimates are, however, proxy´s of the actual economic value, since it may cost much to abate (e.g. nutrient emissions) although the welfare derived from less nutrients may be smaller than the abatement costs.

Condition	**Goods and Services**
Nursery; Migration routes; Aeration (oxygen)	Fish
Nutrient availability; Ground water fluctuation; Pollination; Soil formation; Erosion control; Biological control	Food and other harvestable products
Erosion control (waterways); Sedimentation control	Transportation possibilities
Nutrient recycling (e.g. denitrification); Carbon sinking (organic matter); Metal binding; Silicium production; Salinity control	Clean Water
Water absorption of soil (sponge function)	Protection against floods
Carbon sequestration	Protection against climate change
Fish nursery, natural succession, biological control etc.	Recreational opportunities
Several functions that lead to biodiversity, such as natural succession and biological control	Existence and bequest of biodiversity (non-use)

Table 1. Linking conditional functions to goods and services

From the above, one can conclude that linking conditions to goods and services, does not only help us to prevent omissions and overlap in valuation studies, but it also explicates a choice in valuation methods. By means of a case study on the Scheldt estuary in Belgium, we shall show that the choice between valuing conditional functions on the basis of avoided costs or final goods and services on the basis of willingness to pay or market prices, can be made on the basis of information availability[8].

3. Case study: the Scheldt estuary in Belgium

The Belgium government is faced with the problem of protecting the population against floods in the Sea Scheldt Estuary. The existing flood protection plan for the Scheldt, which is called Sigma Plan, stems from 1977 and needs to be updated with an eye on the possible effects of climate change. Eight alternatives have been developed to update the protection plan (see table 2). They vary from higher dykes, storm flood barriers, connecting rivers,

8 When it concerns small amounts of changes in e.g. nutrient recycling, so small that actual water quality improvements are not yet noticeable to the people, one can only value this on the basis of abatement costs.

to creating inundation areas. In order to determine which alternative is the best way to protect society against floods, the alternatives are compared by means of socioeconomic cost-benefit analysis (= CBA)[9].

Five of the eight alternatives involve the rehabilitation of inundation areas, which, in fact, represent new ecosystems and thus generate ecosystem benefits. Five types of inundation areas are distinguished:

1. Agricultural inundation areas: these are created by constructing a ring dyke behind the existing river dyke. The land between the dykes remains in agricultural use but is flooded in case of storm floods to protect the hinterland.
2. Wetlands: these are constructed in the same way as agricultural inundation areas. The difference between the two is that here the area between the dykes is turned into a wetland.
3. Reduced Tidal Areas: these are also created by adding a ring dyke, but now the area between dykes will be flooded twice a day by a flood gate.
4. River expansions: these are made by creating a ring dyke and by allowing the river dyke to disappear under water. This means that land is returned to the river.
5. Wet River Valley restorations: in river valleys the river dykes are removed, allowing the river to flow freely over the grass lands.

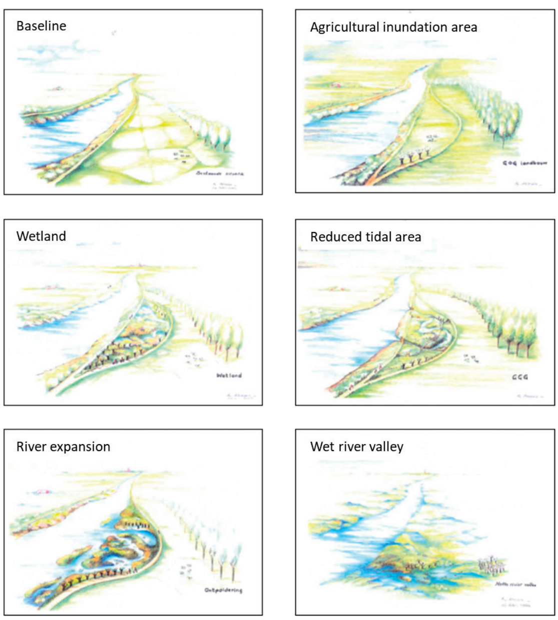

Figure 3. Artist impressions of the natural solution for the Scheldt estuary.

9 And an environmental impact assessment. In this article we focus on the CBA, as that involves ecosystem valuation.

Figure 3 shows artists impressions of these five types of natural solutions in comparison to the baseline situation. It may be noted that in the baseline the rivers have dykes on both sides. The alternative protection plans consist of different combinations of inundation areas. Table 2 gives a brief overview of the composition of the alternative plans.

Alternative	**Composition**
Storm flood barrier	No inundation areas
Higher dykes	No inundation areas
Inundation areas up to a safety level of 1 flood per 4000 years:	a) only Agricultural Inundation Areas and Wetlands; (b) Agricultural Inundation Areas and Reduced Tidal Areas; (c) Agricultural Inundation Areas, Wetlands and River Expansions
Inundation areas up to a safety level of 1 flood per 2500 years	Several Agricultural Inundation Areas and Wetlands
Inundation areas up to a safety level of 1 flood per 1000 years combined with higher dykes protecting Antwerp	Several Agricultural Inundation Areas and Wetlands
Connection between West and East Scheldt	No inundation areas
Connection between West and East Scheldt combined with inundation areas	Several Agricultural Inundation Areas and Wetlands
Restoration of upstream river valleys	(a) Several Agricultural Inundation Areas, Wetlands and Wet River Valleys, (b) Few Agricultural Inundation Areas, Wetland and Wet River Valleys (small storm flood barrier)

Table 2. Composition of flood protection alternatives.

In the CBA, both the benefits of protection against floods and the ecosystems´ benefits[10] of the five types of inundation areas are determined as well as the construction costs. In order to be able to determine the ecosystem benefits by means of the new functions of nature approach, the inundation ecosystems need to be defined in a more detailed way. Table 3 gives an overview of the ecotope composition of the five inundation ecosystems. This composition is influenced by nature management such as mowing and grazing. Since the Scheldt estuary is characterised by a transition from brackish to fresh water, a distinction is made between brackish and fresh water Reduced Tidal Areas and River Expansions[11]. In CBA it is necessary to indicate when benefits occur therefore the development time of ecotopes is also given[12].

10 Although the benefits of flood protection are also ecosystem benefits, they are treated separately in the CBA for the alternative protection plans. This is because technical solutions, such as storm flood barriers, also generate flood protection benefits.

11 For Agricultural Inundation Areas, Wetlands and Wet River Valley, this distinction is not relevant. Agricultural Areas are only flooded in case of emergency and do not change into brackish systems, though they can suffer from salt damage. Wetlands and Wet River Valleys only occur in the freshwater regions.

12 Some ecosystem benefits such as recreational opportunities will only occur after some years when the vegetation is developed. Other benefits, such water purification will occur immediately.

Characteristics	Agricultural Inundation Area	Wetland	Reduced Tidal Area	River Expansion	Wet River Valley
Ecotope composition in climax stage	100 % meadow, cornfield or production forest	Unmanaged: 100 % willow forest Managed: 50 % reed land and 50 % 5 willow forest	Fresh and unmanaged: 100 % willow forest. Fresh and managed: 20 % water vegetation, 40 % reedland and 40 % willow forest. Brackish unmanaged and managed: 20 % water vegetation, 40 % mud flat and sandbank and 40 % salt marsh.	Fresh and unmanaged: 100 % willow forest. Fresh and managed: 33 % water vegetation, 33 % reedland and 33 % willow forest. Brackish unmanaged and managed: 33 % water vegetation, 33 % mud flat and sandbank and 33 % salt marsh.	50 % swampy grasslands and 50 % structure rich grasslands
Development time	none	5 years	5 years	5 years	5 years
Salinity	fresh and brackish	fresh	fresh and brackish	fresh and brackish	fresh
Flood frequency	1 to 10 times per year	1 to 10 times per year	700 times per year, but less in climax stage	700 times per year, but less in climax stage	50 to 150 days per year
Tidal movement	no	no	yes	yes	no

Table 3. Ecotope composition and other characteristics of inundation areas.

4. Benefit calculation of the inundation areas

In order to calculate the economic benefits generated by the five types of inundation areas, an inventory was made of the welfare functions they perform. It was found that the inundation ecosystems fulfil several functions that lead to changes in human welfare.

Table 4 breaks these functions down into eleven goods and services and the conditional functions behind those goods and services. For each row in table 4 a choice was made between valuing the good or service or valuing the most limiting conditional function as a proxy for the value of the good or service. The choice that was made is underlined. The motivations behind each choice are practical. For example, it was decided to value the aeration function that Reduced Tidal Areas and River Expansions fulfil instead of the increased fish production, because there were no data available to predict the increased fish production, whereas it was possible to estimate the addition of oxygen from flooding. For clean water, a similar argumentation was used. There was no data on people´s appreciation for cleaner surface water, but it was possible to calculate the ecosystems contribution to nutrient reduction and the resulting saved cost of waste water treatment.

Goods and Services	**Conditional functions**	**Quantification**	**Monetarization**	**Inundation area**
Fish production	Aeration (most limiting) Nursery	Model prediction	Water treatment costs	RTA, RE
Wood production	Nutrient absorption etc.	Existing data on yields	Market prices	RTA, RE, W
Reed production	Idem	Existing data on yields	Market prices	RTA, RE, W
Shipping possibilities	Prevention soil erosion	Rough estimates on the basis of interpolation of existing data	Dredging costs	W, RTA
	Sedimentation control			W, RTA, RE
Clean surface water:				
- nutrient poor and algae free water	Nutrient purification (N, P)	Model prediction	Water treatment costs	W, RTA, RE
- oxygen rich water	Carbon sinking (C)	Model prediction		RTA, RE
- heavy metals free water	Metal binding (Cd, Cu, Zn, Cr, Pb, As, Ni, Hg)	Numbers from literature		W, RTA, RE
Protection against climate change	Carbon storage (CO2)	Numbers from literature	Internationally authorised value	W, RTA, RE
Recreational opportunities	Several, no specific condition was identified as being the limiting factor	Data from ferries and field counts	Empirical measurement of willingness to pay per visit	AIA, W, RTA, RE, WRV
Fish recreation	See Fish production	Existing data on fish club memberships	Cost per year of a club membership	W, RTA, RE
Housing amenities	idem	Rough estimate of affected houses from Environmental Impact Assessment	Hedonic price transferred from Dutch study in % of the average house price	AIA, W, RTA, RE, WRV
Non-use (i.e. welfare derived from the sheer existence of nature regardles of use possibilities)	Several conditions to biodiversity, no specific condition was identified as being the limiting factor	Number of households in Flanders	Empirical measurement of willingness to pay per household	W, RTA, RE, WRV

Acronyms:
AIA = Agricultural Inundation Area, W = Wetland, RTA = Reduced Tidal Area, RE = River Expansion, WRV = Wet River Valley.

Table 4. Goods and services linked to conditional functions, quantification and monetarisation

Table 4 does not only show which welfare generating functions the five types of inundation areas fulfil, but it also shows how these were quantified and monetised.

Quantification of functions

The quantification method differs per function. For some functions, such as wood production, soil erosion, housing amenities, and fish recreation, existing data sources were used. For other functions, such as the binding of heavy metals, a literature review was done for studies conducted on comparable ecosystems (Cox et.al, 2004). For the functions, aeration, nutrient purification, and carbon sinkage, the quantification was done by means of model predictions. A special substance flow model for the Scheldt estuary of the University of Antwerp was used for this purpose.

Monetisation of functions

The different functions were monetised by means of different valuation methods. Goods and services, such as wood and reed production, were valued on the basis of market prices. All conditional functions, such as erosion control and nutrient purification, were valued in terms of abatement costs, such as dredging costs and water treatment costs.

Two services, recreation and nonuse, were valued by means of an empirical Contingent Valuation Study. In this study, 1.704 inhabitants of Flanders were asked to state their willingness to pay for recreational visits and for nonuse (i.e. conservation without using). The CV-questionnaire was set up according to the prescriptions of the NOAA Guideline (Arrow et.al, 1993). Since the CVM comprised of two different values and five different ecosystems it was quite complex.

An extra complicating factor was that each type of inundation ecosystem will be realised at several locations which have not been identified yet. Fifty percent of the interviews were held among recreationists in the Sea Scheldt Area and fifty percent were held outside this area. This was done to guarantee that the sample included both recreationist and nonusers. For representativity, interviews were spread across 33 different locations and during different days of the week over a period of three months. To prevent seasonal bias, respondents who were not recreating at the moment of interview, were asked if they visit the Sea Scheldt Area at other moments in time. If so, they were regarded as recreationists. Table 5 shows the results of the CVM-study.

Statistical tests on the difference in willingness to pay for the different types of inundation areas showed that only the differences in willingness to pay for the Wet River Valley and the other types were significant. Both the recreational value and the nonuse value of the Wet River Valley were significantly lower than the values of the other types.

Ecosystem	average willingness to pay for recreation in Euro per visit (st.dev)	n	average willingness to pay for non-use in Euro per household per year (st.dev)	n
Overall value	1.68 (3.80)	1.328	15.50 (24.73)	1.439
Agricultural Inundation Area	1.76 (4.67)	158	n.a.	0
Wetland	1.61 (3.19)	284	16.10 (10.24)	335
Reduced Tidal Area	1.77 (4.76)	288	16.33 (24.88)	371
River Expansion	1.92 (3.55)	290	15.62 (23.86)	366
Wet River Valley	1.40 (2.93)	308	13.99 (25.63)	367
Acronyms: st.dev = standard deviation, n= number of measurements, n.a. = not available.				

Table 5. CVM-results: willingness to pay for recreation and non-use

5. Results per ecosystem

After the quantification and the monetisation of the different functions of the five types of inundation areas, a spread sheet model was built to calculate the present value of the ecosystem benefits. Present values were calculated taking into account the ecotope composition[13], the development time and saturation[14], the difference between fresh and brackish water[15] and the impact of nature management[16]. The latter was modelled as a variable for the sake of conducting a sensitivity analyses afterwards. Table 6 presents the results of these calculations, assuming that all nature is managed. For the details of the calculation of each benefit in table 6, the reader is referred to Ruijgrok and Lorenz (2004).

Table 6 shows that the fresh water Reduced Tidal Areas produces the largest economic benefits. The Wet River Valley and the Agricultural Inundation Area generate the smallest benefits. This is because there is hardly any nature development in these two areas compared to the baseline situation. For both the Reduced Tidal Area and the River Expansion, the fresh water areas produce greater benefits than the brackish water areas. This can almost entirely be ascribed to the difference in nutrient purification (plant absorption). From table 6 one can also conclude that after the nonuse benefits (which is not per hectare), metal binding forms the largest benefit category, followed by sedimentation and nutrient purification.

13 This determines the quantification of the wood and reed production and of nutrient absorption by the vegetation.

14 Saturation occurs for functions such as the binding of heavy metals and the sedimentation control. When a mud flat or salt marsh is mature, the input and output of heavy metals and sediment will be in balance, resulting in zero net catchments. Here, saturation was assumed to occur after 20 years.

15 This influences the quantification of ´nutrient absorption by the vegetation´ and of ´carbon storage´.

16 This has an impact on the quantification of ´nutrient absorption´ and ´wood and reed production´.

	Agricultural inundation area	Wetland	Reduced Tidal Area	Reduced Tidal Area	River Expansion	River Expansion	Wet River Vally	Unit
Ecosystem functions**:	fresh	fresh	fresh	brackish	fresh	brackish	fresh	
Aeration	0	0	87	38	87	38	0	€/ha
Wood	0	8,630	6,904	0	5,696	0	0	€/ha
Reed	0	6,421	5,137	0	4,238	0	0	€/ha
Erosion	0	260	260	260	0	0	0	€/ha
Sedimentation	0	292	20,426	20,426	20,426	20,426	0	€/ha
Nutrient purification	0	14,990	25,022	15,304	23,572	14,864	0	€/ha
rinse out (N, P)***	0	1,929	1,929	1,929	1,929	1,929	0	
denitrification (N)	0	5,846	10,084	6,138	10,084	6,138	0	
plant absorption (N, P)	0	7,215	5,772	0	4,762	0	0	
burial (N, P)	0	0	7,237	7,237	6,797	6,797	0	
C sinking	0	0	3,242	3,242	3,242	3,242	0	€/ha
Metal binding	0	507	35,501	35,501	35,501	35,501	0	€/ha
Carbon storage	0	3,421	2,737	2,808	2,257	2,808	0	€/ha
Recreational opportunities	1,381	1,381	1,243	1,243	2,037	2,037	374	€/ha
Subtotal per ha	1,381	35,903	100,561	78,823	97,057	78,917	374	€/ha
Fish recreation	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	€/pound fish
Housing Amenity	-50,400	-50,400	-50,400	-50,400	-50,400	-50,400	-50,400	€/2 homes
Non-use	0.0	796.2	796.2	796.2	796.2	796.2	718.6	M€ if total area is this type

* The present values are computed over an infinite time span, except for benefits that physically stop after a certain number of years (e.g. metal binding stops after 20 years).
** The functions aeration, erosion, sedimentation, nutrient purification, C sinking, metal binding and carbon storage were all valued by multiplying the modelled number of mmol O2, m3 of sediment, kg of N and P, tons of C, kg of metals per hectare per year respectively the energy cost per mmol O2, the dredging cost per m3 sediment, the water treatment cost per kg N and P and metal etc. for the Scheldt estuary.
*** These are the benefits of reduced nutrient input into the environment as agricultural land is transformed into nature.
**** These are the negative benefits if one detached and one attached house, with an average value of resp. € 320.000 and € 100.000 lose their view on the river.

Table 6. Benefits per ecosystem type (present values at 4 % interest*)

6. Cost Benefit Analysis on alternative protection plans

As explained before, the Belgian government intends to choose between several flood protection plans, which are composed of different combinations of the five types of inundation areas. This means that the ecosystem benefits of a protection plan can be calculated on the basis of the benefits per type of inundation area. Table 7 presents the results assuming that all nature is managed. Only alternative protection plans that involve the creation of new nature areas are presented. Although the alternative plans do not cover exactly the same amount of land, this leads to minor differences in benefits (accounted for in table 7) and to slight differences in costs.

Table 7 shows that alternative 3b, which involves the creation of Reduced Tidal Area´s, wherever possible, to realise a safety level of 1 flood per 4000 years, generates the largest ecosystem benefits, followed by alternative 3c and 8a.

Alternative flood protection plans*	Agricultural inundation areal	Wetland	Reduced Tidal Area	River Expansion	River Expansion	Wet River Vally
3. Inundation areas up to a safety level of 1 flood per 4000 years:						
(a) Only Agricultural Inundation Areas and Wetlands	-0.21	282.24	0.00	0.00	0.00	282.03
(b) Agricultural Inundation Areas and Reduced Tidal Areas	0.09	0.00	984.69	0.00	0.00	984.79
(c) Agricultural Inundation Areas, Wetlands and River Expansions	-0.19	114.58	0.00	769.82	0.00	884.22
4. Inundation areas up to a safety level of 1 flood per 2500 years: Agricultural Inundation Areas and Wetlands	-0.52	245.49	0.00	0.00	0.00	244.97
5. Inundation areas up to a safety level of 1 flood per 1000 years combined with higher dykes protecting Antwerp: Agricultural Inundation Areas and Wetlands	0.17	184.13	0.00	0.00	0.00	184.29
6. Connection between West and East Scheldt combined with inundation areas: Agricultural Inundation Areas and Wetlands	0.15	142.97	0.00	0.00	0.00	143.12
7. Restoration of upstream river valleys:						
(a) Several Agricultural Inundation Areas, Wetlands and Wet River Valleys	-0.78	162.48	0.00	0.00	453.18	614.88
(b) Few Agricultural Inundation Areas, Wetlands and Wet River Valleys & small storm flood barrier	-0.57	57.57	0.00	0.00	610.10	667.11
* See also table 2.						

Table 7. Ecosystem benefits per protection plan (present values in million Euro´s at 4 % interest)

Although the investment costs vary per alternative, they are estimated at approximately 500 million Euro. This means that the ecosystem benefits of alternative 3b, 3c, 8a and 8b surpass the costs[17]. This allows for the conclusion that investments in the development of new ecosystems within the flood protection plan are a sound investment from a societal perspective. It also leads to the conclusion that natural flood protection can compete with traditional technical solutions such as dyke heightening and storm flood bar-

17 This does not, however, mean that the other alternatives have a negative net result. Besides ecosystem benefits, each alternative also generates safety benefits in the form of avoided flood damage costs.

riers, thanks to the ecosystem benefits. Though not shown in table 7, it was found that natural solutions could compete with all the technical ones (plan 1 storm flood barrier, plan 2 dyke heightening and plan 6 connecting rivers). The ecosystem benefits more than compensate the cost difference between the natural and technical solutions.

Comparison of the Guideline with other approaches

The presented results may raise the question whether we would have had different results, had we not applied the approach of the Dutch guideline. Table 8 presents rough estimates in case: (a) just cash flows, such as wood and reed yields, had been taken into account; (b) the conditional functions behind clean water, transportation possibilities and fish production had been added up to the direct values of these goods and services; and, (c) only the easily measurable benefits of recreation and nonuse had been accounted for.

Alternative flood protection plans	Presented estimate of this study	Estimate based on only cash flows **	Estimate based on values of conditional functions in addition to values of goods and services ***	Estimate based on only recreation and non-use values
Alternative 3a*	282.03	13.28	786.25	255.63
Alternative 3b	984.79	19.40	2,547.48	755.83
Alternative 3c	884.22	20.23	2,263.36	669.36
Alternative 4	244.97	9.84	691.65	226.31
Alternative 5	184.29	5.79	526.01	173.18
Alternative 7	143.12	3.91	411.10	136.00
Alternative 8a	614.88	10.30	1,828.56	609.47
Alternative 8b	667.11	2.47	2,020.22	677.74

* See table 7 for a description.

** Only the functions that generate direct cash flow (wood production, reed production, recreation, and housing) were included here.

*** All final goods and services plus the conditional functions mentioned in table 4 are included here.

Table 8. Comparing the estimated ecosystem benefits with other approaches (present values in million Euro)

Table 8 shows that if we had estimated the ecosystem benefits of the alternative flood protection plans solely on the basis of cash flows, the benefits of all alternatives would be much smaller than the costs of ca. 500 million Euro. This would lead to the conclusion that ecosystems are a bad investment. If the values of all ecosystems´ functions had been included without eliminating overlap, the benefits of all but alternative 7 would greatly surpass the costs. Since the costs of alternative 7 are actually smaller than 500 million Euro, this would lead to the conclusion that they are all good investments.

Such a conclusion is usually not very helpful in political decisionmaking processes for two reasons[18]. Firstly, policy makers and politicians need discriminating results, that reveal different consequences of choices. And secondly, they usually feel that benefits, which are of the different order of magnitude as costs, are incomparable.

Finally, if we only include easily identifiable ecosystem values in the calculations, such as recreation and nonuse benefits, the results become more discriminating and more in line with the magnitude of investment costs again. This approach is, however, completely dependent upon CVM results. On the European mainland, this dependency is usually considered a problem, since this method is still very prone to criticism and therefore rarely applied to support actual political decisions. If the CVM results are not accepted, the ecosystems benefit will become zero, which brings us back to the original problem of ecosystems having little weight in political decisions.

7. Conclusion

This study leads to the conclusion that the natural solution of inundation areas is a serious alternative to technical flood protection solutions, such as storm flood barriers or dyke heightening due to the ecosystem benefits that they produce. Judged against the magnitude of ecosystem benefits, one may also conclude that the estimated ecosystem benefits in this study are discriminating between alternatives. They do not completely overrule the costs, which would render them useless for political decisionmaking. At the same time, the ecosystem benefits are large enough to support the necessary investments in nature development. The case study showed that the approach of the Dutch guideline, resulted in a realistic value estimate that was quite different from the results we would have had using other approaches. Moreover, this estimate was actually used in a concrete national political decision and it influenced that decision as the Belgian government opted for inundation areas where possible.

8. Discussion

In international literature on ecosystem valuation, the functions of a nature approach is widely used by both ecologists and economists (e.g. Seidl and Moraes, 2000; Wetten et.al., 1999; Costanza et.al., 1997; Perman et.al., 1996; Sorg and Loomis, 1986; Pearce and Turner, 1990; Kirkland, 1988;). These two groups use a different definition for the term ‘function’ (Brouwer, 2003).

18 This does not reduce the fact that from a scientific perspective such a conclusion should be helpful.

Ecologists use this term for ecological processes, servicing the maintenance of the ecosystem. As a consequence, ecologists, engaged in economic valuation studies, focus on valuing ecological processes, such as nutrient recycling, waste absorption, carbon sequestration and erosion control. These processes do not always lead to welfare (e.g. denitrification does not lead to welfare at locations where there is no eutrophication problem). Sometimes several processes lead to one and the same welfare effect (e.g. denitrification and silicium production both lead to clear water). Since functions may overlap, valuing them all separately may cause serious overestimates of the ecosystem's value (see Box 1).

Regulation functions	Production functions	Carrier functions	Information functions
Storage and recycling of nutrients	fuel wood	recreation	education
Storage and recycling of waste	medicines	habitat and nursery	research
Groundwater recharge and discharge	(clean) water	human habitation	cultural heritage
Flood control	raw materials	energy production	
Erosion control	genetic resources	agricultural crops	
Salinity control	food	grazing (life stock)	
Water treatment		transportation	
Climatic stabilisation			
Carbon sequestration			
Nurseries/ migration routes etc.			

This checklist contains potential overlap between functions. E.g.: Doesn´t ´erosion control´ lead to more ´agricultural crops´ and isn´t that ´food´? Doesn´t ´water treatment´ result in ´clean water´? Do ´climatic stabilization´ and ´carbon sequestration´ not both lead the protection against the negative effects of climate change? Don´t ´nurseries´ and ´fish migration routes´ lead to more ´food´ in the form of fish?

Box 1. Overlap of functions leading to overestimated values

Economists use the word 'function' for processes that service human needs. They focus on easy-to-perceive goods and services, such as timber and recreational opportunities. They do not systematically investigate which processes are going on in the ecosystem that might possibly generate welfare. Therefore, they run the risk of omitting things, leading to underestimates of ecosystem values. By linking the goods and services that directly generate human welfare to conditional functions that indirectly produce welfare, the economists´ and the ecologists´ approaches are combined, resulting in less extreme estimates and hopefully resulting in a more frequent inclusion of ecosystem values in actual political decisions.

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Building with Nature as a cross-disciplinary approach: the role of hybrid contributions

1. Expanding the realm of inquiry

The incentive for this publication was to expand the realm of enquiry around the topic of Building with Nature (BwN), for two main reasons. First to gain an interdisciplinary, and therefore deeper, understanding of BwN as an object of study. Secondly, but no less important, is an understanding of how *different forms of knowledge* contribute to our learning regarding BwN. When we understand the contribution of several academic disciplines and knowledge from practice, we may eventually get to the point where we can identify how they can collaborate successfully to contribute to BwN as an interdisciplinary field.

Finding strategies for successful cooperation is needed for a second generation of BwN to evolve. Despite the promotion of interdisciplinary learning at the strategic level of universities, a genuine progress on the operational level has lagged behind. An unwritten consensus in the scientific field of trans- and interdisciplinary learning (TD&ID), is that progress is hindered by two main obstacles: bias against interdisciplinary scholars in the recruitment and assessment procedures of academic departments (the operational powerhouse of the university) and key differences in the language, methods, notions of validity, and general culture between disciplines, in particular between the exact and social sciences. Different disciplines therefore operate in isolation, which results in a limited, and sometimes even biased, view on a shared subject of study. This knowledge fragmentation undermines society's regard for academia, and worse, contributes to humankind's failure to address grand challenges, like climate change and inequality.

As showcased by the contributions in this publication BwN is addressed from different disciplinary backgrounds and domains. However, the approaches all feature inter-, multi-, and transdisciplinary characteristics that prove that BwN is a complex knowledge field that needs the cooperation of scientists, engineers, designers, artists, etc. In fact, it shows that BwN is not merely a field that can only be understood from a single point of view, or separate views next to each, but that it entails a more comprehensive and hybrid approach in which natural processes, infrastructure, spatial qualities and societal perceptions are considered part of the same.

2. Art, Design, and Science

A useful distinction for types of knowledge relevant to understanding the interaction between the involved disciplines is offered by Lee (2011). She distinguished Art, Design, and Science as core knowledge domains that relate to reality in different ways (figure 1). While the nature of Art is to *question* reality, Science seeks to *explain* it. Design's nature is ultimately to *change* reality. When we consider Art, Design, and Science as knowledge domains of a radically different nature, we can understand and position the contributions in this book and how they relate to each other.

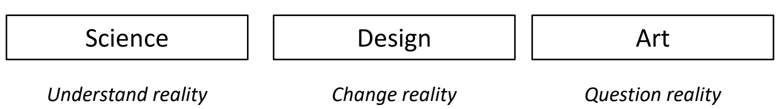

Figure 1. The three different knowledge domains and their inquiry according to Lee (2011)

However, when we apply the framework of Lee, it is not to classify or separate the contributions and the related disciplines, but to show the overlap or focus. Therefore, we visualised the three knowledge domains as a force field, in which disciplines can operate between different knowledge domains, given a specific focus or discipline (figure 2).

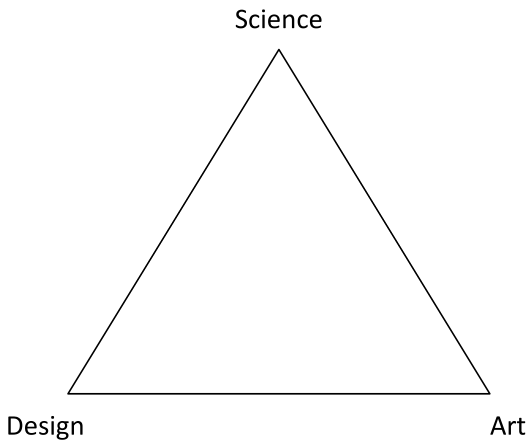

Figure 2. The three different knowledge domains as force field

When positioning the contributions of this book in the force field, different clusters of hybridity can be derived from the various approaches to BwN (figure 3).

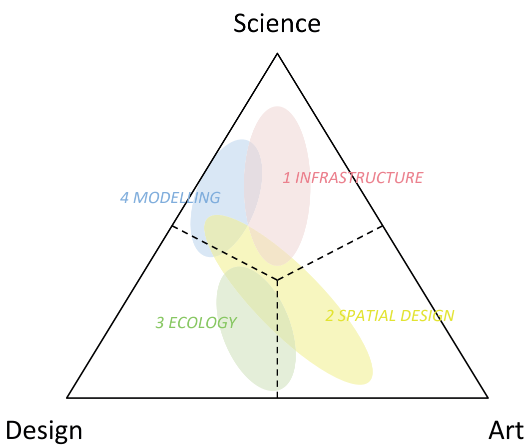

Figure 3. Positioning of the chapters of BwN perspectives

The positioning of the contributions is arbitrary but gives an impression of the nature of the chapters. A first glance at the mapping of the chapters shows that most contributions originate from the exact field of science -*explaining* reality- (chapter 1 and 4). Considerable effort is made to gain an understanding of dynamic systems and the control of it, via modelling and management. Spatial design (2) of BwN is represented by both landscape design and ecology, with specific contributions making the crossover from science to design. Art is under-represented in this publication. As a pioneering field, many art projects arise from the Building with Nature philosophy, but blossom as an autonomous discipline, separate from academic output.

However, they play an important role in the societal dialogue and embedding of BwN, questioning the new realities that come from large-scale system interventions.

When taking a closer look at the contributions within each chapter, certain directions for interdisciplinary knowledge and collaboration can be seen. From the field of science and engineering, two directions for interdisciplinary knowledge can be observed.

First of all, there is the movement from fundamental science on BwN (understanding reality) towards the modelling of this complex and dynamic reality. This is represented by the contributions 'Beach-dune Modelling', 'A novel coastal landscape model', 'Natural solutions' and 'A systematic design approach', which illustrate the sequential steps from fundamental knowledge (*understanding* reality) towards the modelling of BwN (*representing* reality) to the prediction of BwN processes (*projecting* reality); and finally, to an assessment of BwN solutions (*evaluating* reality) and a resetting of the values related to BwN (*redefining* reality). This cycle of understanding, representing and redefining BwN as reality, will not only improve the understanding of BwN as a technique itself, but also makes way for applied science and design, where models are used as key interdisciplinary tools between specialist knowledge, spatial design, and management.

Secondly, a closer understanding of BwN as a complex system also raises new questions. On the one hand, there is the scaling issue (De Vries et al) – redefining BwN as reality. Secondly there is the operationalisation of BwN. This involves other types of knowledge, such as the embedding of BwN as infrastructure (Brand & Hertogh), or interdisciplinary team-roles for the management of BwN (Klaassen et. al) establishing Building with Nature as a learning community. It shows that with the redefinition of BwN, interdisciplinarity is no longer an option, but a necessity.

The design perspective in this publication is represented by two chapters: Spatial Design and Ecology. Both chapters contain contributions with a direct crossover to science, such as 'Urban Dunes', translating the understanding of sedimentation processes to design principles. The contribution 'Odums dark bottle' refers back to the early days of ecology research as a systems approach, illustrated by design practice. The contribution of 'BwN in landscape practice' shows how ecological understanding has become an integral part of landscape design practice, changing reality. Ecological notions are integrated in the design of the human habitat, not just adding functionality, but also generating beauty, another feature of design.

All three articles state that for BwN to incorporate a full systems approach, the anthropological aspects of BwN should be addressed. This by including communities in the understanding, advocacy, and decision-making of BwN projects and the inclusion of the urban system in future solutions.

The need to involve the anthropological layer in BwN is also emphasised by the contributions 'Building with Landscape' and 'Pioneering Sand Motor', operating from the art perspective to question the reality of BwN. Both raise public awareness for BwN techniques in response to climate change and sea level rise. In 'Building with Landscape', a series of installations at the Oerol-festival, on the island of Terschelling, were used to first change reality– a clear feature of design. To create the individual installations, anthropological or cultural interpretations and reflections were used as valid input alongside scientific facts – another design-feature. These installations were not only meant to connect the technique within its spatial and social context (as landscape architecture), but also to make it public in events, such as Oerol, to discuss its value in an open debate (*validation* of reality). This induces a second round of interpretation and reflection, that demonstrates the explorative reasoning that Lee associated with design. It can also be seen as a different road to understanding, *to explain BwN in societal terms* – a feature of science.

What evolves from these observations is that BwN, as an approach, does not function on the basis of dividing disciplines. They all showcase a degree of hybridity in their approach, whether in their multi-, inter-, or trans-disciplinarity, or through the overlaps of their different knowledge domains.

3. Convergences for BwN as an interdisciplinary field

'Convergence' is the deep integration of knowledge, techniques, and expertise from multiple fields to form expanded and (perhaps) new frameworks for addressing scientific and societal challenges and opportunities (NSF, 2016). Ultimately, convergence is a process that aims to streamline different types of knowledge into consensus on the true nature of particular challenges and how they should be dealt with effectively. When looking at the directions of development in the chapters, we can recognise four frontiers for the convergence of knowledge as takeaways for the future development of BwN: the merging of models; expanding the frame of reference; human inclusion, and the integrative role of design.

Merging models

In the Models-section, a shared understanding seems to emerge on how the existing models of sub-systems can be merged in order to get a closer representation of the reality of BwN ('Landscape Model', 'Beach-dune Modelling'). This understanding was established by the merging of existing models for subsystems that were created within the discipline of coastal engineering into a 'seamless' landscape model, but also by demonstrating how different the resulting decisions are when ecosystem values are over or underestimated ('Eco-system benefits'). This not only enables engineering to assess the impact of interventions to other subsystems, but also to represent and project BwN processes within their context, as an important tool for spatial design. Vice versa, within the process of spatial design, valuable testing grounds become apparent, that can be validated by modelling. Ultimately integrated models help to fill the gap between specialist knowledge, spatial design, and decision-making as complementary parts of the process.

Expanding the frame of reference for Building with Nature

A second, less obvious convergence is demonstrated through the perceived benefits of Building with Nature. This is a tangible shift towards an acknowledgement of both the contextual and cultural dimensions of Building with Nature – induced by design practice. However, implementation demonstrated that even with dual objectives, Building with Nature interventions have consequences for elements of the overall coastal system that were not considered. Such consequences – in particular the perception and recreational use – could complicate or improve a new generation of Building with Nature-projects. Managing the existing 'frame of reference' for BwN was the challenge for the 'Assessment of effectiveness', 'Ecosystem-Benefits' and 'Scale-resolving'-contributions.

Human inclusion

Several contributions point out a knowledge gap in BwN regarding the effects of human occupation in nature-based solutions. As Wijnberg et al. (2020) have put it: "A clear mismatch arises from the absence of buildings and human activities in current numerical models simulating morphological developments". This is the missing step in the modelling for integrated BwN-solutions that serve the interests of nature, flood protection, and society at large. The true nature of BwN is thus more than a matter of understanding different natural processes – as human behavior interferes with these processes, and thus makes the performance of BwN less predictable.

Secondly, for broader societal acceptance, BwN solutions need to develop from technical artifact to a new generation of coastal landscapes, including its cultural layer; as pointed out by 'Building with Landscape' and 'Pioneering Sand Motor'. This requires a separate dialogue and process for the technique to be perceived and integrated in society. The interdisciplinary understanding of Building with Nature seems to be that, while existing BwN projects perform rather well (their secondary objectives in particular), human occupation patterns, perception, and use are vital, yet non-operationalised elements, that can determine Building with Nature's future success.

The integrative role of design

Overall, the design and art contributions have emphasised the contextual and cultural dimension of Building with Nature. This contextualisation also features in the contributions from Science, albeit less prominently. Strikingly, 'contextualisation' of Building with Nature was also observed as a product of the engineering roles in collaborative design-processes ('Engineering roles').

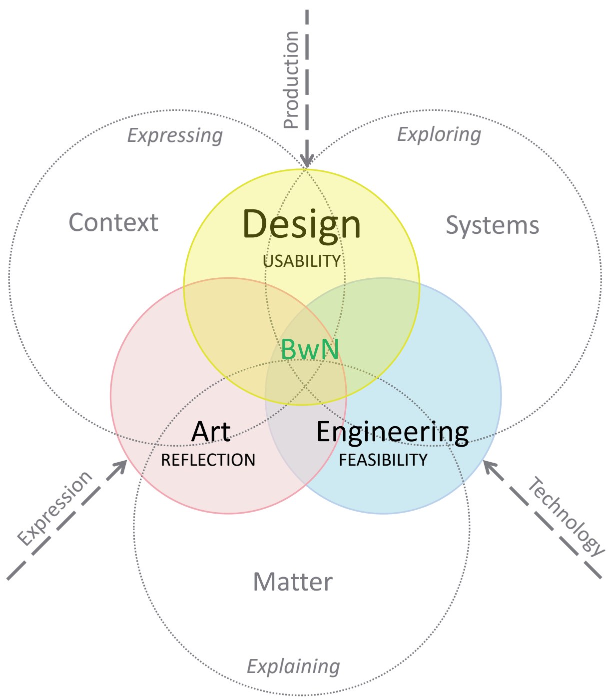

Figure 4. Integrated design as an *exploratory* discipline, connecting with both art as an *expressive* discipline, and science as an *explanatory* discipline (after Lee, 2011).

Looking in particular at 'Urban Dunes', it appears that design can expand the scope of our understanding, in this case combining the functionality of urban development with Building with Nature approaches. 'Urban Dunes' has also offered a point of departure to operationalise human occupation patterns in Building with Nature-models. In 'On-site installations', the engagement of cultural values and therefore the harmonisation of coastal protection and public approval, is promised (though no empirical evidence is given). Possibly, through its applied nature ('to change reality'), design can also provide a bridge between science on the one hand and society on the other. By translating and incorporating dispersed specialist technologies into spatial solutions, it opens up BwN to a wider context, and simultaneously provides a contextual and social feedback loop to science, such as the development of waterfronts. The integrative capacity of spatial design will enrich our understanding of BwN since contextual and societal values are added to the scope.

To conclude, the field of practical sciences demonstrates a wide range of approaches geared towards converging knowledge production and application. Several contributions exist where 'understanding reality' is developed beyond a single, universal explanation that can be verified simply as true of false. For example, 'BwN as integrated infrastructure', 'Engineering roles', and 'Odum's dark bottle' all aim to explain BwN by re-interpretation of former knowledge. They seek to change our understanding via an explorative narrative, in search of new values that redefine BwN. 'Building with Landscape', (land-) art projects are used as input to learn about man's perception of (Building with) Nature, while in 'BwN in landscape practise', design-projects are used for a similar purpose. They demonstrate the new layers of understanding BwN to enrich our quest for sustainable coastal landscapes. Science, after all, does not have the monopoly on knowledge.

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Building with Nature perspectives

Cross-disciplinary BwN approaches in coastal regions

This publication offers cross-disciplinary perspectives for Building with Nature (BwN) as an approach for the design and engineering of resilient coastal landscapes. The key philosophy of BwN is the employment of natural processes to serve societal goals, such as flood safety. The starting point is a systems-based approach, making interventions that use the natural system's shaping forces to perform measures by self-regulation. With the project Sand Motor in South Holland as a prime example, the BwN approach has evolved into the next generation of nature-based hydraulic solutions, such as coastal reefs and green dikes, to become a new dynamic, spatial strategy for coastal regions. This publication addresses the main drivers and critical factors for embedding BwN in its physical and societal context while integrating knowledge to offer more than the sum of its separate solutions. This new way of cross-disciplinary thinking and designing in BwN is illustrated by a series of actual projects and research from spatial design, infrastructure, modelling and ecology perspectives.

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