BUILDING WITH NATURE

Thinking, acting and interacting differently

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EcoShape

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Cover photo Kite surfer at the Delfland Sand Engine in the Netherlands (2012).
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FOREWORD

Deltas and coastal zones around the world are rapidly becoming the focus of urbanization and economic development. By 2050 roughly half the world's population will be living in cities in such areas. The same areas harbour ecosystems that are massively important from both an economic and an ecological perspective and are essential for our food supply. These facts alone make the sustainable socio-economic development of deltas and coastal zones a challenge.

The changing global climate puts additional pressure on what is already a challenging situation. How do we deal with sea level rise, with shifts in the discharges of river systems, with subsidence and drought, and with the interactions between climate and built-up areas, such as heat stress and runoff? How do we deal with salinization and guarantee adequate water supplies?

For the Netherlands, finding answers to these questions is a matter of survival. This is why we have the Delta Programme, anchored in a special law, the Delta Act, with two objectives: to guarantee our water safety and adequate water supplies. This long-term programme has been devised to deal with an uncertain future. The direction of change is clear, but its magnitude is not. That is why we need to look for flexible solutions, to do what is necessary, but to avoid over-investment. And we want our solutions to be integrated and sustainable, to make sure our investments in water safety and water supply as much as possible also serve additional interests, while taking into account their impact on our environment.

Building with Nature is a concept that perfectly fits that approach. Where possible we strive to reach our objectives by making use of natural processes, creating integrated solutions that are flexible, that help to safeguard our economy and boost our ecology, that are both cost effective and sustainable, and that make our country safer and more attractive as a place to live.

The need for such solutions was recognized at an early stage and led to the formation of a consortium in which government, knowledge institutions and private enterprises joined forces, building a unique network of expertise to expand our knowledge of how this concept can be developed and realized in projects. This is the Ecoshape consortium. The present book is the result of this unique cooperation. It gives some striking examples of various environments in which the concept of Building with Nature can be applied.

As government commissioner for the Delta Programme in the Netherlands, I attach great value to this innovative concept as a contribution to the safe and sustainable development of not only the Dutch delta, but of deltas and coastal areas around the world. It is therefore with great pleasure that I recommend this book to you.

Wim J. Kuijken
Government commissioner for the Delta Programme in the Netherlands

CONTENTS

Experimental sand nourishment on the Galgeplaat, an intertidal shoal in the Eastern Scheldt estuary

THE ECOSHAPE CONSORTIUM

The Building with Nature innovation programme is carried out by EcoShape, a consortium of private partners, government agencies and knowledge institutes operating at the nexus between nature, engineering and society.

New challenges associated with urbanization, economic development, sea level rise, subsidence and climate change demand an innovative approach to hydraulic engineering that aligns the interests of economic development with care for the environment. Building with Nature responds to this demand: working with natural systems in such a way that meets the need for infrastructure while creating opportunities for nature (see page 9). To demonstrate that the approach works, the €30 million Building with Nature innovation programme (2008–2012) was initiated by two major Dutch dredging companies, Royal Boskalis Westminster and Van Oord, and is carried out by the EcoShape consortium.

THE ECOSHAPE CONSORTIUM

The EcoShape consortium consists of partners in the private sector, such as dredging contractors (Boskalis, Van Oord and the Dutch Association of Dredging Companies), equipment suppliers (IHC Merwede) and engineering consultants (ARCADIS, Royal HaskoningDHV and Witteveen+Bos); the public sector, such as government agencies (Ministry of Infrastructure and the Environment) and local authorities (Municipality of Dordrecht); and applied research institutes (Alterra, Deltares and the Institute for Marine Resources & Ecosystem Studies, IMARES), universities (Delft University of Technology, the University of Twente and Wageningen University) and research institutes (Royal Netherlands Institute for Sea Research, NIOZ). The Building with Nature programme is co-funded by the partners, with subsidies from the Ministry of Infrastructure and the Environment, the European Regional Development Fund and the Municipality of Dordrecht, and support from strategic partners such as the Port of Rotterdam (see page 38). The partners operate jointly under the name EcoShape, a foundation in law that administers and represents the programme.

Experts and scientists from the partners executing the programme have a wide variety of backgrounds, disciplines and reference frames. Having a common office has enabled them to develop a common language and culture, and to communicate across disciplines and organizations, even though the latter are sometimes competitors in the market. Consistent investments in the collaboration have created an atmosphere of trust, mutual respect and solidarity. The EcoShape team has been a critical factor in the success the programme.

PROGRAMME OBJECTIVES

Based on experiences from past and ongoing hydraulic engineering projects with a building-with-nature signature, the EcoShape partners have defined an interdisciplinary programme with the following objectives:

- *Gathering and developing knowledge of ecosystems that enable water-related Building with Nature.* The programme aims to fill the gaps in our knowledge of the dynamic interactions between biotic and abiotic ecosystem components, ecosystem responses to human activities, and ways to deal with uncertainties and multi-stakeholder decision-making processes.
- *Developing scientifically based and location-specific design rules and environmental norms.* For want of a better approach, authorities responsible for engineering projects sometimes impose rules and norms copied from other projects in quite different environments. Tuning those rules and norms to specific locations will yield approaches that fit better with the local environment.
- *Developing expertise in applying the Building with Nature concept.* The programme is translating the scientific knowledge acquired into practical information and tools in order to improve the skills and experience of users to a level that will enable appropriate applications.
- *Demonstrating that Building with Nature solutions work, with practical examples.* The programme is building up a portfolio of Building with Nature solutions in hydraulic engineering projects that will serve as a source of inspiration for future designs.
- *Finding out how we can ensure that the Building with Nature concept is adopted by society.* Many societal factors influence whether or not a solution is adopted. The programme aims to understand how this process works and how we can best act in order to ensure that Building with Nature alternatives are seriously considered in project development.

THE APPROACH

The Building with Nature programme has adopted a learning-by-doing approach by contributing to or initiating (pilot) projects in five environments: sandy shores, estuaries, tropical coastal seas, shallow shelf seas and deltas lakes. Prior to each project, the EcoShape partners observe the ecosystem processes and suggest innovative designs for each phase. After implementation, the partners participate in the monitoring process and in the analysis and interpretation of the data gathered. In parallel, relevant knowledge gaps are being addressed by 19 PhD projects, each of which is coupled with at least one ongoing (pilot) project in order to link their work to practice. As a final step, the partners are making a significant effort to ensure that the acquired knowledge contributes to practice via the Building with Nature Design Guidelines (see page 36).

OUTCOMES

The programme has yielded several significant outcomes. The fruitful and open collaboration between the consortium partners has led to the creation of a vibrant interdisciplinary network of experts and scientists and a rich source of innovative design ideas. The pilot experiments described in this book have shown that sustainable, multifunctional and adaptive solutions to infrastructure problems in environmentally sensitive areas really do work. The approach enables governments to cope with future societal and environmental change and opens new market perspectives. The most important outcome, however, is the programme's contribution to aligning the interests of economic development and care for the environment.


BUITEN-BEELD / HH

BUILDING WITH NATURE

In their search for sustainable hydraulic engineering solutions, the Dutch engineers, ecologists and social scientists that form the EcoShape consortium are moving away from building *in* nature towards building *with* nature.

More than half of humanity lives in urban areas located near rivers, deltas or coastal areas. As the world's population grows and prosperity levels rise, so too will the demand for goods (food, energy, merchandise) and services (transportation, accessibility, safety). Accommodating this growth will involve the development of hydraulic infrastructure, such as harbours, access channels, land reclamation and flood defences. Sea level rise and climate change are reinforcing the urgent need for adaptable designs. At the same time, people need space for recreation – beaches, parks and waterfronts – which generates its own special demands on spatial and infrastructure planning. These developments need to be realized in often fragile environments that are under constant pressure.

Sustainable development is crucial if we are to maintain river, delta and coastal environments around the world, and the ecosystem services they provide that are essential for humankind. They include provisioning services, related to the supplies of food and other products; regulatory services, related to natural processes such as water purification and flood control; and cultural services, related to recreational, spiritual and other non-material benefits that people derive from nature. Finally, they offer support services that are necessary for the delivery of all other ecosystem services, but may not benefit humans directly, such as nutrient cycling, water storage, regulation and recharging, as well as wildlife habitats, nesting sites and foraging grounds.

Balancing the sustainable functioning of ecosystems on the one hand, with the demand for their development and use on the other, is one of the greatest challenges for the future of humankind.

BUILDING WITH NATURE DESIGNS

It is crucial that we learn to design infrastructure that can serve more than just one purpose, that is aligned with natural processes rather than working against them, and that is adaptable to cope with changing conditions such as sea level rise and climate change. Traditional approaches focus on minimizing the negative impacts of envisaged infrastructure projects (building *in* nature) and compensating for any residual negative effects (building *of* nature). As a next step beyond these 'reactive' approaches, Building *with* Nature aims to be proactive, utilizing natural processes and providing opportunities for nature as part of the infrastructure development process.

The challenge to accommodate the needs of nature and other stakeholders into new project designs is an essential element of the Building with Nature approach. 'In the past, project developers focused almost exclusively on the primary function, such as protection against flooding', says Huib de Vriend, scientific director of Building with Nature. 'The new approach challenges designers to combine flood defences with nature development and/or creating opportunities for other functions, such as recreation or housing. It is essential that the primary function of infrastructure be aligned with the interests of both nature and stakeholders, in order to arrive at sustainable and socially acceptable solutions'.

ADAPTABLE SOLUTIONS

Since the 1980s, Dutch pioneers such as Honzo Svašek and Ronald Waterman have experimented with the idea of using the dynamics of natural systems to create new land and opportunities for nature and recreation. The Building with Nature programme has adopted these ideas, developed them further and extended them to broader areas of application. The use of adaptable solutions allows society to respond gradually to changing circumstances such as sea level rise and climate change. The typical building blocks of such adaptable solutions are salt marshes, sand nourishments and ecosystem engineers, as presented in the following chapters.

A traditional response to sea level rise, for example, is to strengthen coastal defences and to build higher dikes. These kinds of projects have a given design lifetime and are constructed all at once, based on an agreed scenario of design conditions. The Building with Nature approach promotes the consideration of more gradually developing solutions. Especially when used in combination with traditional, proven technologies, this approach can lead to cheaper and more aesthetically appealing solutions that adjust or can be adjusted to changing circumstances.

ACTIVE STAKEHOLDER INVOLVEMENT

Water-related infrastructure projects are likely to affect the interests of a variety of stakeholders, especially in densely populated areas. Building with Nature also means building with society. 'Stakeholder involvement is important for two reasons', says Mark van Koningsveld, senior engineer at Van Oord Dredging and Marine Contractors and leader of the Building with Nature Design Guidelines and data management sub-programmes. 'First, traditional infrastructure projects often encounter growing resistance from people who will be affected. It is easy to dismiss such resistance as the "not in my backyard", or NIMBY syndrome, but project developers have to realize that they are interfering with these people's social habitats. Second, local people know a lot about the area where they live, and their tacit knowledge can be very useful for understanding natural systems and processes, and how they will interact with man-made structures. Stakeholder involvement can inspire surprising new solutions.'

IT IS CRUCIAL THAT INFRASTRUCTURE PROJECT DESIGNS ARE ALIGNED WITH NATURAL PROCESSES

Involving the public provides valuable insights into local systems and processes, and so is more likely to lead to better solutions that stakeholders are more likely to accept. Rather than opposing ideas that have been precooked in some faraway 'ivory tower', people take ownership of projects and even promote them.

▼ Shore nourishment by rainbowing

▼ Filling gabions with oyster shells

▼ Abundant life on a tropical coral reef

‘Projects work a lot better if they take into account the interests of stakeholders rather than ignore them’, says De Vriend.

GOVERNANCE PROCESSES

All Building with Nature projects have to comply with existing legislation, regulations and procedures. If they do not, obtaining the necessary permits may be problematic and more traditional alternatives may be chosen in the tendering process. Obtaining permits may involve explaining the envisaged benefits to regulators. In several cases such discussions have been critical in being granted permits for pilot experiments or even full-scale projects.

Because Building with Nature is also building with society, governance is an important aspect of every project. ‘We have to approach governance the same way as we approach an ecosystem’, explains De Vriend. ‘That means we have to figure out how the system works, and who are the important players.’ Van Koningsveld describes this process as ‘backward mapping’: ‘Building hydraulic infrastructure means intervening in both natural and social systems. We have to peel away the layers of the onion to identify all the processes and arenas that might lead to acceptance or refusal of a project approach. Backward mapping is the most effective way to do this: start with the final project decision, and then map backwards in time to understand all the steps that will be required to arrive at that decision. This helps to identify and connect to relevant arenas and actors at the right time.’

DEALING WITH UNCERTAINTIES

Neither natural nor social systems can be made to change course by pushing a button. In fact their responses to interventions involve many uncertainties. An important aspect of Building with Nature (and society) is finding ways to deal with them. For example, if part of the protection of a coastal area involves planting willows it might be a good idea to plant different varieties to reduce the probability that one plant disease wipes out the entire shore protection.

▲ Sand mining in the North Sea

▲ A shallow foreshore of the IJsselmeer

‘Building with Nature forces us take a step back, rethink the problem and analyze the natural and social systems involved’, says Gerard van Raalte, senior engineer at Royal Boskalis Westminster and (together with Van Koningsveld) leader of the Building with Nature Design Guidelines sub-programme. ‘Together with the stakeholders we try to explore and evaluate the options. Only then can we start thinking about a solution. Compared with traditional approaches, this calls for the three fundamental changes: to think, act and interact differently.’

OUTLINE OF THIS BOOK

This book presents five examples of Building with Nature projects in which infrastructure developments have been aligned with the natural systems within which they have been built. The projects have been designed to utilize natural processes and provide opportunities for nature to develop.

The Delfland Sand Engine was designed to make use of the power of winds and currents to help protect part of the Holland coast, while encouraging the development of new dunes and the valuable flora and fauna associated with them (page 13). A similar project with sand engines to revitalize the wetlands of the IJsselmeer demonstrated that the active involvement of stakeholders is essential (page 28). In the Eastern Scheldt estuary, oysters are being used as ‘ecosystem engineers’ to prevent the further erosion of the tidal flats locally (page 16). Using new methods of marine construction, the aim is not just to reduce the environmental impacts of hydraulic engineering projects, but also to promote marine and coastal ecosystems and biodiversity (pages 21 and 25).

Individuals not directly involved with the execution of the projects offer their perspectives on the Building with Nature programme as a catalyst of innovation (page 33). Finally, for readers whose curiosity has been aroused, the last chapter outlines the Building with Nature Design Guidelines derived from the projects.

The Delfland Sand Engine was designed to use wind and currents to protect part of the Holland coast, shown here at low tide in autumn 2011, three months after completion

BEELDBANK RIJKSWATERSTAAT

EXPANDED HORIZONS

The Delfland Sand Engine project is exploring the benefits of sand nourishments concentrated in space and time. Initial results indicate that this strategy is effective in countering coastal erosion, while providing opportunities for nature and recreation.

The Holland Coast is part of the 350 km long North Sea coast of the Netherlands. For centuries, its beaches and dunes have protected the low-lying hinterland, including the Randstad, the country's economic heartland. At the same time, the sandy shores of the Holland Coast have been eroding as a result of the combined effects of diminishing supplies of river sediments, ongoing land subsidence and rising sea level. Left unchecked, such erosion will seriously threaten the flood protection and other functions of the coastal system. Finding effective ways to counter this structural erosion is an urgent priority for Dutch policy makers.

Traditional coastal management in the Netherlands has focused on protecting the hinterland against flooding, and has led to an impressive system of 'hard' sea defences such as dikes and embankments. In 1990 the scope of national policy was widened to include measures to counter structural erosion. The preferred method of intervention was, and still is, to nourish the coast at regular intervals with small volumes of sand dredged from the North Sea. The total volume of sand needed for these nourishments has steadily increased, from 6 million m^3 in 1990 to over 12 million m^3 per year since 2001.

In 2008 the Delta Commission, a body set up by the government to consider ways to ensure flood protection and water supplies in times of accelerated sea level rise and climate change, recommended extending coastal nourishment. For such schemes, experts anticipate that 40–85 million m^3 of sand per year will be needed by 2100, depending on the actual rate of sea level rise. The use of such large volumes of sand has led to questions about how these nourishment schemes might provide other benefits in the future, perhaps by creating areas for nature and recreation, as well as countering coastal retreat.

CONCENTRATED NOURISHMENTS

The Building with Nature concept has inspired the development of a new coastal maintenance strategy: concentrated nourishments. The idea is to deposit a significant stock of sand in one location, which is then gradually redistributed across and along the shore by the wind and waves. By making use of natural processes to redistribute the sand, this innovative approach aims to limit the disturbance of local ecosystems, while also providing new areas for nature and recreation.

Concentrated nourishments are seen as a sustainable way to compensate for the erosion of sandy shores. 'Traditional nourishment schemes have involved depositing small volumes of sand, and covering ecosystems on the seabed every 4–5 years', says Stefan Aarninkhof, senior engineer at Royal Boskalis Westminster and member of the EcoShape management team. 'But with concentrated nourishments, either the footprint is smaller, or the frequency of disturbance is lower, or both. While the sediment is being redistributed, there are virtually no indirect effects on coastal ecosystems, as benthic organisms are able to adapt to gradual changes in seabed topography'.

Concentrated nourishments may vary in size and shape, depending on site-specific factors such as national coastal policy, established practice and the availability of sand. They may range from relatively small, regular pulse nourishments (see box below) to sudden mega-nourishments with a design lifespan of several decades. The largest application of this concept so far is the Delfland Sand Engine on the Holland Coast.

THE DELFLAND SAND ENGINE HAS BECOME A FOCAL POINT FOR COASTAL RESEARCH AND INNOVATIVE COASTAL MANAGEMENT

THE DELFLAND SAND ENGINE

The design of the Sand Engine project (see box, page 15) was driven by a number of considerations, including the morphology of the shoreline and the local ecology. Based on the anticipated rate of erosion along the coast over the project's 20-year design lifespan, it was calculated that a volume of 21.5 million m^3 of sand would need to be deposited offshore. The shape of the nourishment was inspired by the potential of the coast to provide areas for nature and recreation. It was decided to create a hook-shaped peninsula that would provide resting areas for seals at the end of the spit, with a shallow lagoon that would offer habitats for flatfish. Part of the sand would be transported onshore, promoting the development of pioneer dunes, with associated vegetation, along the beach. And, in anticipation of the scientific and public interest the project was likely to generate, the design also included a platform for a visitor centre and an observation tower.

Work on the Sand Engine was completed in mid-2011, and preliminary monitoring results show that so far it is behaving as predicted. Sediment is indeed being transported along the coast, seals have been visiting the area and a rare plant species, the frosted orache (*Atriplex laciniata*), has been found growing on a newly formed juvenile dune. Also, the Sand Engine has proved to be a hotspot for wind, wave and kite surfers.

As expected, the sandy hook soon began to bend and extend towards the shore, leaving a narrow feeder channel for the lagoon parallel to the beach. The channel generated very strong currents, however, and in turn reports in the local media highlighting the potential risk to swimmers. 'The actual behaviour of the system, including the development of the feeder channel, was as predicted', says Jasper Fiselier, a water management professional at Royal HaskoningDHV and member of the Building with Nature team, who prepared the EIA report. 'What was not expected,

Pulse nourishments

Pulse nourishment involves the frequent introduction of relatively small volumes of sand in the surf zone, in order to maintain an eroding shoreline. The idea is that once placed in the highly dynamic surf zone, the sand is rapidly absorbed into the coastal system. The footprint of such nourishments is small, thus minimizing ecological impacts. The effectiveness of this nourishment strategy was confirmed in a recent pilot experiment on the Holland coast, where three sand groynes were constructed, each with a volume of some 200,000 m^3. Initial monitoring has shown that the groynes rapidly turned into sandy capes, and that virtually all the sediment was retained in the upper part of the shoreface. This means that the interval between these nourishments can be longer than those of shoreface nourishments of a similar size, where only some 50% of the sand comes onshore. Moreover, the sandy capes attract recreational users such as kite surfers. We can conclude that this concept allows for the development of innovative, cost-effective coastal maintenance strategies, with minimal stress on local ecosystems and a positive effect on recreation.

An unprecedented experiment

The Delfland Sand Engine is a pilot project to assess the effectiveness of concentrated nourishments in protecting the coast of the Netherlands. In this unprecedented experiment, involving the introduction of 21.5 million m^3 of sand rising up to 7 m above mean sea level, the sand is distributed by natural processes over the shoreface, beach and dunes. The Sand Engine is seen as a climate-robust and environment-friendly means of countering coastal erosion, while the (temporary) presence of surplus sand also creates new areas for nature and recreation. Since the project was completed in 2011, the Sand Engine has been closely monitored and will be the subject of extensive long-term research to document and assess its natural evolution, and to translate this experience into generic knowledge that will be applicable elsewhere.

however, was the reaction in the media, which had initially hailed the Sand Engine as an icon of innovative coastal engineering and a bonus for coastal recreation. For the project team, this turnaround highlighted the importance of managing expectations and maintaining open communication with stakeholders. It reminded us that the partners must remain involved throughout the project, but especially during the transition phases from project design, to construction, to project operation and maintenance.'

A FOCAL POINT

From the early days, the Sand Engine experiment has been a collaborative effort between public authorities, private companies and research institutes. As a result, the Sand Engine has become a focal point for coastal research and innovative coastal management. Over the next five years, the project will be closely monitored and, with funding from the Ministry of Infrastructure and the Environment, the European Regional Development Fund, the Dutch Technology Foundation STW and EcoShape, extensive research programmes have been defined that will include detailed studies of the evolution of the Sand Engine and the driving mechanisms behind it – physical, ecological as well as social.

The Building with Nature programme will incorporate the findings of these studies into its open-access Design Guidelines, which will contribute to the design and implementation of similar projects in the Netherlands and elsewhere in the future. 'Many countries around the world are now having to deal with coastal erosion', says Aarninkhof. 'By translating our findings into generic principles and practical guidelines, we hope to pass on our knowledge and experience so that others can benefit.'

GUIDELINES AND TOOLS

Based on the results of the Delfland Sand Engine experiment, the Building with Nature programme has developed:

- practical guidelines for the design and implementation of coastal maintenance projects;
- tools for the rapid assessment of optimal locations, as well as the volume, frequency and shape of nourishments;
- detailed simulation models to predict their morphological evolution over time, the process of dune formation and the environmental impacts;
- lessons learned, including the potential of concentrated nourishments to improve coastal protection, while also providing opportunities for nature and recreation; and
- advice on the important issue of governance, such as how to identify (and involve) all relevant stakeholders and to ensure the participation of public, private and academic partners.

PROJECT DETAILS

PROJECT: Delfland Sand Engine (Netherlands)
OBJECTIVES: Ensuring long-term coastal safety, promoting nature development and recreation, and testing innovative methods of coastal nourishment
LOCATION: Ter Heijde, Province of South Holland
INITIATORS: Ministry of Infrastructure and the Environment/Rijkswaterstaat, Province of South Holland
INSTITUTES INVOLVED: IMARES, Deltares, Delft University of Technology, Wageningen University and Research Centre, Royal HaskoningDHV, Van Oord, Boskalis
DIMENSIONS/VOLUMES: 21.5 million m^3 of sand. Initial area 100 ha, goal 35 ha of new beach/dunes after 20 years
STAKEHOLDERS: Rijkswaterstaat, Province of South-Holland, Delta Programme, Dutch Lifeguard Association, WWF, Association of Regional Water Authorities, the Dutch water sector (research institutes, universities, consultants, contractors)
PROJECT PERIOD: Construction period March 2011 to March 2012
HIGHLIGHTS: Average construction speed (production): 1.1 million m^3/week, about 6 truckloads per minute. Already the best surf spot in the Netherlands

An oyster reef in the Eastern Scheldt estuary will dissipate wave energy and trap sediment in its landward side, halting the erosion of the tidal flats locally

ARIE KIEVIT / HH

Using oyster reefs to protect tidal flats in estuaries

NATURE'S ENGINEERS

Tidal flats provide a variety of ecosystem services. Driven by climate change and human activities, however, erosion is now a common phenomenon. Experiments in the Eastern Scheldt estuary show that oyster reefs can mitigate tidal flat erosion while creating new habitats.

The Eastern Scheldt estuary in the Netherlands is part of the delta created by the rivers Rhine, Meuse and Scheldt. Since the mid-1980s, the estuary has been heavily affected by engineering works. A half-open storm surge barrier now separates the estuary from the sea, while on the landward side a series of dams have effectively closed off several rivers and thus the inflow of freshwater.

The barrier has diminished both the tidal prism and the average velocity of the tidal current in the estuary by about a third. As a result, the channels within the estuary are now deeper and wider than is needed to accommodate the reduced current and tend to fill in with sediment. This, and the altered hydrodynamics within the estuary, has led to the gradual erosion of the tidal flats. Eventually, without intervention, large areas of these flats, and the ecosystem services they provide, will be lost. Not only are tidal flats valuable, diverse and productive habitats, but, equally important, they also dissipate wave energy, and so help to protect the hinterland from flooding.

EASTERN SCHELDT ESTUARY

Now a national park, the estuary is an important foraging area for a variety of wading birds, and is part of Natura 2000, a network of nature protection areas across the European Union. Located near the densely populated Randstad, the economic heart of the Netherlands, the estuary is a popular area for recreational activities such as sailing, birdwatching, scuba diving and fishing. Due to the good water quality, the Eastern Scheldt is an important area for the commercial production of shellfish such as mussels and oysters.

If coastal protection were the only function of the tidal flats, then raising or strengthening the dikes behind them could compensate for their erosion. But the Building with Nature programme takes a broader perspective. 'We look for ways to ensure the safety of the hinterland and to promote the productivity and biodiversity of the estuary at the same time', says Anneke Hibma, a senior engineer at Van Oord Dredging and Marine Contractors and member of the EcoShape management team.

The storm surge barrier will continue to drive morphological changes in the estuary for a long time to come, but the tidal flats should be preserved. There is little experience with protecting tidal flats from erosion, so researchers from the EcoShape partnership are conducting a number of pilot projects in the estuary.

One experiment, in an area of the estuary called the Galgeplaat, involves sand nourishment to a shoal or sandbank (see box, page 19). To monitor ecological development, EcoShape installed a self-sustaining autonomous Argus-Bio monitoring station. The station uses six video cameras to provide continuous data on the presence and behaviour of benthic species, birds and seals on the shoal, and any changes that occur. It can also provide insights into the processes of flooding and drying of shoals and morphological changes at crucial times such as during storm events.

EXPERIMENTS IN THE EASTERN SCHELDT HAVE DEMONSTRATED THAT IT IS FEASIBLE TO USE OYSTERS AS ECOSYSTEM ENGINEERS

Another experiment, the shellfish reef pilot project, aims to prevent sand being transported into the tidal channels by using reef-forming shellfish as 'ecosystem engineers' (see box below). The project is using the Pacific oyster (*Crassostrea gigas*), a species introduced to the Netherlands by fishermen in the 1960s.

'The Pacific oyster builds three-dimensional reef structures that are effective in dissipating wave energy and protecting the underlying sediment from erosion', explains Tom Ysebaert, a marine ecologist at the Institute for Marine Resources and Ecosystem Studies (IMARES) and the Royal Netherlands Institute for Sea Research (NIOZ) and leader of Building with Nature's estuaries sub-programme. 'Nature has shown that shellfish reefs are strong enough to withstand the power of storm winds and waves.'

REEF GROWING

To 'grow' a reef, a substrate of (dead) oyster shells is placed on the tidal flat. To prevent the shells being washed away with the tide or during storms, they are stowed in boxes made of steel wire known as gabions. In the summer oyster larvae – which need a hard substrate on which to grow – attach themselves to the shells and gradually build up a solid reef structure that is able to withstand winds and waves.

Once the oysters have established themselves, the steel wires of the gabion corrode away, after which the reef will have to survive on its own, constantly renewing itself by attracting new larvae. 'We don't know yet how long these reefs will survive', says Ysebaert, 'but some of the natural oyster reefs in the Eastern Scheldt are at least 30 years old'.

The first experimental reefs, placed in position in 2009, were rather small, just 10 by 4 metres. In 2010 three larger reefs were constructed, each 200 metres long and 8–10 metres wide. The first monitoring results show that the reefs are functioning as intended, but their effects on the local environment differ. Oyster larvae are attaching themselves to the shells and are developing into adult oysters. The reefs are preventing erosion in those parts of the flats in their 'shadow'. In one case, there has been no erosion at all in the area protected by the reef, compared with about 2–3 cm erosion per year in unprotected parts of the estuary. The reefs are also causing local sedimentation as predicted. However, at least one of the reefs in a very


ARTERRA PICTURE LIBRARY / ALAMY

◀ The Pacific oyster (*Crassostrea gigas*) was introduced to the Netherlands in the 1960s when a severe winter almost wiped out the native European flat oyster

Ecosystem engineers

Species whose structures or activities are able to modify the local physical environment are referred to as ecosystem engineers. Assemblages of such species, including oyster reefs, salt marshes and mangroves, can be effectively used to enhance coastal protection. Oysters transform soft sediments into hard, complex 3D structures that modify the near-bed water flow and dissipate wave energy, thereby influencing the dynamics of sediment transport and settlement near the bed. Oyster reefs deliver several other ecosystem services, such as water filtration, and the provision of habitats. The biogenic structures formed by the oyster aggregations offer habitats for dense assemblages of invertebrate species, as well as shelter and foraging grounds for juvenile fish and crustaceans. Oyster reefs are among the most diverse marine habitats.

Sand nourishment

The Galgeplaat is a large tidal flat in the Eastern Scheldt, with a surface area of 950 hectares. Since 1985, when the storm surge barrier was built, the equilibrium between sedimentation and erosion has been disturbed. The Galgeplaat has already lost an area of about 50 hectares and its average height has decreased by more than 30 cm.

As an experiment, in 2008 an area of about 20 hectares of the Galgeplaat was nourished with over 130,000 m^3 of sand, using new methods to reduce turbidity during dredging and deposition. The idea was that the wind and waves would slowly spread the sand so that the surrounding ecosystems on or near the bed would be disturbed as little as possible. In practice, most of the sand indeed remained in place, and the benthic ecosystem has now largely recovered.

exposed area is trapping a lot of sand, which might hamper the development of established oysters.

LOCAL CONCERNS

The project is also testing ways to address local concerns that the reefs might interfere with vested interests of various stakeholders. Commercial shellfish growers feared that the oysters in the artificial reefs might compete for food with other species in the estuary, at the expense of their own shellfish beds. The project team hopes to alleviate their concern by showing that the oysters in the artificial reefs consume a negligible part of the food available in the estuary. If tens of kilometres of artificial reefs were to be added, however, an evaluation of their effects on overall food stocks will have to be reconsidered.

Humans do have a taste for Pacific oysters, but harvesting them might reduce the effectiveness of the reef to protect against erosion. There are other harvesting options, however, that enable the reefs to contribute to the local economy as well. One commercial shellfish grower is experimenting with spat collectors, i.e. long nylon tubes ('socks') filled with mussel shells on which oyster larvae can settle. Once the oysters are established, the collectors are taken to culture plots where the spats can grow to maturity.

It is early days yet, but the experiments in the Eastern Scheldt have demonstrated that the use of oysters as ecosystem engineers for erosion prevention is feasible, both technically and biologically. It also seems socially acceptable – at least to the shellfish growers in the estuary.

The projects in the Eastern Scheldt have shown that highly dynamic environments such as estuaries, where interlinked physical processes are at work, offer exciting opportunities to build with nature.

GUIDELINES AND TOOLS

The successful application of solutions of this kind in other locations requires, apart from the necessary know-how, accurate knowledge of the workings of the local social, physical and ecological systems. Based on preliminary results of the field experiments in the Eastern Scheldt, the Building with Nature programme has developed the following generic and freely accessible products:

- practical guidelines on the design, construction and placement of artificial oyster reefs;
- an easy-to-use tool for assessing locations where such reefs can be placed, together with a rapid assessment tool for selecting appropriate areas for sand nourishment; and
- lessons learned from the experiments on the natural recolonization of tidal flats following nourishment.

PROJECT DETAILS

PROJECT: Pilot Ecosystem Engineers and Tidal Flat Nourishment (Netherlands)
OBJECTIVES: Testing of mitigating measures for tidal flat erosion
LOCATION: Eastern Scheldt estuary
INITIATORS: EcoShape, Ministry of Infrastructure and the Environment/Rijkswaterstaat
INSTITUTES INVOLVED: IMARES, NIOZ, Deltares, Delft University of Technology
DIMENSIONS/VOLUMES: Reefs: gabions filled with oyster shells (230 tonnes in total). Three reefs, each 200 × 10 × 0.3 m. Nourishment: 130,000 m^3 of sand over 20 ha (height 0.6–0.7 m)
STAKEHOLDERS: Ministry of Infrastructure and the Environment/Rijkswaterstaat, Province of Zeeland, shellfisheries, nature organizations
PROJECT PERIOD: Reefs: 2009 and 2010; nourishment: 2008
HIGHLIGHTS: Hands-on experience in the construction of shellfish reefs. Eco-morphological development of nourishment monitored using Argus-Bio cameras

Sometimes referred to as 'walking trees', mangroves are a natural way to stabilize tropical coastlines while providing rich habitats for many species

TOM STACK / ALAMY

DIVERSITY AT WORK

Economic development should strengthen tropical coastal ecosystems such as coral reefs, seagrass meadows and mangrove forests. Adopting a Building with Nature approach can help to preserve, restore or even enhance the ecosystem services they provide.

Marine infrastructure developments such as harbours and flood defences are essential for economic growth and coastal protection. In tropical regions, these developments often take place near sensitive marine ecosystems that provide many valuable services (see box, page 22). As well as supporting diverse flora and fauna, these ecosystems provide natural coastal protection by dissipating wave energy and by trapping and stabilizing sediment. Developing marine infrastructure while strengthening these ecosystems is a major challenge for densely populated areas in the tropics such as Singapore.

In its push for economic development, the island state of Singapore has embarked on an extensive programme of land reclamation that has increased its area by almost 20%. At the same time, many coastal ecosystems, such as coral reefs, seagrass meadows and mangroves, have declined or even disappeared, triggering an awareness of the need to ensure healthy ecosystems and sustainable development.

ECOSYSTEM-BASED MANAGEMENT

'The state of Singapore is now very much aware of both the importance and the vulnerability of their coastal ecosystems', says Claire Jeuken, senior adviser at Deltares and leader of the Singapore sub-programme of Building with Nature. 'To prevent further damage to the environment, the government has introduced strict regulations covering the design and construction of marine infrastructure projects.'

A cornerstone of the Building with Nature approach involves detailed analyses of physical, ecological and social systems. Such studies are essential not only in the temperate regions where most of the programme's pilot projects are located, but also in tropical areas like Singapore, which is the focus of Building with Nature's tropical sub-programme. In tropical coastal waters, the analyses involve assessments of how coral reefs, seagrass meadows and mangroves respond to changes in turbidity and sedimentation. Once the effects of such changes are estimated, it is possible to adjust both the design of a project and its execution. 'The idea is to move away from an emission- or source-based system to one based on impacts', says Jeuken. 'That means focusing on the health of the ecosystem rather than on the amount of silt present.'

The Building with Nature project team, which includes researchers from the National University of Singapore, is keen to encourage a shift towards such an impact-based approach. 'The challenge is to identify and develop relevant biological early warning indicators to assess the status and health of the ecosystem during and after marine construction operations. Such bio-indicators (see box, page 23) can then be used to adjust the construction process to ensure the well-being of the ecosystem', Jeuken explains. 'Dredging operations, for example, are often required to comply with rigid limits on the turbidity they produce. It is possible, however, that exceeding such limits temporarily is not harmful to an ecosystem, as long as it does not continue for too long. But if the ecosystem is exposed for too long to sediment concentrations below the limit, this can have disproportionately serious effects and may even alter its sensitivity to short-term concentration pulses.'

CORAL REEFS, SEAGRASS MEADOWS AND MANGROVE FORESTS MAY OFFER NATURAL AND EFFECTIVE WAYS TO PREVENT COASTAL EROSION IN THE TROPICS

Insights into the site-specific responses and thresholds of corals and seagrass to pulses in turbidity and sedimentation, and to what extent those responses depend on earlier sensitization, are essential to enable impact-based design and management of dredging operations. The researchers have carried out field and laboratory experiments with seagrass and corals to identify and quantify these relationships, and have begun a one-year project to monitor changes in physical and ecological conditions at three coral reefs off the Singapore coast.

Once site-specific thresholds for turbidity and sedimentation have been established for an ecosystem and the ambient hydrodynamic and sediment conditions are known, it will be possible to design a dredging operation so that it has minimal environmental impact. For this purpose, the team has developed a generic Interactive Dredging Tool to assist in the design and evaluation of dredging operations.

MULTIFUNCTIONAL COASTAL PROTECTION

Protecting ecosystems by adaptive management of construction operations is just one side of the story. The other focuses on how to encourage the development and use of these ecosystems to provide multifunctional coastal protection. Coral reefs, seagrass meadows and mangroves, either alone or in combination, may offer natural and effective ways to prevent coastal erosion, as well as to enhance other ecosystem services such as water filtration and opportunities for fisheries and recreation.

Designing such ecosystem-based coastal protection is far from straightforward, because ecosystems need specific conditions in order to successfully establish and survive. Seagrasses, for example, need soft substrates, adequate sunlight and relatively sheltered conditions, whereas coral larvae require hard substrates as well as sunlight. The challenge is to identify which of these conditions are missing and how they can be created in the design.

To demonstrate the applicability of the Building with Nature concept in tropical environments, the team has launched a pilot project to design a multifunctional coastal protection scheme in the East Coast Park area of Singapore. Created on reclaimed land, with an artificial beach to meet the increasing demand for

Enriching hard structures

Quay walls, breakwaters, piers, jetties and other 'hard' structures offer opportunities for Building with Nature solutions. Existing structures may not have been designed to provide habitats for marine species, but can be altered during maintenance or upgrading, such as by retrofitting special tiles that provide a variety of habitats.

The design parameters for enhancing hard structures, new or existing, include the shape and slope of the structure, the choice of materials and their porosity. The limiting factors include temperature, irradiation, hydrodynamic forcing (tidal range and currents), exposure to waves, the scale of the structure and the biodiversity of surrounding ecosystems. The design can provide habitats for specific species, or be optimized to benefit the ecosystem surrounding the structure.

Bio-indicators

The environmental limits on dredging operations are sometimes rather indiscriminate. For example, if turbidity levels exceed a given threshold, dredging either has to stop or mitigating measures have to be taken such as limiting the allowable overflow time. Rather than focusing on one source of potential impact, efforts should be guided by the resilience of the local ecosystem.

Developing impact-based rules requires biological indicators that provide information about the health and resilience of an ecosystem. For seagrass meadows, for example, a lengthening of the leaves indicates too little sunlight penetration, possibly due to turbidity. Other bio-indicators may include the disappearance of one or more key species or a change in the composition of a marine community. Some rapidly responding bio-indicators might be used to adapt the dredging process in real time. For coral reefs, a good candidate might be the concentration of metabolites in the mucus produced by coral polyps. When a reef is under stress, the composition of the mucus changes almost immediately, and that change can be measured.

recreation space, this area of the coast is threatened by erosion, and the extent of seagrass beds and coral reefs offshore is limited. The envisaged design solution should alleviate the coastal erosion, enhance the potential for recreation and strengthen biodiversity, while also taking into account the proximity of busy shipping lanes and housing developments.

'Obviously, rehabilitating an ecosystem may take a long time, even in the tropics', says Tjeerd Bouma, a senior scientist at the Netherlands Institute for Sea Research (NIOZ) who is involved in the tropical sub-programme. 'Once suitable conditions have been created, it is necessary to consider whether there is enough time to allow the ecosystem to develop naturally, or whether it is necessary to lend a hand, for instance by planting suitable plant species. The answer will depend on the support for either of these options within society.'

HABITAT-PROMOTING TILES

In a densely populated area such as Singapore, it is not always possible to use natural ecosystems for coastal protection. If there is not enough space for such ecosystems, for instance, hard structures such as seawalls or breakwaters may be used. Normally, relatively few marine species colonize these structures, but it might be possible to make them more attractive by providing for a variety of microhabitats. To test this idea, the researchers attached a variety of habitat-promoting tiles to two seawalls.

Preliminary studies have shown that the assemblages of species that colonize the tiles vary considerably depending on the design, with some attracting more than twice as many species as control samples. This finding demonstrates that smart designs can promote biodiversity. The researchers have now developed software for designing tiles of varying complexity, a key factor for biodiversity on hard substrates.

GUIDELINES AND TOOLS

The Singapore project team has generalized the experiences and preliminary findings from the field experiments, and has developed:

- a rapid assessment tool (the Interactive Dredging Tool) to investigate how far turbidity plumes from dredging operations spread through the coastal system and impact sensitive species;
- guidelines on the habitat requirements of corals, seagrass and mangroves derived from the literature and the results of laboratory experiments; and
- software to help design tiles that can be mounted on seawalls and other hard structures to promote biodiversity.


CORBIS

PROJECT DETAILS

PROJECT: Field, Laboratory and Design Experiments for Eco-friendly Solutions (Singapore)
OBJECTIVES: Experimenting with biodiversity-promoting ecotiles; generating information on the sensitivity of corals, seagrass and mangroves to turbidity; and testing Building with Nature erosion-mitigating designs for East Coast Park
LOCATION: Singapore (P. Hantu, Kusu, Raffles, St. John, Sungei Buloh Reserve, Tanah Merah Terminal and East Coast Park)
INITIATORS: EcoShape, in collaboration with the National University of Singapore (SDWA and TMSI research institutes and NUS Marine Biology Laboratory)
INSTITUTES INVOLVED: Deltares, IMARES, NIOZ, NUS SDWA, NUS TMSI
DIMENSIONS/VOLUMES: 96 eco-tiles installed (40 × 40 cm, eight surface designs) between P. Hantu and Kusu; two coral reef monitoring locations (Raffles and P. Hantu); one mangrove monitoring location (Sungei Buloh); 15 seagrass shading nets (each 1 m^2; Tanah Merah); protection concept for 15 km of coast along East Coast Park containing 80+ hard structures
STAKEHOLDERS: National parks, MPA, HDB, BCA, NEA, PUB, and the Singapore marine sector
PROJECT PERIOD: 2010–2012
HIGHLIGHTS: Unique dataset compiled on the responses of marine species to duration and intensity of turbidity exposure

Jumbo hopper dredgers at work landscaping a borrow area in the North Sea – the Dutch extracted 200 million m^3 of sand for phase I of the extension of Rotterdam harbour

Encouraging recolonization with smart designs

SEABED LANDSCAPING

The extraction of sand and gravel from the seabed of coastal seas temporarily wipes out the local benthic ecosystem. Seabed landscaping is a way to create a variety of habitats that encourage rapid recolonization and possibly higher biodiversity and productivity.

The sandy bed of the North Sea, an example of a shallow coastal sea, features a variety of large-scale undulations, or bedforms, typically up to about 10 metres high. Large, relatively stable tidal ridges, with crests several kilometres apart, are oriented almost parallel to the prevailing tidal currents. There are also smaller sand waves, hundreds of metres apart, aligned perpendicular to the currents. These sand waves are mobile, and move slowly (up to 10 metres per year) across the seabed.

The variations in the height of these ridges and sand waves, as well as in the size of sand grains and hydrodynamic conditions on and near them, create a variety of habitats with a high biodiversity and productivity. These sandy habitats are home to fish species such as plaice and sole, as well as shellfish, worms and other seabed dwellers that protect themselves by burrowing in the sand. They feed on organic material captured in the sediment or filter their food from the water.

The seven countries surrounding the North Sea utilize its waters for a variety of economic activities, including fisheries and shipping, and more recently energy production (wind turbines, oil and gas platforms) and the associated cables and pipelines. For the Netherlands in particular, the bed of the North Sea is also a vital source of sand and gravel.

DYNAMIC PRESERVATION

In 1990 the Dutch government adopted a policy of ‘dynamic preservation’, identifying sand nourishment as the preferred means to maintain the sandy coast and counter coastal erosion. The Dutch currently extract about 12 million m^3 of sand from the North Sea each year for coastal nourishment.
Over the period 1890–2008 relative sea level in the Netherlands rose at a steady rate of 1.8–2.0 mm per year. ‘If this relative sea level rise continues in the future, an additional 7 million m^3 of sand per year will be needed for every extra millimetre’, says Stefan Aarninkhof, senior engineer at Royal Boskalis Westminster and member of the EcoShape management team.

Apart from the 12 million m^3 of sand used for coastal maintenance, a further 13 million m^3 are extracted each year for use by the building industry. The sand is dredged from designated offshore extraction pits, known as ‘borrow’ sites, where the water must be at least 20 metres deep in order to avoid disturbing the nearshore sediment balance. Until recently, the depth of these extraction pits was not allowed to exceed

2 metres below the seabed, to prevent the water becoming stratified and depriving plant and animal communities on or near the seabed of oxygen.

Since 2008 the demand for North Sea sand has multiplied as a result the construction of Maasvlakte 2, a project to extend Rotterdam harbour, in which 2000 hectares of land will be reclaimed from the sea. In the five years to 2013, a total of 240 million m^3 of sand will be needed. To limit the area that will be disturbed it was decided that the depth of the extraction pits could be extended to 20 metres below the seabed. For the Building with Nature programme, the question was how to encourage the recolonization, and promote productivity and biodiversity of such deep extraction pits.

INSIDE THE LANDSCAPED BORROW AREA WE NOW FIND FOUR TO FIVE TIMES MORE FISH, AND MORE SPECIES, THAN OUTSIDE IT

SEABED LANDSCAPING

Traditionally, dredging operators would extract sand, leaving the floor of the pit relatively flat. However, a flat seascape does not encourage biodiversity. Natural bedforms (see box, left) feature gradual changes in terms of water depth, grain size, mud content and surrounding currents, thus providing a variety of habitats for diverse marine species. It was therefore decided to test the hypothesis that local seabed landscaping would help to speed up the process of recolonization, and promote higher biodiversity and productivity.

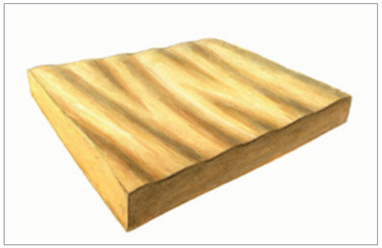
The experiment involved selective dredging, leaving behind two sand ridges in the designated borrow area for Maasvlakte 2. These artificial bedforms are about 700 m long and 100 metres wide with crests 10 metres high, similar to natural sand waves. The first ridge was created in 2010 in the eastern part of the borrow area, and the second in 2011 in the southern part (see box, page 27).

The recolonization of the Maasvlakte 2 borrow area has been monitored since 2010. 'Inside the pit we actually find four to five times more fish, and more species, than outside it', says Martin Baptist, a marine ecologist at the Institute for Marine Resources and Ecosystem Studies (IMARES) and leader of Building with Nature's monitoring sub-programme. 'We now want to know whether this is because of the seabed landscaping within the pit, or the presence of the pit itself. From the data obtained so far we conclude that the largest assemblages of fish are found near the artificially created bedforms.'

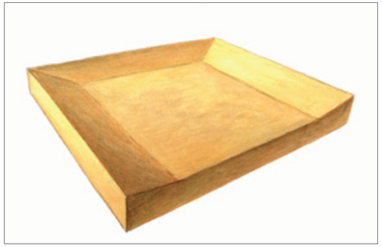
Underwater landscaping

In addition to the landscaping of borrow areas, which involves working with loose, sandy substrates, there are other opportunities for underwater landscaping in coastal seas. The number of offshore wind farms has increased rapidly in recent years, amid considerable opposition for fear of negative impacts. But preliminary studies indicate that wind farms can have positive effects on the environment and wildlife. Rocks are often placed around the base of wind turbines to prevent scouring. Both have been found to function as artificial reefs, attracting new species of bottom-dwelling fish such as cod.

Marine mammals such as porpoises appear to seek shelter within wind farms, where fishing vessels are not allowed to operate. The effects on birds have been mixed, with wind farms attracting some species while deterring others. These positive impacts of offshore wind farms were generally not anticipated in the original designs, although most aimed to minimize potentially negative effects (building *in* nature). Initial monitoring results suggest that such positive effects could be maximized if they were to be considered in the planning and design process from the start (building *with* nature).



▲ Areas of the seabed with natural sand waves have been found to be ecologically richer than more uniform areas



▲ After sand mining, the borrow areas used to be left relatively flat, discouraging the process of recolonization.

▲ Building with Nature is experimenting with selective dredging, leaving artificial sand ridges in the borrow areas

Environment-friendly sand mining

Within the Maasvlakte 2 project, an important aspect of the experiment with seabed landscaping concerned the alignment of the artificial ridges and troughs. The crest of one of the ridges is aligned east–west, perpendicular to the direction of the tidal current in the North Sea, and another runs parallel to it. Natural sand waves are always perpendicular to the tidal currents, while tidal ridges are almost parallel to it. For dredging companies, it is easier and cheaper to create bedforms that run parallel to the current. By considering the impacts of both orientations in the experiment, it will be possible to assess how to combine the environmental benefits of seabed landscaping with the most cost-effective construction methods.

GOVERNANCE

In any infrastructure project, the complexity of the legal framework is often proportional to the number of stakeholders involved. This rule of thumb certainly applies to coastal waters where there are many different, sometimes conflicting interests, ranging from nature and fisheries conservation, to coastal protection and the need for open shipping lanes. The designated borrow areas for Maasvlakte 2 are covered by a maze of national policies and regulations, EU directives and guidelines, and international conventions, all of which have to be taken into account when applying for a permit for a sand extraction pit, even an ecologically attractive one.

In the case of the experimental sand mining pit, matters were even more complicated as it would be carried out as part of the Maasvlakte 2 project. The permit for the project was time-limited, so there was no room for delays in either completing the legal processes or carrying out the work. 'That meant we had to discuss our plans in detail with the many different stakeholders in order to ensure that the experiment was completed within the permit period', says Aarninkhof.

The contractors, Royal Boskalis Westminster and Van Oord, needed to prove that the area to be landscaped would be morphologically stable. Moreover, they would have to avoid complex bed shapes as these might affect the construction schedule for Maasvlakte 2, and hence the costs. The Port of Rotterdam added an extra requirement that the seabed landscaping operation should fit seamlessly into the ongoing land reclamation process. Because of that, the contractors and the Port of Rotterdam were involved early in the design and planning phase. 'The governance of the project demanded a lot of attention', says Aarninkhof, 'but in the end we managed to align the interests of all the stakeholders.'

GUIDELINES AND TOOLS

The Building with Nature programme has generalized the experiences and results of the seabed landscaping experiment within the Maasvlakte 2 project, and has developed:

- practical guidelines on the selection of locations, design and construction of landscaped borrow pits;
- numerical models to predict the behaviour of bedforms and the stability of the sand banks created;
- lessons learned regarding the necessary conditions for habitat development and the natural recolonization of underwater landscapes after construction; and
- advice on the important issue of governance, such as identifying and contacting relevant stakeholders and drawing up an inventory of relevant policies and legal issues that need to be addressed.

PROJECT DETAILS

PROJECT: Landscaping in Sand Extraction Area (Netherlands)
OBJECTIVES: Promoting recolonization of sand extraction pits using innovative landscaping
LOCATION: North Sea, 20 km offshore from the Port of Rotterdam
INITIATORS: EcoShape, PUMA consortium
INSTITUTES INVOLVED: IMARES, Deltares, University of Twente, Royal HaskoningDHV, Boskalis, Van Oord
DIMENSIONS/VOLUMES: Two ridges, each 10 m high, 700 m long
STAKEHOLDERS: Port of Rotterdam, PUMA, Ministry of Infrastructure and the Environment/Rijkswaterstaat, the Dutch water sector (research institutes, universities, consultants, contractors)
PROJECT PERIOD: 2010–2011 (construction)
HIGHLIGHTS: Post-construction monitoring (benthos/fish sampling) has revealed five times more fish in the landscaped area

The wetlands along the shores of the IJsselmeer help to protect low-lying Friesland from flooding while supporting rich and diverse ecosystems

BUITEN-BEELD / HH

ENGINES OF CHANGE

National responses to sea level rise will require decisions that may prove unpopular at the community level. By bringing together national, regional and local stakeholders, the Building with Nature approach can raise awareness and open up windows of opportunity for innovative solutions.

The management of large freshwater lakes in low-lying areas such as deltas is often complex, involving controlling the water level and minimizing the impacts of pollution caused by nutrient runoff, including algal blooms, on lake ecosystems. It also involves maintaining hard structures, such as dikes and harbours, as well as reducing the risk of storm-induced water level surges that may threaten communities and economically or ecologically important areas along the lakeshore.

These issues have long been the subject of discussion for the IJsselmeer, a large delta lake in the Netherlands, created in 1932 when the Zuiderzee was closed off from the sea. In 2008 the Delta Commission, set up by the government to consider ways to adapt to sea level rise and climate change, proposed gradually raising the water level of the IJsselmeer by up to 150 cm by 2100. This would be necessary, the commission advised, to allow the level of the lake to rise with the sea level, and thus to maintain the capacity to discharge surplus water to the sea.

Communities around the lake were taken aback by the prospect that the flood defences surrounding the IJsselmeer would have to be raised or replaced. Doing so would have major impacts on the towns and villages along its shores, and would also threaten many of the wetlands between the lake and the dikes.

But the proposal prompted municipalities and local inhabitants to look at these areas from a fresh perspective. ‘They realized they had ignored the wetlands for too long, and that they needed to do something to protect them for the future’, says Kris Lulofs, a water management expert at the University of Twente and leader of Building with Nature’s governance sub-programme. ‘They looked at various methods that could be used to protect and revitalize the lakeshore, and became aware of the idea of a sand engine.’

SAND ENGINES

Raising the water level of the IJsselmeer would inundate areas that are part of Natura 2000, a network of nature conservation sites across the European Union. But this is only permissible, according to European legislation, if there are compelling reasons to do so and if the loss of wetland habitats is compensated for elsewhere. The areas in question cover thousands of hectares, according to Erik van Slobbe, senior researcher at Wageningen University and leader of Building with Nature’s IJsselmeer sub-programme. In such a small and densely

Delta lakes under threat

The IJsselmeer and many other delta lakes – such as Lake Pontchartrain near New Orleans, USA, the Etang de Berre near Marseille, France, and Lake Tai in the Yangtze River delta in China – are ecological hotspots, but they are susceptible to algal blooms, turbidity and water quality degradation. They are also threatened by human interference, such as flood control, harbour development, land reclamation and water extraction. Usually the focus has been on optimizing one of these functions, while minimizing potentially negative impacts on wildlife habitats and other natural resources.

Disconnecting salt water lakes from the sea, as in the Netherlands, can eliminate threats such as storm surges, but it does not prevent nutrient runoff from agricultural land into the lake, increasing the likelihood of algal blooms. New regulations on water quality and nature conservation have improved the situation in recent years, but many lakes remain under pressure. The challenge is to find a balance between human demands and preserving the integrity of lake ecosystems, in order to maintain ecosystem services they provide in the long run.

THE PROJECTS PROVED INSTRUMENTAL IN RESTORING THE RELATIONS BETWEEN THE VARIOUS LEVELS OF GOVERNMENT

populated country it would not be easy to compensate for the loss of such a large area.

A sand engine involves depositing a large volume of sand near the shore, which is then gradually brought onshore by winds, waves (and in winter ice). The idea of applying the sand engine concept in the IJsselmeer was developed by the Atelier Friesland, a think-tank organized by the province of Friesland that included representatives of all levels of government involved.

Sand engines in the IJsselmeer would be used to reinforce and revitalize the wetlands along the eastern shore through sand nourishment. Today, the wetlands protect the dikes surrounding the lake by dissipating wave energy, and support diverse riparian ecosystems. Raising the level of the lake would certainly flood the wetlands, destroying those functions. But in the meantime, the experimental sand engine projects could be used to find out whether, and to what extent, the wetlands would be able to grow in step with the rising water level.

Three such projects were defined and discussed with the local authorities and stakeholders. The projects proved instrumental in restoring the relations between the various levels of government, but they were also used to extend the political playing field. 'By broadening the issue', says Lulofs, 'we were able to create more room for solutions to emerge.'

EXPERIMENTS

In 2011, once the necessary permits had been obtained, 20,000 m³ of sand were deposited 200 metres off the Workumerwaard nature reserve and bird sanctuary, one of the many natural wetland areas on the eastern shore of the lake. Vegetation in this area is losing diversity and vitality, and the experiment aimed to see if the sand engine would help to revitalize it. Observations show that so far the movement of sand onshore has been rather slow, although the process was accelerated by the action of ice piling up during the harsh winter in February 2012. It is too early to judge whether the experiment has been a success.

A second sand engine is planned near Oudemirdum, another nature reserve bounded by a dike. The aim here is to investigate whether a sandy foreshore can help to protect the dike when the water level rises or fluctuates. There have been some complaints from people living near the lake, however. 'This is not only building with nature, but also with society', says Van Slobbe. 'So if people oppose our experiments, we won't proceed. We don't want to force our ideas onto people, but we do hope to convince them with good arguments.' In this case, the people were convinced and the nourishment is expected to begin before the end of 2012.

▼ Workshop on sediment management between various Building with Nature projects in the Markermeer, the Netherlands

Sand engines in shallow lakes

Sand engines are created by dredging sand from the lake floor or seabed, depositing it a short distance from the shore and allowing the wind and waves (and sometimes ice) to transport it to the area to be nourished. Unlike the Delfland Sand Engine on the North Sea coast (see page 13), those in the IJsselmeer are less exposed to waves, although they may experience significant storm-induced water level surges. This explains why the rate of onshore sand migration in the IJsselmeer is much lower than in the case of Delfland.

'The aim of the experiments in the IJsselmeer is to examine how sand is transported,' says Erik van Slobbe, 'and how nature reacts to the gradual supply of sand – which pioneer species establish themselves and how ecosystems evolve.' The success of the sand engines will depend on the dynamics of waves and currents. If the system is insufficiently dynamic the sand will remain in place. If the wind and waves are strong enough to move the sand, but onshore transport mechanisms are weak, the sand may simply disperse and have little effect.

A third sand engine was intended to compensate for beach erosion near the village of Hindeloopen, but here the local people could not be convinced, as they feared it would silt up the entrance to the yacht harbour. 'There was a risk', says Van Slobbe, 'and we could not prove it was manageable. So we concluded that the sand should not be deposited. Instead, we agreed to build a computer model of sand transport along the coast and conduct virtual experiments to assess the risk.'

GOVERNANCE

As the Hindeloopen example demonstrates, aligning the interests of the authorities, stakeholders and the public is critical to getting Building with Nature projects implemented. It involves far more than obtaining the necessary permits; that is only the last step in a process that can take years.

Decision making in the Netherlands takes place at three levels: the authorities (national, provincial and municipal), project initiators (government agencies, NGOs and the private sector) and the local level, where communities have their say in a project. For the Ijsselmeer projects, experts from the various authorities and the partners involved in project development discussed the options and identified where further research was needed. But in the cases of Oudemirdum and Hindeloopen, the project initiators at first paid too little attention to the concerns of local stakeholders, and it was only when they were invited to participate in the planning and design processes that the projects could proceed.

The IJsselmeer sand engine projects show that local stakeholders' interests must be carefully considered in the design as well as in the execution of Building with Nature interventions. Rather than presenting predetermined technical designs, project developers need to work together with stakeholders, in a process of co-creation.

GUIDELINES AND LESSONS LEARNED

The IJsselmeer sand engine projects, although still in their early stages, have yielded practical information that has been incorporated into the Building with Nature Design Guidelines, including:

- technical aspects of small-scale sand engines in shallow lakes;
- the physics and ecology of shallow lake shores;
- systems analysis and preparations for lake shore nourishments;
- the governance of projects in complex administrative environments; and
- innovative monitoring of sand displacement in lakes.

PROJECT DETAILS

PROJECT: Sand Motors IJsselmeer (Netherlands)
OBJECTIVES: Testing adaptive approaches to lakeshores with changing water levels; understanding adaptive governance
LOCATION: IJsselmeer – Workumerwaard and Oudemirdumerklif
INITIATIATORS: It Fryske Gea, Natural Climate Buffer Coalition, Province of Fryslân (Friesland), Water Board of Fryslân, Ministry of Infrastructure and the Environment/ Rijkswaterstaat, EcoShape.
INSTITUTES INVOLVED: Alterra, Deltares, University of Twente, Wageningen University, ARCADIS, Witteveen+Bos
DIMENSIONS/VOLUMES: Workumerwaard: 20,000 m^3 of sand, Oudemirdumerklif: 20,000 m^3 of sand
STAKEHOLDERS: Nature reserve management; provincial, municipal and water management authorities; recreational entrepreneurs; local inhabitants; lake management
PROJECT PERIOD: Workumerwaard: constructed 2011; Oudemirdumerklif: planned end 2012
HIGHLIGHTS: Morphodynamics mainly driven by storm events and ice movement. Innovative measurement technique using fibre optics.

OUTSIDE PERSPECTIVES

The EcoShape partners have shown how the Building with Nature concept can be applied in practice. Here, executives of the partner organizations and individuals not directly involved with the projects share their views of the programme as a source of innovation.

Initiated by the private sector, the Building with Nature innovation programme is a unique experience of collaboration between people with a wide variety of backgrounds, disciplines and frames of reference. This is felt so by those actively involved in the execution of the programme, but also by stakeholders at some distance from the daily work.

‘At the start of the programme, Building with Nature was primarily an innovative idea. With the involvement of the private partners and their practical inputs, we have been able to develop the Building with Nature concept and to demonstrate what it means in practice’, says Henk Nieboer, director of Witteveen+Bos and member of EcoShape’s Usability Review Board. ‘It has been quite inspiring that people from such varying backgrounds could spend so much time together working on this topic. The resulting network has been an enormous benefit, enabling us to quickly establish effective multidisciplinary teams whenever a complicated tender or project requires us to do so.’

Getting Building with Nature ideas implemented in practice requires presenting them to the relevant decision makers in the right form and at the right time in the project realization process. For any actor, whether an individual, a research institute, a private company or an non-governmental organization, it is often difficult to get innovative ideas integrated early enough in the process. Now that EcoShape is gradually being accepted as an impartial, independent sounding board or contributor of ideas, it can help to ensure that sustainable alternatives are introduced as early as possible in the decision-making process.

A CATALYST OF INNOVATION

EcoShape has played a role as a catalyst of innovation in several situations in the Netherlands. It was involved as a sounding board in the Delfland Sand Engine project, and provided inputs to the Delta Programme on the inclusion of Building with Nature elements in flood defence systems. At the request of the Port of Rotterdam, EcoShape organized a brainstorming meeting to generate Building with Nature ideas for widening Rotterdam’s Amazonehaven seaport.

EcoShape not only plays a catalyzing role as a consortium, but it also supports its individual partners to identify sustainable project alternatives. ‘We actively promote the implementation of Building with Nature findings in our daily practice, in both national and international projects’, say

A driving force for innovation

J. William Kamphuis, emeritus professor at Queen's University, Kingston, Ontario and chair of EcoShape's Usability Review Board

'Building with Nature is a unique example of how universities and applied research institutes can develop new knowledge in direct contact with end users. Discussing new findings and practical applications can trigger extremely fruitful and enriching two-way interactions, compared with the usual one-way flow of knowledge. The programme's emphasis on innovation rather than research alone encourages a focus on usability and the rapid dissemination of results.

A strong point is the programme's ongoing efforts to document and share the research findings. The OpenEarth system for sharing data, models and tools (www.openearth.nl), co-developed by EcoShape, is a great step forward, as is EcoShape's wiki-based Building with Nature Design Guidelines (www.ecoshape.nl), where all the programme's lessons learned are shared and updated. Both OpenEarth and the wiki-based guidelines will outlive the Building with Nature programme and will continue to be a driving force for innovation, exchange and collaboration for years to come. The programme has set an example that is worthy of broader follow-up.'

◀ Trapping dune sand with marram grass: a traditional Building with Nature method of coastal maintenance

THERE IS A POTENTIAL FOR BUILDING WITH NATURE TO DEVELOP INTO A BROAD INTERNATIONAL MOVEMENT

Pieter van Oord, CEO of Van Oord, and Peter Berdowski, CEO of Royal Boskalis Westminster.

'Our proactive approach has resulted in innovative designs that have been realized, such as in the construction of underwater diving reefs in dike reinforcement projects along the Eastern Scheldt estuary in the Netherlands', says Pieter van Oord. 'Also, the adaptive approaches for dredging in sensitive areas, developed in Building with Nature, have been included in recent tenders for major projects in Australia, such as the nearshore works for the Ichthys liquefied natural gas terminal in Darwin, which Van Oord is currently executing. The Australian environmental criteria for marine construction projects are arguably among the strictest in the world. It is good to see that the approaches developed by EcoShape, combined with our in-house experience, have made a difference there.'

The Building with Nature approach has also benefitted Boskalis, says Peter Berdowski. 'In the Noordwaard project in the Rhine delta, Boskalis is implementing a large riverbank realignment project aimed at offsetting the effects of severe rainfall and high water levels. As part of the "Room for the River" programme, Boskalis has introduced an innovative wave-attenuating willow foreshore as a Building with Nature measure that avoids the need to raise a certain dike. It is an exciting new approach, and the project has drawn a lot of positive public attention. An international project where proposing a Building with Nature approach has helped us make a difference is the Falmouth cruise ship terminal in Jamaica. Here, smart project design in combination with an extensive coral transplantation programme has helped to preserve a valuable sensitive habitat while enabling economic development, both of which are important for Jamaica.'

Van Oord and Berdowski agree that these successful projects demonstrate that Building with Nature offers opportunities for future market development. 'We anticipate that the environmental engineering elements of our projects will become more prominent in the future.'

ECOSYSTEMS AND INFRASTRUCTURE

Operating at the interface between ecosystems and infrastructure, Building with Nature usually means going beyond the state-of-the-art in project design. This triggers new questions to which there are no clear-cut answers. Whereas previously the design of sand nourishments focused on accretion and erosion, Building with Nature coastal nourishment designs prompt additional questions, such as how long it is likely to take for ecosystems to recover or for new ones to become established. Similarly, Building with Nature designs using hard materials, such as rubble or concrete, trigger questions not only regarding the stability of structures, but also about habitat development.

'The concept of Building with Nature is inspiring for the new generation of ecological researchers investigating what positive impact on nature can be achieved by ecological engineering', says Martin Scholten, general director of the Animal Sciences Group and IMARES, both part of the Wageningen University and Research Centre. 'Wageningen University and Research and Delft University of Technology are now collaborating to integrate Building with Nature into their curricula. A first step has been taken by jointly developing a course on ecoshaped aquaculture, for both Wageningen and Delft students.'

'It is good to see that the research done in Building with Nature is beginning to influence a wider research agenda', says Marcel Stive, professor of hydraulic engineering at Delft University of Technology. 'In July 2012, for example, the Dutch Technology Foundation STW awarded funding for NatureCoast, an integrated research programme that will focus on questions that emerge from the Delfland Sand Engine project. The programme will involve researchers from a wide range of disciplines and institutes, who will translate their knowledge into practice with the help of EcoShape.'

A golden triangle

Jan Hendrik Dronkers, Director General, Rijkswaterstaat

'Innovation in civil engineering infrastructure development is high on the agenda of the Rijkswaterstaat, the executive arm of the Netherlands Ministry of Infrastructure and the Environment, which is responsible for the design, construction, management and maintenance of the country's water infrastructure. We therefore welcome think tanks like EcoShape for their clever and environmentally friendly ideas.

We do have in-house think tanks addressing issues of this kind, but EcoShape and the Building with Nature programme are unique because of the active involvement of private partners with practical experience in infrastructure development. In fact, this network is a perfect example of the so-called "golden triangle": the joined forces of government, private parties and knowledge institutes as partners collaborating to generate and promote innovation.

Rijkswaterstaat would like to play a role in promoting the ideas developed in Building with Nature, and has entered into a trilateral agreement with EcoShape and the Association of Regional Water Authorities. A continuation of the Building with Nature programme would enable this agreement to be fully exploited.'

TOWARDS AN INTERNATIONAL MOVEMENT

'The Netherlands is not the only country where the concept of working with nature in infrastructure development is receiving attention', says Harry Baayen, director of Deltares and chair of EcoShape's board of governors. 'The World Association for Waterborne Transport Infrastructure (PIANC) advocates the Working with Nature concept, which is much in line with that of Building with Nature. The US Army Corps of Engineers is developing the Engineering with Nature concept, which focuses on the nature-friendly use of dredged material from waterway maintenance. The UK has adopted a strategy of Managed Coastal Retreat, which aims to reduce the pressure on flood defences by creating more space for floodwater. Many other initiatives are now applying the Building with Nature concept, albeit without explicitly using that label.

▲ Coastal nourishments such as the Delfland Sand Engine can have positive effects on recreation

'Such initiatives indicate that there is a potential for Building with Nature to develop into a broad international movement, promoting a different way of thinking, acting and interacting in water-related infrastructure development. EcoShape's wiki-based Building with Nature Design Guidelines provide an ideal platform for collecting and sharing knowledge and expertise, enabling us to build on previous efforts.'

Developing a shared repository of tools and lessons learned

GUIDELINES FOR DESIGN

The Building with Nature Design Guidelines offer practical information and tools for developers and users of hydraulic engineering projects on ways to use ecosystem services and provide opportunities for nature.

The Building with Nature concept challenges project developers, designers and users to think differently, act differently and interact differently. 'Each project provides a unique opportunity to induce positive change. Building with Nature principles, which can be introduced in any phase of any project, may help to achieve this', say Mark van Koningsveld (Van Oord) and Gerard van Raalte (Boskalis), co-leaders of the Building with Nature Design Guidelines sub-programme. 'The previous chapters have described projects that have been realized with the help of the Building with Nature innovation programme. The many lessons learned from these projects have been collected in the Building with Nature Design Guidelines, which are accessible via the EcoShape website: *www.ecoshape.nl*.'

The guidelines are targeted at two groups of readers:

- *Individuals responsible for the development, design, realisation and operation of hydraulic engineering projects*, including project owners/proponents, ecologists, engineers, consultants, water-related infrastructure contractors, etc.
- *Individuals or organizations that can potentially influence the criteria applicable to a project and can challenge the first group*, including national and local authorities, policy makers, politicians, administrators, standards institutes, NGOs, financiers, etc.

THE GUIDELINES

The guidelines start by introducing the Building with Nature philosophy, and then describe the main design principles and the five general design steps that are invariably involved, usually in a cyclical process, in generating Building with Nature project designs:

- Step 1: Understand the system (including ecosystem services, values and interests).
- Step 2: Identify realistic alternatives that use and/or provide ecosystem services.
- Step 3: Evaluate the qualities of each alternative and preselect an integral solution.
- Step 4: Fine-tune the selected solution (practical restrictions and the governance context).
- Step 5: Prepare the solution for implementation in the next project phase.

The process of putting these general design steps into practice may be approached from the following three perspectives:

The natural environment perspective
In any project, a good starting point to look for Building with Nature opportunities is the natural environment or ecosystem in which the project is to be embedded. The guidelines currently describe five environments: sandy shores, estuaries, tropical coastal seas, shallow shelf seas and delta lakes. Users entering the guidelines via this route should first consider which of these environments most closely resembles the one in which they are working. Each environment is unique, with its own characteristics, related ecosystem services and associated opportunities.

The project perspective
Each phase of a project represents an important trigger for considering Building with Nature opportunities. The guidelines provide specific advice for each of the following project phases: initiation, planning and design, construction, and operation and maintenance. Users entering the guidelines via this route should first consider the phase of the project realization process they have reached. Each phase follows the same design steps, although the characteristics of these steps may vary from phase to phase.

The governance perspective
The governance context, i.e. the complex set of legislation, regulations, decision-making processes, etc., is a third perspective from which Building with Nature opportunities may be developed. The triggers and obstacles ensuing from this context will need due consideration if those opportunities are to be realized in practice. The guidelines at present offer information and advice on the following aspects of governance: networks, regulatory contexts, knowledge contexts and realization frameworks.

THE KNOWLEDGE BASE

The guidelines are underpinned by the Building with Nature knowledge base, which consists of a wide range of building blocks, tools, example cases and knowledge pages. The building blocks enable designers to make first-order quantifications of typical elements of a larger overall design. The tools include methods, concepts and strategies that can be used in the different project phases and design steps. Together, the example cases form a portfolio of Building with Nature solutions as they have been implemented in projects. The knowledge pages contain more information on the various topics and issues that have been addressed during the programme.

COURSE MATERIALS

In order to make the Building with Nature design principles accessible to a larger public, the EcoShape partners have developed course materials and tutorials that are being used in workshops and training courses at various collaborating education institutes (Delft University of Technology, Wageningen University and Research Centre, and the Zeeland and Van Hall Larenstein Universities of Applied Sciences). The Netherlands Foundation for Postgraduate Education also organizes Building with Nature courses for professionals. Moreover, the tutorials have been formulated in such a way that they can be also used on an individual basis.

FUTURE DEVELOPMENT

'The Building with Nature Design Guidelines have deliberately been developed in the form of a wiki', concludes Huib de Vriend, scientific director of Building with Nature. 'Although an editorial board controls contributions to the wiki, the guidelines are open to inputs from other parties, as they are supposed to be developed further via lessons learned from new projects or whenever additional knowledge becomes available. Readers who wish to use the guidelines directly, or contribute to them, are warmly encouraged to visit the EcoShape website: *www.ecoshape.nl*.'

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