INTEGRAL DESIGN OF MULTIFUNCTIONAL FLOOD DEFENSES
MULTIDISCIPLINARY APPROACHES & EXAMPLES
Edited by Baukje Kothuis, Matthijs Kok

Multifunctional flood defenses protect areas against flooding, but they also serve other functions as well. Although these types of defenses can be seen almost everywhere, they pose special technical and governance challenges.

This book is about a unique interdisciplinary research program developed to tackle some of the issues designers and managers of multifunctional flood defenses are confronted with, and also to provide some practical solutions. The book discusses a variety of case studies, but also considers the difficulties involved in setting up an interdisciplinary study with PhD students from different fields. Interviews with some of the end users and reflections by researchers involved in the field make this book a ‘must read’ for everybody who is involved in protecting societies against flooding.

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The MFFD program is a collaborative multidisciplinary STW Perspectief research project

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smart use of new technologies: combining these assets leads to creative solutions and public support. But we should not forget: the extremely high flood safety standards we have set in the Netherlands imply a long road towards implementation of new dike reinforcement modes and strategies. Water managers are not fond of techniques that have not yet been tested in practice. Nevertheless, this is the only way forward if multifunctional flood defenses are to be considered seriously.

This is why I heartily welcome this book, full of great examples of multifunctional flood defenses, addressing opportunities and challenges in their design. Hopefully, the book will serve as an inspiration for anyone that warmly supports our dikes. I'm one of them, in my role as ambassador for flood safety within the Water Authorities, but above all, as dijkgraaf at the local Water Authority of the newly created land in the Zuiderzee.

Hetty Klavers

MULTIFUNCTIONAL FLOOD DEFENSES: NO FAD, BUT NECESSITY

PREFACE

One of my favorite maps is the Dijkenkaart in the beautiful atlas ‘Dutch Dikes’ (Pleijster & Van der Vreeken, 2014). Dikes are the only marks on the Dijkenkaart. Nevertheless, one notices immediately that it represents the Netherlands. This beautiful map shows clearly:

- The importance of the dikes: 60% of the country is flood-prone, threatened by sea, rivers and lakes;
- The immense length these dikes encompass: all together about 22,000 kilometers, and
- The wide variety of dikes: from a winding old-age levee to the straight dikes and dams of the Zuiderzeewerken.

Dikes determine the Dutch landscape. And more than that: our dikes show the almost genetically entrenched Dutch collaborative mindset. For centuries the Dutch have known that defense against floods is essential to be able to live in the low country, and that cooperation is indispensable. Water Authorities are born out of this need and belong to the oldest governmental institutions of the Dutch polity.

The challenges have not diminished over time. Climate is changing; space is scarce; and behind the dikes residential and economic activities are constantly increasing. These developments also challenge the Water Authorities. Could dikes serve more goals than ‘just’ flood protection? Multifunctionality is the magic word. Sometimes in a light mode, with benches for recreation and bike paths, and at other times on a larger, more serious scale, with integrated parking garages and bolevards, or buildings that are constructed as part of the flood defense.

Being aware of multiple interests, trusting the Dutch ‘polder’ culture (which reflects the intention to reach consensus), and
As the ancient Greeks already knew: everything flows. Water is, therefore, a metaphor for life, for matter, for movement, for energy and for much more. Less philosophically speaking, water also has a direct impact on our daily life: it affects our safety from flooding, it relates to our food production, it is a prerequisite for life processes in organisms, it provides us with hydro-energy and affects us in many ways more. People living in deltas are acutely affected by water: by 2020 this will be about five percent of the world’s population. Many urban areas are located near the coast, with their housing, industrial production zones, harbors and food production areas. These coastal zones not only needs to be protected from flooding from the sea, they are also under pressure from these other societal demands.

The Multifunctional Flood Defenses program (MFFD) was based on the notion that multiple spatial demands can, conversely, be achieved with limited space by emphasizing multi-functionality: a smart combination of functions and technological solutions that often require multi-stakeholder decision making. For flood defenses, this means that we need to understand the interplay between their primary function (protecting against flooding) and other societal needs, such as the need for recreation, eco-services, housing or renewable energy; and all of this needs to be translated into a design that integrates future uncertainties, such as those associated with climate change. Moreover, this needs to be translated into a design that integrates the different functionalities, clearly including the landscape. Finally, we need to ensure a viable governance approach that includes a multi-stakeholder perspective. The need to understand these diverse issues was the inspiration for the MFFD program, a coherent program consisting of eight work packages and involving eighteen PhD candidates and postdocs.

For STW (the current NWO domain TTW - Stichting voor Technische Wetenschappen - Applied and Engineering Sciences), the MFFD program was one of their first integrative and multidisciplinary programs. At present, these kinds of programs have a well-established position within the range of TTW instruments. In the water sector alone, the MFFD program has been followed by successful programs such as Nature-Coast, RiverCare, WaterHakasus and, most recently, All Risk (the direct successor of the MFFD program). Clearly, a lot has been learned about how to build such programs, much of it thanks to the pioneering work of the MFFD program. To get a sense of the difficulties involved in managing this new type of program, consider the following:

- How can we create a common, shared perception of the research aims?
- How can we prevent the sometimes seemingly disparate research lines from diverging?
- How can we engage the so-called knowledge users, both on a program and project level?

A special thanks should go the postdocs who have applied themselves to these tasks, often above and beyond what they were hired to do. By organizing ‘reflection days’ (which, for us as program officers, were always interesting and fun to attend), a real and lasting sense of community has been built (see Figure 2 and also p. 132).

The book that you are currently holding consists of many interesting case studies. These cases were provided by the knowledge users and, besides contributing to knowledge and integrating it, they proved to be a very valuable way of engaging these users directly with the research. This book, together with other ‘non-academic products’ of this program such as flyers and games (see e.g., Figure 1), is an example of the care and effort that has been taken to make academic knowledge accessible and applicable.

For us as program officers, it was a true pleasure working with these smart, creative and committed researchers and end-users who have made a milestone in the way that multidisciplinary programs can be integrated; the added value of this program creates a truly societal impact. We hope that, upon reading this book, you will be as inspired to build upon this knowledge, as we have been inspired during its creation.

IMPLEMENTATION OF KNOWLEDGE

Erwin Meijboom, Ruben Sharpe

STW - DUTCH TECHNOLOGY FOUNDATION

Drs Erwin Meijboom was Program Officer of the STW Multifunctional Flood Defences Research Program from 2012 until 2015. He currently works as a Policy Officer at the Netherlands Organisation for Scientific Research (NWO).

Dr.ir. Ruben Sharpe was Program Officer of the STW Multifunctional Flood Defences Research Program for Technology Foundation STW from the start of the program in 2012 until 2015. He currently works as a Policy Officer at the Netherlands Organisation for Scientific Research (NWO).

As we have been inspired during the creation of this book, as we have been inspired during its creation.
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INTRODUCTION

SOCIETAL NEED FOR MULTIFUNCTIONAL FLOOD DEFENSES

Matthijs Kok is Professor of Flood Risk at the Faculty of Civil Engineering and Geosciences at TU Delft. In 2016, he was Program leader of the ‘Integral and Sustainable Design of Multifunctional Flood Defenses’ research program. In 2017, he was Program leader of the Stuttgart Science and Technology Foundation’s (STW) research program, ‘All RISK’, which will study the implementation of new risk standards in the Dutch national flood protection program (2017-2022).

It is widely recognized that floods affect more people globally than any other type of natural hazard, causing some of the largest economic, social and humanitarian losses. Many measures are available to reduce flood risk, among them spatial planning tools, early warning systems and the construction of flood defenses. Since more and more people are expected to live in deltas in the near future, flood risks will substantially increase unless measures are taken. Flood defenses are one of the measures available in our toolkit to reduce the risk of flooding. Flood defenses are intended to protect land from inundation. These can come in many types, ranging from soil structures, sheet piles to storm surge barriers. The Netherlands is a country that would not exist without flood defenses (for an overview of the protected area, see Figure 1). A common design parameter included in all these flood defenses is the failure probability of the structure, which depends on its strength and the hydraulic loads it faces. Unfortunately, the actual failure probability often differs from the design failure probability (often called the safety standard), for example due to deterioration of the structure and management. The ultimate goal is to substantially increase safety over current defense designs, so that the yearly failure probability might (for example) be less than 10^-6. Another advantage of a multifunctional flood defense is that it potentially broadens the financial base of the project. For example, if a parking garage is combined with a flood defense, then the parking garage can help to finance the flood defense and vice versa.

The functions of multifunctional defenses were investigated for both urban and rural areas, and on both regional and local scales. In built-up areas, these include infrastructure and development (or redeploy-ment) of real estate for housing, work and leisure, in rural areas, these include infrastructure, ecological values, and recreation (via landscape design). Research assessed the safety of multifunctional structures, but also the ‘governance’ of multifunctional flood defenses in the context of multiple users, varying administrative rules, and in some cases different legal frameworks. The flexibility and robustness of the defenses was investigated integrally, considering both economic and engineering perspectives. Case studies addressed the practical need for safe and multifunctional solutions, with the goal of facilitating the integration of disciplinary knowledge.

The research program had the following objectives:

- To gain insight into the behavior of the multifunctional flood defenses during extreme storms (e.g., extreme water levels and high waves);
- To develop and design new risk assessment methods for multifunctional flood defenses, in both urban areas (for example, constructions in or near the flood defense) and rural areas (for example, landscape design or ecological values);
- To develop new governance and asset-management principles for multifunctional flood defenses in both design and management phases;
- To incorporate physical and safety knowledge into the assessment of failure probabilities of all types of flood defenses (including multifunctional ones), and optimize this knowledge economically;
- To include uncertainty (e.g., due to climate change or socio-economic developments) in the design of multifunctional flood defenses, and to develop new design principles incorporating flexibility and robustness.

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The program faced a number of scientific challenges:
- Evaluating the reliability and risk of multifunctional flood defenses requires new methodologies, since the risk to a multifunctional defense is not simply the sum of the risks to the individual functions. Current approaches neglect extra functions when assessing future failure probabilities. For example, it is not known how a road on top of a dike influences failure mechanisms.
- The behavior of objects in soil bodies (e.g., concrete structures or pipes) is not completely understood. Modern numerical modeling tools need to be combined with experimental work (e.g., laboratory experiments to validate these models) in order to assess the structural behavior.
- Governance strategies, financial forecasting and real estate predictions need to be made under uncertain future conditions. The challenge of multifunctional flood defenses lies in the long term. Flood defense managers tend to prefer mono-functional flood defenses because the reliability of multifunctional dikes has not been properly investigated, and because the time scale of the other functions can differ from the function of flood protection.
- Multifunctional flood defenses need to be integrated into urban and rural (riverine) landscapes. The flood defense is sometimes seen as an unwanted obstacle, and the challenge is to find ways to integrate protection into landscapes in an appealing manner.
- Multifunctional flood defenses need to be flexible and able to accommodate for large uncertainty in future conditions, such as changing hydrological conditions due to climate change or social and cultural factors caused by socioeconomic changes.

Case studies serve a key role in this program. The NWO domain Applied and Engineering Sciences (TTW; Toegepaste en Technische Wetenschappen previously Technology Foundation STW) explicitly involves users of technology, in order to develop techniques that fit practical needs and contribute to societal demands. Applying case studies involving users has several advantages: new knowledge can immediately be tested, and users receive the knowledge in a very efficient way. The program includes two research tracks: disciplinary ‘extension research themes’, and ‘multidisciplinary integration challenges’ (see Figure 3). Extension research themes aim to extend disciplinary theories and to develop new theories and knowledge, while trans-disciplinary integration challenges (interdisciplinary research) extend knowledge to adjacent research fields.

The expertise of three universities, with seven different research groups within these universities, was combined in the MFFD program. The Delft University of Technology (TU Delft) was heavily involved, since flood defenses research in the Netherlands is concentrated there, in particular in the Faculty of Civil Engineering and Geosciences (CEG). The input of hydraulic engineering knowledge by this faculty is complemented by the wider urban design and governance perspectives of the TU Delft Faculties of Architecture and the Built Environment (A&BE) and of Technology, Policy and Management (TPM). The Environmental Sciences Group of Wageningen UR offers a combination of practical and scientific research in a multitude of disciplines related to the green world around us, and the sustainable use of our living environment: knowledge of water, nature, biodiversity, climate, landscape, forest, ecology, environment, soil, landscape and spatial planning, geoinformation, remote sensing, flora and fauna, urban green, man and society. The research group at Twente University in the department of Water Engineering and Management is renowned for its research on the behavior and management of large-scale natural water systems. Combining this wide variety of complementary knowledge resulted in five years intense research and collaboration, which we have summarized in this publication for this STW program’s ‘end-users’, all participants, and other interested parties.

Figure 2 (left page). Overview of all research topics and researchers in Multifunctional Flood Defenses program (cartoon by Stephan Timmers, TOTALSHOT in collaboration with all MFFD researchers).

Figure 3 (right). Structure and scientific approach of the research program featuring the importance of case studies as a base for knowledge development for integral design.
Baukje Kothuis

A FIVE-YEAR RESEARCH PROGRAM IN ONE BOOK

Dr Baukje Kothuis was a Postdoc in the STW-MFFD program at the Faculty of Technology, Policy & Management, TU Delft in the project ‘Urban and Rural MFFD design’. She also works at the Faculty of Civil Engineering & Geosciences as a researcher in the MFFD Program ‘Integral & Sustainable Design of Multifunctional Flood Defenses’. She has been involved in several projects in different universities as an independent consultant and co-PI in the IUFRO-UNESCO research and education exchange program ‘Coastal Flood Risk Reduction’ to develop partnerships for international research and education.

A whole five-year research program in one book! That is no doubt remarkable. The trans-disciplinary character of our efforts can be found in multitude of papers, reports, journal articles, posters, presentations and, ultimately, through our dissertations across multiple disciplines. However, to create an overview for various interested parties, to have at hand to start discovering integral knowledge and, not unimportant, to communicate the efforts and outcomes of integral design, is what we hope to provide with this book.

In the Table on page 14, the set-up of the STW Perspectief Multifunctional Flood Defences research program (MFFD’s) is summarized. Two research lines were envisioned to address the anticipated challenges. The research questions arising from these challenges were ultimately translated into eight research projects:

1. Hydraulic impact of overtopping waves on a multifunctional flood defense;
2. Structural assessment of multifunctional flood defenses;
3. Safety and reliability assessment of multifunctional flood defenses;
4. Urban design challenges and opportunities of multifunctional flood defenses;
5. Governance and finance of multifunctional flood defenses;
6. Contribution of multifunctional flood defenses to landscape values and spatial quality;
7. Governance and finance of multifunctional flood defenses;
8. Design support for multifunctional flood defenses;

The white pages in this book describe disciplinary knowledge developed within these research projects, including methods and approaches. Case studies where this knowledge often derive from:

- often in collaboration with end-users and other stakeholders - are described in the colored pages in between. In the first three sections of the book we have clustered several research themes to guide interested readers towards information about their specific interest:
  - Section 1: Risk assessment;
  - Section 2: Design & governance;
  - Section 3: Governance & knowledge transfer.

Each of these sections starts with the perspective of a so-called ‘STW end-user’, a field expert from one of the organizations that were involved in one or more projects or case studies. They explain how they have collaborated with and outcomes of the MFFD program were useful for them and their organization. Each section ends with two reflections by project leaders. They elaborate on the work done, the current state of affairs concerning multidisciplinary flood defenses and the challenges that still have to be addressed.

The fourth section of the book, named ‘Program Cases’, is the account of one of the methods to achieve transdisciplinary knowledge development. We choose several extensive cases of (intended) integral multifunctional flood defense design to work on with a team of researchers from different disciplines. Two of those, the Rotterdam Roof Park and the Houston Galveston Bay Region, are presented in the last section of this book. Although we found out that developing integral knowledge within an academic setting is not an easy job, we are convinced the reader will enjoy and can use the interesting results of these cases.

Finally, we would like to thank all contributors to the program, to this book, to the case studies, and to all of our other knowledge development efforts. We hope this book is an inspiration for anyone who is involved in one way or another in the integral design of multifunctional flood defenses.

READING GUIDE
INTERVIEW

INTEGRATING FUNCTIONS FOR MULTIFUNCTIONAL USE

In Gerben Spaargaren is head of the group ‘Flood safety and policy’ at engineering consultancy firm Witteveen+Bos, where he focuses on integrating different fields of expertise within the company in the domain of flood safety. Previously, he worked at the policy department of the Water Authority of Delfland. Gerben is one of the knowledge-producers in the StM-Multifunctional Flood Defenses Program project ‘Risk Assessment of Multifunctional Flood Defenses’. Gerben collaborated with Mark Voorenndt on structural evaluation of multifunctional flood defenses (see pages 20-25) and Paul Hölsher on wind turbines and dike safety (see pages 50-53).

How would you describe a multifunctional flood defense?

“‘For me, it is about integrating the functions. The concept ‘multifunctional flood defense is getting a lot of attention, but it has been around for a long time. That’s because we’ve always demanded a list of this kind of a line-element along the water. We’ve built roads on dikes, and we like to live on them and use them for recreation. But be aware: All these things can only be done if flood protection is guaranteed. If this goes wrong, the consequences are profound. The Dutch system we’ve created is vulnerable, so there’s no other option but multifunctional design in many locations. Integration has become a necessity, there is no way back. And since many multifunctional issues are funded by government, involved parties have no choice but to collaborate.’”

“In my opinion, it’s not so much about multifunctional flood defense structures, but about multifunctional use of an area. We tend to separate the flood protection function from the other functions of the project. There may be a road on a dike, but the asphalt layer and the foundation of the road must be above the dike crest level required to meet boundary conditions for flood protection. So we raise the dike half a meter, or even a meter. While potentially, the foundation and the pavement could also function as flood-barrier structures.”

What specific kind of knowledge is needed for integrated design of a multifunctional flood defense?

“You can design each flood barrier as strong as you want, design and construction are not the problem. But for a real multifunctional flood defense, you’ll have to find a solution to management and maintenance challenges, as those create the risks. How do you manage governing, responsibilities, and safety levels over different lengths of time? Mark’s methodology helps investigate what the various functions of the structures unambiguously, so that they can make arrangements with each other about use of that wall.”

How were you and your organization involved in the project?

“We are interested in risk assessment of structures at, on, or in the multifunctional flood defense. In those cases, different stakeholders consider different risks. As a consultancy firm, we get questions from all sides: ‘Can you advise us the best way to construct the dike, considering putting a wind turbine or building on it?’ But also: ‘We want to build that turbine or that building. Can you help us build it at close to the dike or even on or in it, and find the arguments for doing that?’”

“Paul Hölscher investigated the effect of vibrations of wind turbines. And there are more issues, especially now that wind turbines are getting bigger. For example, what happens if a turbine falls over and hits the flood defense? Or the turbine house, or one of the blades? Some say it completely shatters if it falls, others are not so sure about that. These kinds of issues make a water manager say: ‘If that turbine is 150m high, it needs to be at least 150m from the dike.’ A classic example of separate functions, keeping the turbine at such distance that it cannot fall on the dike. It is practical, but immediately limits a lot of options. It’s all about calamities and failures. Paul’s research project has developed the first part of this knowledge, but a lot more is still needed.”

How did the academic research project match your organization’s practical needs?

“We participated in this research program to acquire more tools for integrated multifunctional design. A lot of times, the technical knowledge is available, and technical problems can be solved. It’s more challenging to handle multifunctional design in the larger context. At Witteveen+Bos we work with three design loops, ranging from rough to fine. The working methodology that Mark has set up is in line with how we work in practice. He just started a new project looking into the various issues, especially the risks of wind turbines on flood defenses; actually, this is a follow-up on Paul and Mark’s work combined. Paul’s research on the effects of vibrations is expanded, as a wind turbine or near a dike obviously has more effects. And Mark’s methodology helps investigate what the various effects could be.”
Flood risk reduction aims to minimize losses in low-lying areas. One of the ways to reduce flood risks is to protect land by means of flood defenses. The Netherlands has a long tradition of flood protection and, therefore, a wide variety of technical reports written and guidelines developed for designing and assessing typical flood defenses. These documents have been prepared by the Dutch Technical Advisory Committee for the Flood Defenses (Technische Adviescommissie voor de Waterkeringen, TAW) and apply to dunes, lower and upper river dikes, lake and sea dikes, water-retaining hydraulic structures, etc. These documents contain methods and criteria to determine the reliability of flood defenses, based on the present state of technology and research.

Due to continuously expanding urban activities and the need to improve the present protection level, flood defenses are often combined with structures that serve other functions than flood protection. Examples of these multifunctional flood defenses are parking garages in quays, houses whose façades retain water and wind turbines on dikes. However, the current TAW guidelines are not suitable to multifunctional structures, since they assume specific shapes of flood defenses, like gates or embankments. Multifunctional flood defenses, conversely, consist of atypical structural elements that require a different approach. The lack of official standards or guidelines causes difficulties in estimating whether these multifunctional flood defenses are sufficiently reliable or not. Consulting engineers and research institutes like Deltares have acknowledged this gap. This problem was also observed by Knoeff et al. (2013), and mentioned by Van Mechelen (2013), Jongerius (2016) and Kentrop (2016). To address this, we developed a generic method to evaluate the reliability of multifunctional flood defenses.

Mark Voorendt is lecturer of Hydraulic Engineering at the faculty of Civil Engineering & Geosciences, TU Delft University of Technology. In the STW-MFFD program he worked as a PhD candidate in the project ‘Structural assessment of multifunctional flood defenses.’ Mark graduated in 2017.

Dissertation title: ‘Design principles of multifunctional flood defences.’

PhD Supervisor: Prof. dr. ir. Han Vrijling, TU Delft

Legend
1. Water retaining element
2. Erosion proof element
3. Supporting element
4. Subsoil
5. Objects
6. Transitions
7. Wave dampening elements

This generic method identifies structural elements based on their contribution to the flood protecting function. First, the main function of a flood defense was subdivided into sub-functions. Second, structural element types were related to these sub-functions. With help of a function analysis, we found that a flood defense needs to perform the following sub-functions:

To retain water:
- to provide sufficient retaining height;
- to prevent water flowing through the flood defense;
- to prevent water flowing under the flood defense;
- to prevent water flowing around the flood defense.

To transfer the acting loads to the earth:
- to provide strength;
- to provide stability;
- to provide stiffness.

To resist all transferred external and internal loads.

These sub-functions were subsequently linked to the different structural elements that together compose flood defenses. In Figure 1, this example contains all structural element types.
First, we try to identify water-retaining elements (type 1). The clay layer that seals off the sand core at the outer dike slope is an obvious water-retaining element. Another water-retaining element is the permanent flood wall in the form of sheet piles. In this example, the retaining wall is extended with an additional water-retaining element.

Next, we can look for erosion-proof elements (type 2). This is presumably present, since the outer slope of clay is usually protected by a separate layer. On the inner slope of a traditional sand dike, a clay layer often protects against erosion from overtopping waves. In this example, the clay layer on the outer slope is additionally protected by concrete columns or blocks, which protect against erosion due to waves. The grass layer on the inner slope is also a type 2 element, because it protects against scour from overtopping waves or possible overflow. Another element that protects against erosion due to wave overtopping is the asphalt layer of the road on the crest of the dike. We do not find other elements that exclusively protect against erosion, but the flood wall combines this function with its primary function of retaining water.

Then, we look for type 3 elements, support elements. The clay layer is supported by the dike core, which is a typical type 3 element. The flood wall, already recognized as an erosion-proof water-retaining element, is also sufficiently strong and stable in combination with the counter-pressure of the soil in the dike core, so it also functions as a support element.

The subsols bear the dike core including all external loads acting on it. This is the type 4 element.

Now, we can find three objects (type 5) in this example: a house in the dike, a sewage pipe in the dike, and a house next to the dike. These objects are considered to be part of a dike if they technically influence the functioning of the structure as a flood defense. In some cases, objects that were not originally part of a flood defense become part of it after future reinforcement (after the dike is widened, for example).

Transitions (type 6) are found for example at the interface of the house and the soil. It can, for instance, consist of a strip of asphalt made to prevent seepage. Other transitions are the interface of the sheet pile flood wall and the revetment, the interface between the road and the dike cover (clay layer) and these slope angles change.

Finally, the outer berm is an example of a wave-damping element (type 7), reducing wave forces during extreme conditions; waves will break due to the shallowness created by the berm, which dissipates energy. This reduces overtopping volumes, which allows a lower crest height.

Using this 7-element model, we studied twenty-six different cross-sections of various flood defenses to verify whether the structural elements could be recognized in practice. These real cases were studied for two reasons:

- To check whether the method of distinguishing structural element types is applicable;
- To check whether the derived element types are generic.

The studied examples include typical monofunctional flood defenses, like sea dikes, river dikes and lake dikes, but also a dike coffee and an extendable flood wall. Multifunctional flood defenses were also studied, such as the Roof Park in Rotterdam (see pp. 166-183 in this volume), houses in Dordrecht (Figure 3) and a quay in Hamburg (Figure 4). A discharge sewer was analyzed as an example of a hydraulic structure, and a reservoir dam was taken as an example of an artificial form. This provides a comprehensive range of examples.

All element types could be recognized in these examples and no new types were found. The wide variety of structures that were studied assures that the distinguished structural element types are indeed generic. This means that flood defenses consist of two or more of these element types (a water-retaining element and the subsol are always present).

The structural elements of flood defenses (identified in this model) are indeed generic, and the method of identifying them is practi-
KATWIJK AAN ZEE

CASE STUDY: KATWIJK AAN ZEE

Katwijk aan Zee is a Dutch town on the North Sea, near the original mouth of the Rhine. At the end of the twentieth century, part of the town of Katwijk appeared to be sufficiently protected against storm surges from sea (Figure 2). About 3000 inhabitants were at risk exposed to risks that were higher than what is considered acceptable in the Netherlands.

Katwijk was one of the last weak links along the Dutch coast, according to a 2000 report from the Steering Committee Coastal Vision 2030 (in which the provinces of North and South Holland, Rijkswaterstaat, the National Planning Department, Water Boards and coastal communities participated). Several designs have been made to improve the flood protection of Katwijk, while also addressing the growing parking problems along the boulevard. The final design is described in the following section, followed by another section that presents the alternative design, which has been rejected by the municipality of Katwijk.

The final "dike-in-dune" design

The weak part of the dunes was reinforced between October 2013 and February 2015 with a dike embedded in the dunes. A sub-soil parking garage for 663 cars was then constructed between the dike and the dune area. The dike has a sand core and is covered by concrete blocks on top of a filter layer and geotextile (Figure 3). The crest level of the dike is now higher than 7.50 to 8.00 m, but for aesthetic reasons the dike is now covered with the same sand as the dike and therefore gives the impression that it is a part of the dune. It is not really important whether it is covered with the same sand as the dike or not, for hydrodynamic reasons (the view from the boulevard). It was decided to make the dunes lower but wider, with a seaward extension of the beach.

To achieve an even lower dike, a "hard structure" was needed to prevent further erosion. The total width of the dunes outside from boulevard to dune toe is about 120 m. This is 90 m wider than in the original situation. The dike has a sand core and is covered by concrete blocks on top of a filter layer and geotextile (Figure 3). The crest level of the dike could have been higher than the original situation. The dike has a sand core and is covered by concrete blocks on top of a filter layer and geotextile (Figure 3). The crest level of the dike could have been higher than the original situation. The dike has a sand core and is covered by concrete blocks on top of a filter layer and geotextile (Figure 3). The crest level of the dike could have been higher than the original situation.

The "dike-in-dune" design

The total erosion volume of the dune and beach is a cross-shore factor. One of the major factors when calculating flood protection offered by the dike is its relative height. The dike is not really important whether it is covered with the same sand as the dike or not, for hydrodynamic reasons (the view from the boulevard). The total erosion volume of the dunes and beach during a 1 in 10,000 year flood, which is the flood safety standard for this area (Figure 2). About 3000 inhabitants were at risk exposed to risks that were higher than what is considered acceptable in the Netherlands.

When calculating flood protection offered by the dike, it is not really important whether it is covered with the same sand as the dike or not, for hydrodynamic reasons (the view from the boulevard). The total erosion volume of the dunes and beach during a 1 in 10,000 year flood, which is the flood safety standard for this area (Figure 2). About 3000 inhabitants were at risk exposed to risks that were higher than what is considered acceptable in the Netherlands.

The parking garage was designed at the land side of the flood wall. The flood wall had a double function: in addition to retaining water, it would provide stability to the garage structure. The flood wall was sufficiently strong and stable on its own, so that even if the parking garage were to collapse, that would not affect the flood protection. Similarly with the restaurants proposed on the beach side, adjacent to the flood wall, they are not part of the flood defenses.

A rejected wall-in-dune design alternative

In an early stage of concept development, several alternative designs to improve the coastal defenses of Katwijk were made. One of these designs was developed by the Delft University of Technology, Netherlands Organization for Applied Scientific Research (TNO), Rotterdam's municipal engineering department, the Dutch "knowledge partner for construction" (SBRCURnet), and other research agencies. This design proposed a parking garage in the dunes, but no dike. The seaward wall of the garage would be a flood-retaining diaphragm flood wall 17 to 20 m high (Figure 4).

The idea was that the diaphragm wall would still have to resist the waves after erosion of the 30 meter wide dune in front. The "dune erosion - what it occurs - can proceed quite rapidly: 80 to 100 meters in a few hours, so a 30 m wide dune can reasonably be expected to completely erode during a major storm. A computer simulation showed that these 30 m wide 30 m wide 30 m wide would be completely eroded after 15 hours. Waves would then directly hit and overtop the wall.

The parking garage was designed at the land side of the flood wall. The flood wall had a double function: in addition to retaining water, it would provide stability to the garage structure. The flood wall was sufficiently strong and stable on its own, so that even if the parking garage were to collapse, that would not affect the flood protection. Similarly with the restaurants proposed on the beach side, adjacent to the flood wall, they are not part of the flood defenses.
In the Netherlands, economic cost-benefit analysis plays an important role when deciding on safety levels for flood defenses. The cost of increasing the safety level is weighed against the reduction in flood risk (the benefit). The optimal level occurs where the sum of the cost and benefits is at its minimum; this is shown graphically in Figure 2. However, when conditions change over time, due to for example economic growth, the optimal safety levels change as well. This is illustrated in Figure 3. An in-depth description of the current use of cost-benefit analyses in the Netherlands can be found in Kind (2014).

Specifically, economic cost-benefit analyses can offer support in decisions regarding to whom, when and how much to invest. Where to invest can be identified by selecting locations where benefits outweigh the costs. For these locations, deciding on when and how much to invest can be supported by results such as shown in Figure 3. Additionally, the results of a cost-benefit analysis can be used to clarify the service levels presented by the government to the public.

The benefit part in an economic cost-benefit analysis is the reduction in flood risk. The flood risk associated with a flood defense is often defined as the flood probability times the flood damage. When flood defenses are analyzed separately, each flood defense can have its own, isolated cost-benefit analysis. However, once flood defenses are viewed as dependent on each other, for example if they form a system with multiple lines of flood defenses, the interdependencies between flood defenses as well as between flood defenses and risk for the remaining dike rings. Flood defenses that interact with each other, like the one described in Figure 1, therefore not only protect their own area, but can also influence the safety levels of other adjacent flood defenses.

In my research, the consequence of interdependencies has been expressed in terms of changes in the hydraulic loads. In order to quantify this, various hydraulic loads need to be modeled, as well as potential breaches and potential flood damage resulting from such a breach. As the behavior of a river and its hydraulic loads are important when estimating flood probability, as well as possible damages, including interdependencies in the cost-benefit analysis improves the flood risk part of the cost-benefit analysis.

In order to quantify the flood risk associated with flood defenses, the interdependencies need to be incorporated in probability. These positive or negative.
When interdependencies are quantified and incorporated in a cost-benefit analysis, the results can be compared with those of a simpler cost-benefit analysis without interdependencies. Though the results can differ significantly, the differences are heavily dependent on the specific characteristics of each case. Examples of such case-specific characteristics are the distribution of flood damages over the flood-prone areas, or the ratio between risk and investment costs. Practically, results of a cost-benefit analysis with interdependencies can lead to different sets of optimal safety levels, as well as to different (more efficient) investment schemes for the flood defenses. Furthermore, the method is not limited to traditional flood defenses such as earthen levees; for example, emergency storage areas or storm surge barriers can also be included.

Impact of including interdependencies on a cost-benefit analysis

As previously described, an economic cost-benefit analysis balances risk costs and investment costs. Therefore, a change in flood risk can lead to different economically optimal investments. With interdependencies, the total number of relevant system configurations can become large. For example, suppose the flood defenses in Figure 1 can have five possible heights per defense. Without interdependencies, a total of 5*4 = 20 combinations are possible. With interdependencies, the number of combinations rises to 5^4 = 625. This number increases further if the timing of investments is included. For example, in a case of a time span of 100 years with yearly increments, the number of combinations rises to 2000 and 62,500, respectively. The challenge, therefore, is not only to find the optimal solution among many different options, but also to calculate these different options efficiently, in order to reduce computation time.
A turbulence bore runs up on the seaward slope of the dike and overtops the crest of the dike. Part of the overtopping waves continues across the dike crest, and the other part flows back into the sea. Overtopping flow hits the building, with some of the water being reflected seaward, and some of it passing through the gaps between buildings.

Most buildings built on coastal multifunctional flood defenses in Belgium are low- and medium-rise masonry structures. Thus, a masonry building with a seaward external wall panel on the ground floor was selected as the representative structure for the case study. The most common failures caused by overtopping waves were structural collapse and local damage of non-structural elements.

Structural collapse can occur by two causes:
1. The support or foundation can fail, making the structure lose stability.
2. A key structural element can fail, causing a collapse.

Local damage includes failures that do not lead to collapse, but which do result in the inundation of the ground floor. Local damage primarily concerns two failures:
1. The failure of windows and doors.
2. The failure of façade walls (i.e., non-load bearing walls).

In this case study, we considered both local damage and the collapse of a key structural external wall, which could lead to the collapse of the building.

Two-dimensional physical model tests were conducted using a typical Belgian coastal configuration (such as the one in figure 1).

In low-lying countries like the Netherlands and Belgium, coastal areas are often highly urbanized, and buildings are often built on or close to the flood defense (Figure 2 shows a typical Belgian seaside town). This is an example of multifunctional flood defense, where urban functions are integrated with flood defense structures. In this example, the wide crest of the coastal dike is used as a promenade with building frontage. However, policy makers as well as the users and owners of the properties may be unaware of possible overtopping effects, and they may lack records of wave overtopping and the potential direct damage it can cause. The goal of this research project was to develop a tool that can measure the risks and potential cost of wave overtopping events on buildings.

If waves overtop the dike crest, the overtopping flow can have a severe impact on the buildings on the dike crest. Using a typical Belgian coastal dike with buildings on the top as a case study (see following pages), this research attempts to understand the hydraulic impact of overtopping waves. An overtopping wave is a mixture of moving water and air.

In order to develop practical approaches to design and assess structures, understanding physical force-generating mechanisms is necessary. We developed a practical approach to assess the vulnerability of structures built on coastal dikes caused by an overtopping wave. This approach can be used to design and assess coastal MFFDs in low-lying, highly populated coastal urban regions.

Figure 1 shows the full process of overtopping waves and their impact on a building on the crest of a multifunctional flood defense:
1. Wind generates waves far away from shoreline.
2. Offshore waves reach the foreshore area, increasing wave height and decreasing wave-length. Ultimately, most waves break.

Xuexue Chen

Xuexue Chen works as a Postdoc at Delft University of Technology. She was a PhD candidate in the MFFD program at the faculty of Civil Engineering & Geosciences, department of Hydraulic Engineering & Structures, in the project ‘Hydraulic impact of overtopping waves on a multifunctional flood defense’. Xuexue graduated in 2016.

Thesis title: Impacts of overtopping waves on buildings on coastal dikes.

PhD Supervisors: Prof.dr.ir. Wim Uijttewaal, TU Delft Prof.dr.ir. Bas Jonkman, TU Delft Dr.ir. Bas Hofland, TU Delft

Most buildings built on coastal multifunctional flood defenses in Belgium are low- and medium-rise masonry structures. Thus, a masonry building with a seaward external wall panel on the ground floor was selected as the representative structure for the case study. The most common failures caused by overtopping waves were structural collapse and local damage of non-structural elements.

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In this case study we considered both local damage and the collapse of a key structural external wall, which could lead to the collapse of the building.

Two-dimensional physical model tests were conducted using a typical Belgian coastal configuration (such as the one in Figure 1).
These permitted us to study wave overtopping and overtopping wave impact in the situation where a shallow foreshore affects the wave overtopping of a coastal dike. Based on experiments done in a flume (see Figures 3 and 4), the results show that Generalized Pareto (GP) distribution gives a suitable fit among commonly used distributions for the extreme overtopping forces. The three key parameters of the GP distribution are threshold, scale, and shape. These were empirically determined by using incident wave conditions at the toe and dikes geometry parameters. Based on the results of physical model tests, a new 7-step procedure was suggested as a simple tool for predicting the maximum force occurring during a certain storm peak; the tool shows an overall satisfactory performance (Chen et al., 2016a).

Using this tool, typical overtopping wave impact loads, expected to occur during 1 in 1000-year and 1 in 10,000-year storms, were calculated for the Belgian case. We assessed the vulnerability of buildings on coastal dikes caused by overtopping waves, by comparing the calculated impact load of overtopping waves and the strength of the buildings. We found that the masonry buildings on the coastal dike can withstand a 1 in 1000-year storm, but ground floor inundation can be expected from broken windows. If the building is located 10 to 15 meters from the seafront, non-structural walls are expected to fail during a 1 in 10,000-year storm. However, full collapse of the building may occur during a 1 in 10,000-year storm if the beach becomes badly eroded at the toe of the seaward side of the dike.

The findings of this study on the propagation of overtopping waves on a dike were applied to the case of a Belgian seaside town. By characterizing the resulting impact load on a vertical wall, a model is developed to assess the vulnerability of existing and newly designed buildings on dikes that are exposed to the impact of overtopping waves in low-lying coastal regions. By extending the model to include the impact of overtopping waves on the foundation of the buildings and on potential dike failure, and different type of buildings, the model can become more general applicable.
On coastal dikes in Belgium, many residential buildings are masonry structures with two to three floors (Figure 1). The ground floors are always elevated (Figure 2), and the entrances of the basements are closed by shutters (Figure 3). The most modern buildings are concrete reinforcement structures with concrete piles/columns as foundations. The walls are consisting of masonry or concrete. These buildings are 5 to 9 floors high. Some of the ground floors are elevated, and some are used as cafe, restaurant or store. The ground floors are equipped with large glass windows and doors.

A representative situation for Wenduine, a coastal town in Belgium, is used for the current case study. Figure 1 on page 30 shows the schematic sketch of a building placed on the top of the coastal dike in Wenduine. The beach level is set at 6.5 m above TAW (Tweede Algemene Waterpassing, which refers to Belgian standard datum level), which is chosen from the lowest toe position used in the study of Suzuki et al. (2016). The dike crest level is set at 8.5 m above TAW (and the distance between the building to the seaward slope of the dike (B) is chosen as 10 m in this case study).

In this research, two main simplified failure mechanisms of masonry buildings were considered. One is the collapse of the structural wall like an external load-bearing wall or stability wall, and the other one is localized damage of non-structural components like a non-load-bearing wall and glass windows. The vulnerability of the masonry walls and glass windows against overtopping wave impact was assessed under three scenarios, including two storm surges with return periods of 1000 years (scenario S1) and 10,000 years (scenario S2) and one 10,000 years storm surge with a low beach level (scenario S3). The impact load was estimated by using the approach developed in this project (Chen 2016: 57-81). The overall results indicated that the chance of collapse of the masonry buildings on the dike is low under scenarios S1 and S2. But the non-structural external wall and glass windows are expected to break, which would lead to the inundation of the ground floor of the buildings. However, most of the key external structural walls are expected to fail when the buildings are located near the coast under scenario S3 (i.e. 10,000 years condition with less shallow foreshores). Thus, we recommend increasing the strength of the external masonry wall on the ground, and reinforcing windows to avoid inundation.

Note: This assessment approach was developed specifically for the masonry buildings on a coastal dike with shallow water conditions. The existing masonry design code and empirical overtopping wave load were applied to set the limit state function of bending failure. Thus the applicable range of the hydraulic conditions of the empirical overtopping wave load formula needs to be checked for every other individual case.

This text is an adapted version of part of chapters 5 and 6 in the publication ‘Impact of overtopping wave on buildings on a coastal dike’ (Chen, 2016).
Dirt. Juan Pablo Aguilar-López works as a Postdoc at Delft University of Technology, faculty of Civil Engineering & Geosciences, department of Water Resources. In the MFFD program he was a PhD candidate at Twente University, faculty of Education, Technology (CTW) in the project ‘Safety and reliability assessment of multifunctional flood defences’. Juan Pablo graduated in 2016.


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Juan Pablo graduated in 2016.

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Embeded Structures in Flood Defenses

EFFECTS ON SAFETY AND FAILURES

Multifunctional flood defences (MFFDs) are often represented as large and robust structures where large infrastructure may be allocated. However, multifunctionality is defined only by the type and number of functions and not by the size of the structure itself. In that sense, common flood defense structural embankments such as dikes with roads, pipeline crossings through and under the flood defenses, and buildings embedded within the dikes can also be considered as multifunctional flood defenses. Moreover, large scale MFFDs usually include habitable spaces, which means that access and sanitation infrastructure will almost always be embedded in them as well.

failure mechanisms and design choices.

In the current Dutch context, national legislation for flood management is moving towards more risk-based policies, whereas systems are evaluated based on the probability of flooding and the resultant consequences in an specific event. The probability of flooding is determined by the reliability of the flood defences for different environmental loads. MFFDs will definitely be exposed to the same failure mechanisms as conventional flood defences due to these loads. However, the frequency of failure will change not only due to the effects of climate change and sea level rise, but also because of the additional structures now included in the flood defences.

Extensive research performed around the world and particularly in the Netherlands, has shown that from all the possible failure mechanisms, two of them may account for as much as 48% of the total estimated failure probability. These failure mechanism are the Backward piping erosion and the wave overtopping (Figure 1):• Backward piping erosion (piping): Collapse of the granular foundation due to cavity formation (also known as pipes) derived from fine sediment transport towards the landward side. • Wave overtopping: Landward slope erosion of the grass cover on the landward side caused by overtopped waves.

From a structural design point of view, it is interesting to quantify how the change of dimensions and the inclusion of hard structures influence the failure probability of these two main failure mechanisms depending on possible design choices (Figure 2). The design choices may be categorized into material choices and dimension choices and the combination of them are the ones that determine the flood defense reliability.
Throughout all the failure mechanisms will eventually be simulated in two large scale experiments per flood event and the main characteristics of the structures in the analysis as external boundary conditions tested in the field.

In order to perform such benchmarking, detailed finite element models (FEM) were used. These models simulate both MFFDs with high level of detail. These models allow to simulate the physical processes that governed and monitored in terms of pressures, displacements and inner temperature in order to understand the process and validate the actual model in order to express the reliability. Such selection also includes their computational burden is also high. This can be used for larger amount of calculations. Different algorithms such as artificial neural networks, decision trees, support vector machines and response surfaces are frequently used to build the surrogate model. As they are capable of representing highly complex problems, surrogate models or ‘emulators’ are used to represent two or more probabilistically correlated models as ‘copulas’. These copulas not only allow to represent the additional embedment effects in the actual probabilistic models. However, with this method one robust surrogate model can be used for different locations.

Random variables correlation determines the MFFD estimated reliability of the flood defense for each particular failure mechanism. Therefore it can be used for larger amount of calculations. Different algorithms such as artificial neural networks, decision trees, support vector machines and response surfaces are frequently used to build the surrogate model. We recommend further studying the possibility to develop a generalization of the method designed as long as they were included during the random sampling of both variables. These copulas not only represent two or more probabilistically correlated variables but also to give more importance for large in small values during the sampling process. This is important for FEM as the correct representation of correlation will have a significant effect on the estimated reliability of the flood defense for each particular failure mechanism. Therefore it can be used for larger amount of calculations. Different algorithms such as artificial neural networks, decision trees, support vector machines and response surfaces are frequently used to build the surrogate model. As they are capable of representing highly complex models. In order to perform such benchmarking, this means that it may not always be possible to conduct sufficient model runs to calculate the reliability of these flood protection structures as they are capable of representing highly complex problems, surrogate models or ‘emulators’ are used to represent two or more probabilistically correlated models as ‘copulas’. These copulas not only allow to represent the additional embedment effects in the actual probabilistic models. However, with this method one robust surrogate model can be used for different locations.
Infram bv).

Millingen (Images by 100 L/s/m test in with a road after
grass cover of a dike
low). Final scoured
-

overtopping storms.

Two graphs below:

- Top two graphs: Depth[m]
- Height [m]
- Distance [m]

- RCDM with AVERAGE grass quality
- GCDM with AVERAGE grass qualit

Study points under grass
Asphalt cover
estimated soil core
Initial profile

=100 l/s/

q

=75 l/s/

q

=50 l/s/

q

=20 l/s/

q

study points

=100 l/s/

es

=75 l/s/

es

=50 l/s/

es

=20 l/s/

es

=100 l/s/

m

=75 l/s/

m

=50 l/s/

m

=20 l/s/

m

=100 l/s/

m

=75 l/s/

m

=50 l/s/

m

=20 l/s/

m

=100 l/s/

m

=75 l/s/

m

=50 l/s/

m

=20 l/s/

m

Figure 4. Wave overtopping experiment at Millingen aan de Rijn (Photo courtesy: Juan Pablo Aguilar-López).

CASE LOCATION

In the area of Nijmegen, Rijkswaterstaat tested a stretch of dike near the village of Millingen along the river Rijn. In cooperation with the local Water Authority, Rijkswaterstaat and knowledge institute Deltares, the strength of the grass cover of this dike was researched and tested for wave overtopping that could occur in circumstances of concurr
rent high water levels and a storm. Grass on the dike contributes to its strength, but must be able to cope with waves and currents. The researchers tested which wave overflow caused the grass cover to be destroyed, and which was the impact of objects such as structures and roads on the crest of the dike. Testing was done with a wave-overtopping simulator positioned on the crest of the dike. It repeatedly emplaces at once with thou-

sand s of liters of water, producing large wave forces on the dike. The wave load is increased until there is damage to the grass cover. The results allowed to calibrate and validate the FEM model and the erosion models used for estimating the probability of different scouring depths along the original profile. This experiment was also important because it included the presence of a road which is a typical MFFD example.

(Sources: www.waterschaprijnenland.nl; www.rijkswaterstaat.nl).

WAVE OVERTOPPING EXPERIMENT FOR LEVEE WITH ROAD

In the case of wave overtopping, structures constructed above the flood defense will change the hydrodynamic behavior of the overtopped waves. This will change the scouring rates of the inner grass cover.

A wave overtopping experiment of a flood defense located along the Waal River studied the effects of a structure located on top of the defense. The results of this experiment were used to build a model (Road over crest dike model, RCDM, Figure 3), capable of representing the turbulent hydrodynamic behavior of waves overtopping a dike with a road. An additional model (Grass crest dike model, GCDM, Figure 3), with the same dimensions and tested for the same storm conditions, was also calibrated and validated.

The turbulent effects created by irregular forms and variable roughness along the crest and part of the landward slope (RCDM, Figure 3) were found to have a significant effect in the flood defenses resistance to wave overtopping. In addition, we found that a smoother surface produces less energy dissipation, which means that scouring depths increase along the foreland slope (Figure 3).

For the numerical experiment, the extreme storm events are characterized by the average discharge of overtopping which have their own probability of occurrence. In the actual Dutch legislation it is not allowed to have more than 10 L/s/m of overtopping discharge. The numerical method of combining FEM with surrogate modelling allowed to test both dikes conditions (with road and without). The main conclusion from these simulations is that: the actual existing MFFDs (road+dike) may withstand larger storm events than previously expected. However, for very extreme storms, the presence of roads may not be beneficiary for the wave overtopping reliability. This information was already known but the innovative part is that the present method allows to associate failure probabilities to the scouring profiles.

Juan Pablo Aguilar-López

CASE STUDY: MILLINGEN AAN DE RIJN

RISK ASSESSMENT
CASE LOCATION

Along the river Lek, the northwest west section of the dijkring 16 in front of the city of Vianen, was insufficiently stable for a plausible scenario of future climate change. Therefore it was decided that this section needed to be strengthened so that it would comply with the Dutch statutory safety requirements for the stability of the dike. Hence, a robust field campaign was performed along this dike section in order to collect field soil samples which will allow to validate the actual decision and optimize the future strengthening measures.

As an alternative to a traditional reinforcement measure Water Authority Rivierenland opted for an innovative solution: dike-nail punching or ‘dijkvernageling’. For this project, this meant that over a range of 250 meters 275 nails were drilled just above the closing level of the dike in three rows above each other. The nails were drilled in the dike by an anchoring drill, a kind of customized crawler excavator.

Despite the fact that this dike section was strengthened in terms of slope stability, a large amount of soil data was collected from the subsoil dike foundation which allowed to perform an statistical analysis between the collected samples. This analysis allowed to include the possible effects of correlation in the design of the hypothetical MFDD designed for the encountered conditions in this location.

(Source: www.waterschapsrivierenland.nl)

Juan Pablo Aguilar-López

CASE STUDY: LEKDIJK (VIANEN, UTRECHT)

OPTIMUM LEVEE WIDTH CONSIDERING PIPING EROSION

Based on the materials that are present in the flood defense, the resistance to failure mechanisms also changes as the deterioration rates change. In that sense, the optimum size of flood defenses can be better determined if the inherent uncertainty associated with the materials is reduced.

For the case of piping erosion, grains need to be lifted and transported to the hinter side of the defense for the erosion to progress. In addition, the permeability of the soil which represents the capacity of soil to allow water to flow through its pores, is highly determined by the representative grain sizes of that soil. This means that larger grains allow more spaces in between and consequently less resistance for water to flow. Both variables are involved in the physical process of piping erosion and both are correlated in an unknown degree.

Consequently, the correct choice of the degree of correlation between permeability and representative grain size during the probabilistic assessment will directly affect the MFDD geometrical choice, which determines the potential available space and the estimated MFDD reliability. This was concluded from a case study in a location along the Lek River (The Netherlands), where a large number of samples containing these parameters was available.

A hypothetical MFDD design which complies with the actual safety standards (1/2000) for piping is found to require an average width of 200 meters. However, when permeability and grain size are highly correlated ($\tau \approx 0.692$) as found for the Vianen data set, a width of only 180 meters. For stricter safety standards such as the ones suggested as an educated guess without any scientific support, in the order of magnitude of 100 times less frequent, the obtained results were 200 meters with correlation and 230 meters without correlation as shown in Figure 2 below.

(Source: www.waterschapsrivierenland.nl)
In the Netherlands, over 30 years of research has led to a rigorous methodology for calculating the probability of levee system failure, which has been encoded into the software Hydra-Ring. Two key algorithms calculate the segment failure probability, and 2: the system failure probability. The first is referred to as the modified outcrossing (MO) method, and takes into account the spatial autocorrelations within a levee segment. The latter, referred to as the Equivalent Planes (EP) method, accounts for the correlation between levee segments. The methods are both approximate, and very efficient, but a thorough description of them, as well as a verification, was lacking in the literature. Furthermore, there has been a surge of interest recently in using survival observations - the survival of a levee during an observed (high) water level - to update levee reliability estimates. However, use of the MO and EP algorithms in combination with updating has not been explored.

The implementation and accuracy of these algorithms in combination with a survival observation are topics of current relevance. We explored the development and use of a Bayesian network (BN) for levee system reliability, to augment and verify the methods already in use in the Netherlands. BNs are a type of probabilistic graphical model, in which correlations between variables can be seen in the structure of networks. The BN was used to test the MO algorithm, and correlates the spatial correlation within a levee segment. The latter, referred to as the modified outcrossing (MO) method, and takes into account the spatial autocorrelations within a levee segment. The former, referred to as the Equivalent Planes (EP) method, accounts for the correlation between levee segments. The methods are both approximate, and very efficient, but a thorough description of them, as well as a verification, was lacking in the literature. Furthermore, there has been a surge of interest recently in using survival observations - the survival of a levee during an observed (high) water level - to update levee reliability estimates. However, use of the MO and EP algorithms in combination with updating has not been explored.

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Estimates of levee system reliability can conflict with experience and intuition. For example, a very high failure probability may be computed while no evidence of failure has been observed, or a very low failure probability when signs of failure have been detected. This conflict results in skepticism about the computed failure probabilities and an (understandable) unwillingness to make important management decisions based upon them. Bayesian networks (BNs) are useful in these circumstances because they allow us to use observations to improve our reliability estimates quantitatively. Here we describe the application of a BN to calculate the system failure probability due to the failure mechanism piping, for a set of primary levees protecting the city of Zutphen from the IJssel River (see Figure 1), both with and without a survival observation (i.e. an observed high water level in which the levee survived). We additionally calculate the system failure probability with algorithms from the Hydra-Ring software, to compare system reliability estimates. The structure of the BN in this case study is dictated by the formulaic representation of piping, which is provided in the associated dissertation (Roscoe, 2017). The variables that play a role in the piping mechanism, which are described in Table 1, are the input random variable nodes in the BN. Table 1 also indicates whether a variable is constant over the length of the segment. If so, it will be represented by one node per segment in the system BN. The variables that are not constant are spatially variable and will be represented by n nodes, where n is the number of cross sections representing the segment. Figures 2 and 3 show the BNs for a cross section and a segment (represented by three cross sections), respectively. The number of cross sections is dependent on what is necessary to adequately represent the spatial variability, and generally ranges from 20 to 80. Arcs in the network that lead into functional nodes (nodes with black edges) are described by formulas. Arrows between input random variables (such as $D_1$ and $D_2$) are specified by a product moment correlation coefficient. Tables 2 and 3 show the results for two (hypothetical) observed water levels, one that has a return period of 40 years, and another of 400 years, to see how the reduction in system failure probability depends on the extremity of the observed water level. The prior and posterior system failure probability (the latter is after including the survival observation) were computed with the BN and with the Hydra Ring algorithms. The latter are denoted in the table as MO/EP for modified outcrossing (MO) and equivalent planes (EP), the two algorithms that calculate the segment and system failure probability in Hydra Ring, respectively. For a 1/400 year water level observation in which the levee survived, the ratio of prior to posterior system failure probability is 7.5, which means that the posterior failure probability is 7.5 times lower due to the survival observation. The impact is substantially less with the 1/40 year water level observation, with a ratio of 2.1. An observation with a return period of 40 years is relatively high given the length of the record, but is not high enough to greatly impact a system with such a low prior failure probability. This prompted us to consider when survival observations are useful. In general, they are most useful when the resistance (soil) variables have a large influence on the failure probability, or when the prior failure probability estimate is high. This is discussed in detail in (Roscoe, 2017). The comparison between the Hydra-Ring algorithms and the BN is quite good. In terms of reliability index, which is an alternative and quite common way of communicating failure probabilities, the differences were limited to a few percentage points. Given that the BN is a more exact method with fewer assumptions than the Hydra-Ring algorithms, this serves as a verification of those algorithms.
Variables used in piping analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Constant over segment</th>
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<tbody>
<tr>
<td>(D_0)</td>
<td>Thickness of aquifer</td>
<td>No</td>
</tr>
<tr>
<td>(D)</td>
<td>Thickness of blanket layer</td>
<td>No</td>
</tr>
<tr>
<td>(L)</td>
<td>Distance, waterside levee toe to landside water</td>
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</tr>
<tr>
<td>(\theta)</td>
<td>Bedding angle of sand</td>
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</tr>
<tr>
<td>(d_{70})</td>
<td>70th percentile of sand grain diameter</td>
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<tr>
<td>(\eta)</td>
<td>Drag coefficient</td>
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</tr>
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<td>(\gamma_{wc})</td>
<td>Volumetric weight of blanket layer</td>
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<td>(\gamma_k)</td>
<td>Volumetric weight of sand</td>
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<tr>
<td>(\mu)</td>
<td>Error in critical pressure difference, for uplift</td>
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</tr>
<tr>
<td>(\mu_h)</td>
<td>Damping factor</td>
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<td>(\mu_s)</td>
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</tr>
<tr>
<td>(h_{ls})</td>
<td>Water level on landside of levee</td>
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</table>

Table 1.

For an observed 1/400 year water level: Prior and posterior segment failure probabilities for Segments 13a, 13b, and 14 computed with the BN and the MO method, and the system failure probability computed by the BN, and a combination of the MO and EP methods. The ratio of prior to posterior failure probability is also given.

Return period of observed water level: 400 years

<table>
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<tbody>
<tr>
<td>13a</td>
<td>6.8E-5</td>
<td>4.4E-5</td>
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<td>9.0E-5</td>
<td>4.7E-5</td>
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<tr>
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<td>1.2E-4</td>
<td>11.8</td>
<td>1.6E-3</td>
<td>1.4E-4</td>
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<tr>
<td>14</td>
<td>5.7E-4</td>
<td>1.3E-4</td>
<td>3.7</td>
<td>8.4E-4</td>
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<td>4.8</td>
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<td>System</td>
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<td>2.8E-4</td>
<td>7.0</td>
<td>2.5E-3</td>
<td>3.3E-4</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 2.

For an observed 1/40 years water level: Prior and posterior segment failure probabilities for Segments 13a, 13b, and 14 computed with the BN and the MO method, and the system failure probability computed by the BN, and a combination of the MO and EP methods. The ratio of prior to posterior failure probability is also given.

Return period of observed water level: 40 years

<table>
<thead>
<tr>
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<tr>
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<tr>
<td>System</td>
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<td>9.7E-4</td>
<td>2.0</td>
<td>2.5E-3</td>
<td>1.2E-4</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Table 3.
RISK ASSESSMENT

Both vibrations are observed. At high wind speeds (above the cut out, when the rotor is parked at a safe position) only the vibrations at natural frequencies are observed.

The load at the foundation during a storm can be considered as the summation of a constant static part and a variable dynamic part. These forces change with wind direction and wind speed. Over the longer term, the static part may also change strongly.

The forces from a wind turbine on the foundation were calculated as a function of wind speed by applying the standard design model FAST (Jonkman & Buhl, 2005). A stiff foundation was assumed. Figure 2 shows the results of a sample calculation. The static component has two peak values, one just below cut out speed and one at the maximum expected wind speed. This is because, when the wind exceeds the cut-out speed, the rotor is parked at a position that minimizes the wind load on the rotor. The dynamic load due to the motion of the blades is more or less independent of the wind speed, presumably due to the adjustments. The dynamic load due to the natural frequencies increases more or less quadratically with wind speed.

Strength of the vibrations

The vibrations at the foundation and in the soil around a 3 MW wind turbine were measured at a moment with strong to stormy wind during two hours. The chosen wind turbine has a typical on-shore wind turbine design, with a foundation made of a heavy stiff block placed on a circular row of piles. The structure is located in a typical soft soil area.

During the measurements, the average wind speed was 15 m/s, with peak values up to 23 m/s, which meant the blades were not cut out. Both vibrations are observed. At high wind speeds (above the cut-out, when the rotor is parked at a safe position) only the vibrations at natural frequencies are observed. The load at the foundation during a storm can be considered as the summation of a constant static part and a variable dynamic part. These forces change with wind direction and wind speed. Over the longer term, the static part may also change strongly. The forces from a wind turbine on the foundation were calculated as a function of wind speed by applying the standard design model FAST (Jonkman & Buhl, 2005). A stiff foundation was assumed. Figure 2 shows the results of a sample calculation. The static component has two peak values, one just below cut-out speed and one at the maximum expected wind speed. This is because, when the wind exceeds the cut-out speed, the rotor is parked at a position that minimizes the wind load on the rotor. The dynamic load due to the motion of the blades is more or less independent of the wind speed, presumably due to the adjustments. The dynamic load due to the natural frequencies increases more or less quadratically with wind speed.
The measured peak acceleration was approximately 0.02 m/s$^2$. A representation of the vibrations in the frequency domain clearly shows the behavior that is expected from numerical calculations. In addition the rotor speed, the natural frequencies of the structure are visible.

The horizontal vibrations on the foundation and in the soil were relatively high, showing a peak at a frequency that was not seen in calculations with a stiff foundation. Figure 3 shows the vertical velocity of the vibrations for several distances behind the wind turbine. At low frequency (below 1 Hz), the vibrations from the motion of the blades and tower-nacelle are visible. These are strongly damped with distance. The additional frequency peak at 2.5 Hz can be explained from the resonance behavior of the foundation under a horizontal load combined with the very low stiffness at the surface layers.

Consequences for failure mechanisms

The accelerations in the soil are so low that they do not pose a direct risk to the dike’s stability. Accelerations for a 3 MW wind turbine are expected to be less than 0.1 m/s$^2$ during a severe storm. Failure mechanisms that depend on acceleration of the soil include the stability of the inward and outward slopes.

The high static forces may pose a higher risk to the dike, since the tension forces which eventually result may reduce the strength of the dike material and increase the risk of piping in the area around the wind turbine.

Long-term behavior

The high number of cycles may lead to an additional risk: compaction and fatigue of granular soil. This may lead to small settlements or additional damage to the soil, that reduces the strength on the long term. It may also influence the strength just during a design storm.

The generally used models are not suitable for the number of vibrations generated by a wind turbine, therefore an advanced model has been developed. The application of this model to the situation must still be evaluated.
Multifunctionality may influence risk significantly. Whether it really does and to what extent depends on the physical deviations of the dike with respect to its primary function: defense against flooding. This book presents and evaluates several examples: windmills on top of a dike, buildings or roads on a dike, parking on a dike, or a sewer or oil pipe in a dike. These cases show that safety can be influenced in both positively as well as negatively, depending on the size, materials and relative location of the intervention. This makes studying the safety of a multifunctional dike, compared to the mono-functional dike, an interesting subject.

The multifunctional dike is also a timely subject as it might offer useful solutions for areas with limited space. Here we have to realize that dikes are not only designed to solve current problems, but also those expected for some period in the future. This introduces the challenge that we can expect changes in the future related to the risk. Firstly, the hydraulic loads will change directly due to climate changes and indirectly due to adaptations elsewhere in the water system. Secondly, requirements for the functionality of dike may change in the future: e.g. a different safety level may be required (change of the primary function of the dike), or functions may change or new functions added. These are all uncertainties that we have to deal with now. Due to climate change, we can expect direct changes in loads. We can expect more frequent storms and more extreme storms at sea. Due to climate change, we can expect direct changes in loads. We can expect more and more intense rainfall, directly leading to changes in river discharge. These changes will affect storm and discharge levels, making the current defense level along the sea and river insufficient. To maintain the same protection level in the future, dikes will have to be raised and/or become stronger. In addition, the hydraulic loads will change directly due to climate changes and indirectly due to adaptations elsewhere in the water system.

This book presents and evaluates several examples: windmills on top of a dike, buildings or roads on a dike, parking on a dike, or a sewer or oil pipe in a dike. These cases show that safety can be influenced in both positively as well as negatively, depending on the size, materials and relative location of the intervention. This makes studying the safety of a multifunctional dike, compared to the mono-functional dike, an interesting subject.

Indirect changes are related to adaptations in water systems elsewhere. For example, the outflows from tributaries of the main river might be influenced by artificial measures, leading to more simultaneous flood peaks, as the time between the peaks of largest discharges is reduced. A higher safety level upstream can move the discharges more downstream so that the higher discharges have now a higher probability of reaching downstream locations. One can also imagine that large-scale offshore windmill parks will cause wave resistance and thus alter the tidal dynamics on the basin scale, leading to a different tide pattern. Coastal locations will face significant changes in tidal range, which might be lower or higher. Large-scale land reclamations might have similar effects.

It is hard to predict what future functional requirements dikes may have, beyond their role as flood defenses. One might argue that increasing spatial limitations will put pressure on dikes to provide solutions and alternatives. The kind of functions that we combine with the defense function of the dike may change as well. An example of this is the Afsluitdijk, the Southern Sea Closure Barrier, which was originally designed with a two-lane road, and leaving extra space for a railway to connect the northern part of the North Holland and Friesland. However, as it turned out, car transport grew much faster than forecast. This meant that the proposed railway was replaced by a broader, 4-lane road. If this option had not been available, broadening the dike would have resulted in much higher costs. This example shows that thinking ahead, and leaving space for future (as yet unidentified) needs, might help the future multifunctional use of the dike.

What can this teach us about future multifunctional flood defenses? When choosing a design today, we must realize that in the near future we may have to deal with unexpected changes, often physical ones, caused either directly or indirectly by climate change. At the same time, our social needs may change, affecting both the primary functions of the dike, as well as added functions. What functions can we think of? Fast transport over the dike? Dikes as large-scale waste-deposits? Trying to create a living (self-adapting) dike? In one way or another, we have to deal with all these uncertainties, and I would like to encourage making richer designs than the minimal ones deemed necessary at this moment. The research presented in this book helps to convince that added functions can be combined with high safety levels.
Multifunctional flood defenses: technical design problem or policy challenge?

Reflection

Prof. Drs. J.K. Vrijling is emeritus professor of hydraulic engineering at TU Delft University of Technology, faculty of Civil Engineering & Geosciences and director of Han & Partners. He was one of the founders of the International Multifunctional Flood Defenses research program and is a proponent in the project Safety and reliability assessment of MFFD's.

Over the ages, delta areas have greatly benefited their inhabitants. They generally provide fertile soils, rich fishing grounds and easy water transport, which facilitates trade. These natural resources stimulated population growth and made delta densely populated areas. The threat of flooding by storm surges at sea or high discharges from the rivers has never driven the inhabitants to higher and safer grounds. They accepted the recurrent disasters as inevitable, or they started to defend themselves and their properties by building on existing hills, or by building artificial mounds or even dikes. We can see this in the occurrence of the Dutch words for mounds and dikes in the names of old cities and streets, like ‘hil’, ‘warden’, or ‘terp’, and ‘dijk’ or ‘dam’.

The combination of delta life and relatively costly flood protection proved very successful. Not only have delta cities survived to the present day, many are also the richest parts of their respective country. This wealth means they are well positioned to cope with the challenges of the future that are common to all: population growth, exploitation of natural resources, pollution, soil subsidence, and sea level rise perhaps intensified by climate change.

In the eyes of engineers, such challenges can be overcome by technical solutions, which may be so successful that they further stimulate and enrich city life. Examples are sewers and drinking water supply, which greatly improved public health; but also underground metro and enrich city life. Examples are sewers and drinking water supply, which greatly improved public health; but also underground metro and metro systems, which facilitated trade. These natural resources stimulate population growth and made deltas densely populated areas.

Less efficient solutions seem to be chosen due to the specific planning pathways through the various institutions, which are often governed by different regulations. Combining all the functions efficiently would often extend the completion date of a project too far in the future.

The requirements of the shortest or the politically preferred time path often stretch the goal of the project too far in the future. However, in real-life each function is connected to a special interest group, and the structure has to fulfill all the different functions in order to gain the support of all the various interest groups. Each of the different functions is governed by its own set of laws and regulations, each of which follows a distinct path through institutions like city government, water board, planning authority and, last but not least, the ministry which provides funding. The planning, design, construction and commissioning of the multifunctional structure can follow only one path to completion, with the planning requiring the most time.

To discover, analyse and attempt to solve the real life problem, the specific structure of this research program was chosen (Figure 1). The Horizons project, for example, is a three-year project that seeks to combine all aspects simultaneously to create a solution in a single design. And although this design is still technically quite simple, in practice various interests seem to create problems, leading to the choice of less efficient solutions. The case study in Katwijk (see Figure 2, and Vrijling, pro- gram 24-25 and Amfuaral, page 90–93) shows another example, where the single point of view, the two functions ‘flood defenser’ and ‘parking’ can be combined most efficiently and without compromising safety by combining them into one single diaphragm wall, which may never be pierced for other functions. However, policy regulations prohibited this simple and cheap solution. This forced the designer to propose two separate walls, one for each function. In the course of the study, the real reason that the seemingly simple problem was not solved could not be identified.

Another example of a less efficient solution is the design of the De Kaap (Park&Ride), an attractive shopping mall that looks like a dike (see Program Case, page 116-135). Technically speaking this kind of structure could also function as a sea defense, but in fact the actual dike was built in front, and then both structures were covered by a park. Apparently, the gain of saving space by combining functions could not be made.

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Figure 1: High water in the historic port area of Dordrecht (Photo courtesy: Dordrecht WWZ bank).

Perspective of an end user: Berry Gersonius, municipality of Dordrecht

**LOOKING FOR ADAPTIVE CAPACITY IN DORDRECHT**

INTERVIEW

In Berry Gersonius is an expert on flood safety and stormwater for the City of Dordrecht. He is also a member of the MFFD project team for a Self-Reliant Island of Dordrecht and a senior lecturer in Urban Flood Resilience at IHE Delft. The municipality of Dordrecht was a user of the knowledge produced in the STW-Multifunctional Flood Defenses program projects ‘Flexibility and Adaptability’ and ‘Urban design challenges’. Berry was part of the user committee of Flora Amancor, who researched flexibility and of Peter van Weel, who developed a tool for adaptive flood risk management.

How do you describe a multifunctional flood defense?

“For me there are several forms of multifunctional flood defenses. Functions can be fully integrated, that is optima forma. Another form is when there is less integration, but the flood defense still has multiple functions. On the island of Dordrecht we have many multifunctional defenses, as the dike runs right through the inner city. In the Voorstraat, the buildings are literally on the dike. But I wouldn’t call that full integration.”

“But the Voorstraat is a special case. In the past, the water authority chose to strengthen part of the flood defense with a retaining wall. A strong concrete foundation was implemented along the river to prevent seepage, and all houses got a stop log system. This dike was primarily intended to prevent overtopping and over flow. But Wouter ter Horst and Matthijs Kok of your STW-program put us on a different track. We discovered that the stop log system could also perform a function related to risk standards. If Dordrecht has to meet more strict safety requirements in future, the Voorstraat will relatively soon be too low. Currently, the retaining wall and stop logs are not yet assessed as part of the flood defense. But we would take this system into account: it’s already there! If the reliability is assessed and becomes part of the safety standard, we can buy a lot of time. In that case the dike under the Voorstraat should be updated to standards until roughly the end of the 21st century instead of until about 2030. This way we are able to postpone a very expensive intervention, and potentially save half a billion euros.”

“[In Dordrecht] we also have a nice example of integration optima forma, which is the Noordendijk. There part of the house is built directly against the dike, just below the cret. In the past, the dike was strengthened with a technical intervention that is fully integrated. Foundation and design of a number of houses are part of the dike.”

What specific kind of knowledge is needed for full integration of a multifunctional flood defense?

“For the Voorstraat we still need knowledge to incorporate the reliability of the stop log system into the statutory assessment for the norm. If you want it to be considered part of the defense, you have to set requirements for the closure reliability. You need to know how do you execute the closure in practice? And you need to know how your protocol positively influences the closure reliability to what extent. How do you determine for example the failure probabilities of a Reliable Closure? And how can the water authority and the municipality take this along?”

How were you and your organization involved in the project?

“Dordrecht was one of the case studies of Flora Amancor. She has shown that it is very important to take the adaptive capacity of a flood defense into account. Making a design that can be customized in future will be very important. We’ve learned from the Noordendijk, that this is often a tricky thing. When functions are integrated, it becomes more difficult to heighten or strengthen the dike in the future. This really goes for each form of multifunctional, but especially at the Noor- endijk where the functions are fully integrated. It’s a very attractive architectural design, but options to expand such a design could have been taken into account at the time. If the Noordendijk has to be raised in the future, it will be quite hard in number of places. How did the academic research project match your organization’s practical needs?

“The advice to consider the stop log system and retaining wall for the safety norm was very helpful. But also Peter van Weel’s adaptation strategy research was relevant, and the looked at multifunctional flood defenses in the unembanked area. Those issues are very prominent in Dordrecht. The main part of the inner city—the historic port area—is unembanked. At some locations, floods might too often cause nuisance for citizens in this area. Then streets are closed and sewers cannot be used anymore, and often there is also damage. Currently, as a municipality, we provide residents with information to deal with these flood hazards. But in the long run, say after 2050 or even 2070, we’ll have to decide whether individual solutions are sufficient to be able to live in this area. Would it better to opt for other solutions, such as raising the flood defense in the Voorstraat with a movable barrier encompassing the historic port area? But how to integrate that into the city? And how can we start today to make administrative arrangements? Can that so we can measure residents: It is worthwhile to secure your property’s future. And taking an even broader perspective: what could be a more regional strategy for Rijnmond Drechtsteden, for example another closure regime of the Maeslantkering. How can you make arrangements on a regional scale? From Peter’s research we learned that we need to look at these different scale levels, and its ad- aptation model is a useful tool to do so.”
DESIGN & PLANNING

The design process is iterative because insight into the problem, goal and functioning of the system under development only grows gradually. The main design stages are described below.

1. Analysis

An inventory and analysis of the problem is made using given and found information (project file, informers, literature). This makes it clear exactly what the client wants to be accomplished. This results in a clear formulation of the problem, and an objective, solving the problem. The objective is formulated as fulfilling a certain function like protecting an area against flooding, which is still abstract. Requirements are then derived from the project objective to make it more specific. The designer needs to be restrained from jumping to specific solutions too quickly (generally Multifunctional flood defenses combine several functions into a single system. Therefore, several disciplines need to be combined to design such complex systems. An "integrated design" is a collaborative method that combines several disciplines for designing systems or structures, emphasizing a "holistic" approach. Holism is the concept of considering systems and their properties as wholes, not just a collection of parts. The functioning of the entire system cannot be fully understood solely in terms of its component parts. A holistic, integrated approach is believed to be more cost-effective and sustainable.

Sustainable design could be defined as the philosophy of designing physical objects, the built environment, and services to comply with the principles of social, economic, and ecological sustainability (McLennan, 2004). This contains the three essential elements, or 'pillars' of sustainability: society, economy and environment.

The Roozenburg and Eekels design model (see figure 3) can provide an approach for integrated and sustainable design. According to Roozenburg and Eekels (1995), who were professors in the Industrial Design Faculty of Delft University of Technology, a design starts with specifying functions formulated at an abstract level, and ends in a concrete shape that fulfills the requirements. Another feature of the method is that it can be carried out at different levels of detail. Finally, the method distinguishes five main design stages, which enable designers to phase and organize their design process. According to this method, a design consists of the following stages: analysis, synthesis, simulation, evaluation and decision (Figure 3).

Although in theory these stages logically proceed from each other, in actual practice the process is iterative because insight into the problem, goal and functioning of the system under development only grows gradually. The main design stages are described below.

A METHOD FOR INTEGRATED AND SUSTAINABLE DESIGN

Mark Voorendt

Dr.ing. Mark Voorendt is lecturer of Hydraulic Engineering at the faculty of Civil Engineering & Geosciences, TU Delft University of Technology. In the STW-MFFD program he worked as a PhD candidate in the project ‘Structural assessment of multifunctional flood defenses’. Mark graduated in 2017.

Dissertation title: Design principles of multifunctional flood defenses.

PhD Supervisor: Prof. dr. Han Vrijling, TU Delft.

Multifunctional Flood defenses combine several functions into a single system. Therefore, several disciplines need to be combined to design such complex systems. An “integrated design” is a collaborative method that combines several disciplines for designing systems or structures, emphasizing a “holistic” approach. Holism is the concept of considering systems and their properties as wholes, not just a collection of parts. The functioning of the entire system cannot be fully understood solely in terms of its component parts. A holistic, integrated approach is believed to be more cost-effective and sustainable.

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FIVE DESIGN STAGES

Figure 1. MFFD Zutphen, parking area integrated in flood defense (photo courtesy: Mark Voorendt).

Figure 2. MFFD Arnhem, flood defense incorporating city information building (photo courtesy: Mark Voorendt).

Figure 3. The Roozenburg and Eekels model of the design cycle (Roozenburg and Eekels, 1995).

1. Analysis

An inventory and analysis of the problem is made using given and found information (project file, informers, literature). This makes it clear exactly what the client wants to be accomplished. This results in a clear formulation of the problem, and an objective, solving the problem. The objective is formulated as fulfilling a certain function like protecting an area against flooding, which is still abstract. Requirements are then derived from the project objective to make it more specific. The designer needs to be restrained from jumping to specific solutions too quickly (generally...
familiar structures), because this would spoil the creative phase and likely lead to suboptimal solutions. The analysis phase includes an inventory of stakeholders, boundary conditions, prevailing laws and regulations, requirements, spatial aspects, and risks.

2. Synthesis
During this creative phase, alternatives are generated with brainstorm sessions or by drawing morphological maps. The solutions, that are generated now, use concrete materials and have concrete shapes. Reference projects can be searched for to provide extra ideas. Possibilities for generating additional values can also be thought of at this stage, if the project would appear to be unaffordable without them.

3. Simulation
The proposed alternatives have to meet all the requirements and the system needs to adequately fulfill its function. The main dimensions of the structure or system are usually derived from this main function. Additional calculations can be performed to ensure that the structure meets the requirements regarding structural and user safety. Simulations can also be used to check requirements (e.g., bottlenecks in a transport system can be detected using a computer simulation). For multifunctional flood defenses, an important element of the simulation is determining the project’s constructability. At this state, costs, planning, and spatial restrictions need to be considered, as well as technical and logistical aspects.

4. Evaluation
Once it has been determined that they meet the requirements, the alternatives can be compared with the help of qualitative criteria. Requirements should not be included in the criteria, nor should the costs. Since not all criteria are equally important, they should be weighted. The alternatives get scores per criterion and the product of score and weight factor is calculated. The sum of these products is the value per alternative. To compare the alternatives, these values have to be divided by the costs. The higher the value-cost ratio, the better the alternative. This systematic method of comparing alternatives is called the Multi Criteria Evaluation (MCE).

5. Decision
The alternative with the highest value-cost ratio could possibly be enhanced by adding strong elements from other alternatives, and possibly by adding values. The optimal variant can now be proposed to the client. If the client approves, the ‘winning’ alternative can be detailed in another design loop, where more ideas, detailed calculations and drawings are generated.

If this method is applied to an integrated and sustainable design, several issues need to be addressed. First, the project goal should include all main design aspects. The design, after all, results in a program of requirements, which is used to verify the created solutions. If the design fails to include all the design aspects, the program of requirements will also be incomplete. In that case, there is no guarantee that the resulting system will be integrated and sustainable.

Merely including experts of various disciplines in the design team does not guarantee an integrated design. Specialists tend to design their own part or sub-system, resulting in a design that consists of separate multidisciplinary solutions. So, having a multifunctional design team does not guarantee an integrated design. To achieve an integrated design, two or more disciplines need to work together on one design activity. An integrated design is about creating something new by crossing boundaries, and thinking across boundaries. To achieve that, the multidisciplinary team has to cooperate intensively during the phases of project definition, generation of alternatives and evaluation, at least during the first design loops. When it comes to a more detailed design, for instance the technical design of a reinforced concrete flood wall, multi-disciplinary cooperation is less important, and it is even desirable that this level be carried out by a specialist.

It is important to remember that there is a difference between using the tools properly and using the proper tools; this is the difference between just doing calculations and making a design. The design work is typically suited for an integrated group approach, whereas design calculations are best conducted by individual specialists. Of course, to ensure that the final result is integrated, the outcome of detailed calculations will have to be integrated again into the overall design activity.
Rebuild-by-Design

Competition New York

In response to Hurricane Sandy’s devastation the Northeast United States, U.S. Federal Department of Housing and Urban Development (HUD) Secretary Donovan launched Rebuild by Design in 2013, in collaboration with multiple public and private organizations in New York. New York now take on the design competition model would develop innovative, implementable solutions to respond to the region’s most complex needs. The Rebuild by Design competition was structured as a successive and connected set of stages, established to orient the design process around in-depth research, cross-sectoral and professional collaboration, and iterative design development. Rebuild by Design gathered the talent of the Sand-affected region. From 146 international applicants, 10 interdisciplinary teams were selected to compete in Rebuild by Design’s year-long process. In June 2014, the HUD announced $930 million to be awarded to seven projects that were developed as a result of the Rebuild by Design competition.

Source: www.rebuildbydesign.org

Kevin Raaphorst MSc is a PhD candidate in the STI-MFFD program at the Chair Group Landscape Architecture, Department of Environmental Sciences, Wageningen University & Research (WUR). He is part of the project ‘Contribution of MFFD’s to landscape values and spatial quality’. Kevin expects to graduate in 2017.

(Tentative) dissertation title: ‘Look Closer: Semiotic reflections on the visual communication of multifunctional flood defense landscape designs.’

PHD Supervisors: Prof. Adie van den Brink, WUR
Dirk van der Duin, WUR
Dirk Wijn van der Knaap, WUR
Gérard Bovenkool, Deltares

Research through designing: A landscape architect conducts research through designing (Lenzholzer Duchart, & Koh, 2013). New ideas can be generated, tested, evaluated, and implemented using tools such as design workshops, charrettes, or even a full-fledged design competition such as Rebuild by Design in New York (Rebuild by Design, 2015)(see textbox and Figure 1). The design process generates innovations the the kind that is more than the sum of its parts. The designer is an expert in creativity, and looks for new solutions to myriad problems. In a participatory setting, the designer invites stakeholders to engage with that creativity to come together on neutral grounds, with every participant transcending their own discipline, frame or expertise, thinking with each other instead of for each other, looking for consensus, not conflict (Kempenaar, Westerink, van Lierop, van den Brinkhuijsen, & van den Brink, 2016).

The process described above is an ideal model, and, like all models, it simplifies reality. A design process and certainly that of a multifunctional flood defense (MFFD) project, is not linear. It does not take place in a social, political or financial vacuum. If put on a timeline, that line would be more circular than straight, more angled than smooth. Participatory design processes bring together a diversity of stakeholders, each with their own frames (i.e., their professional and personal backgrounds) and each with their own perception of problems and solutions. Since each MFFD project is different, the involved functions and the involved stakeholders vary. Each project thus poses different challenges and requires different solutions, not only in the design of a physical flood defense structure or landscape, but also in the design of a participatory design process.

To facilitate such processes, landscape architects apply a range of visual tools, techniques and styles. Information is gathered, shared, documented, and analyzed. Ideas are formed, experimented with, criticized, praised, developed further or taken apart completely - all by means of visual representations. Such a range of communicative functions requires a range of visual representation techniques (Raaphorst, Duchart, van der Knaap, Bovenkool & van den Brink, 2017). Designers continuously ask themselves which visual representations are appropriate for a given situation. This question is often answered implicitly and pragmatically: tools are used simply because they work, or avoided because they don’t. But why do some tools work and others not? Do they work for everyone? Can they be improved?

Analytic framework

Due to the diversity and complexity of MFFD projects, we cannot give clear-cut recommendations for use of visual representations in participatory design processes. Rather, we suggest a way of organizing the processes and looking at visual representations that enables facilitators to determine the most appropriate communicative strategy at a specific moment, for specific stakeholders. Making appropriate visual representations requires both the ability to look critically at the design’s context, as well as the ability to express that content in a visual way while taking into account the creative and interpretive context of a participatory design process. This means one needs to vary. Each project thus poses different challenges and requires different solutions, not only in the design of a physical flood defense structure or landscape, but also in the design of a participatory design process.

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Research through designing: A landscape architect conducts research through designing (Lenzholzer Duchart, & Koh, 2013). New ideas can be generated, tested, evaluated, and implemented using tools such as design workshops, charrettes, or even a full-fledged design competition such as Rebuild by Design in New York (Rebuild by Design, 2015)(see textbox and Figure 1). The design process generates innovations the the kind that is more than the sum of its parts. The designer is an expert in creativity, and looks for new solutions to myriad problems. In a participatory setting, the designer invites stakeholders to engage with that creativity to come together on neutral grounds, with every participant transcending their own discipline, frame or expertise, thinking with each other instead of for each other, looking for consensus, not conflict (Kempenaar, Westerink, van Lierop, van den Brinkhuijsen, & van den Brink, 2016).

The process described above is an ideal model, and, like all models, it simplifies reality. A design process and certainly that of a multifunctional flood defense (MFFD) project, is not linear. It does not take place in a social, political or financial vacuum. If put on a timeline, that line would be more circular than straight, more angled than smooth. Participatory design processes bring together a diversity of stakeholders, each with their own frames (i.e., their professional and personal backgrounds) and each with their own perception of problems and solutions. Since each MFFD project is different, the involved functions and the involved stakeholders vary. Each project thus poses different challenges and requires different solutions, not only in the design of a physical flood defense structure or landscape, but also in the design of a participatory design process.

To facilitate such processes, landscape architects apply a range of visual tools, techniques and styles. Information is gathered, shared, documented, and analyzed. Ideas are formed, experimented with, criticized, praised, developed further or taken apart completely - all by means of visual representations. Such a range of communicative functions requires a range of visual representation techniques (Raaphorst, Duchart, van der Knaap, Bovenkool & van den Brink, 2017). Designers continuously ask themselves which visual representations are appropriate for a given situation. This question is often answered implicitly and pragmatically: tools are used simply because they work, or avoided because they don’t. But why do some tools work and others not? Do they work for everyone? Can they be improved?

Analytic framework

Due to the diversity and complexity of MFFD projects, we cannot give clear-cut recommendations for use of visual representations in participatory design processes. Rather, we suggest a way of organizing the processes and looking at visual representations that enables facilitators to determine the most appropriate communicative strategy at a specific moment, for specific stakeholders. Making appropriate visual representations requires both the ability to look critically at the design’s context, as well as the ability to express that content in a visual way while taking into account the creative and interpretive context of a participatory design process. This means one needs to vary. Each project thus poses different challenges and requires different solutions, not only in the design of a physical flood defense structure or landscape, but also in the design of a participatory design process.
In this research project we have developed a framework that can take a different way to take into account stakeholder configurations and the role of stakeholders in participatory processes (Raspopioli et al., submitted). In general, the communicative power of how a design is represented, is determined by an interplay of three key elements:

1. Interactivity: how the design representation engages with the viewer.
2. Readability: the visual qualities of the representation challenge design and expertise in the field. The process of designing is therefore not just about getting ideas on paper, but also about educating each other. This approach helps participants to value each other’s input better, which increases the validity of the choices made during the process.

The interactivity of a design representation (Figure 2) refers to the social context within which the design is created and interpreted. For instance, the degree of co-creation influences the authority of a design and public support for it. Who is allowed to make the design? How interactive is the design process? Are there enough incentives for feedback? If participants feel involved in the creation of a design, they are more likely to support it. If people feel ignored or unappreciated, they are more likely to oppose it. This question of ‘ownership’ is an issue for all stakeholders, and participants, whether that be a city council, an environmental protection agency, or an engineering firm.

The readability of a design representation (Figure 3) refers to the degree people can read and understand that design as a result of its visualization. For instance, we know that reading a map is a learned skill but so is reading and understanding a photomontage. It needs to be able to distinguish the existing situation from what has been added to the picture. Other visual choices, such as scale, perspective or color scheme also greatly influence the readability of a design and carry with them certain visual author-ship. For instance, a 3D rendering with a lot of detail suggests a finished design; this would not be a good choice for a first community meeting unless one wanted to provoke dis-cussion. Similarly, a hand drawn sketch might be a good product of a design workshop, yet it is likely that an engineer would discount it because of its lack of technical detail.

The validity of a design representation (Figure 4) is determined by the content. Content can be both objective and subjective. It can consist of data and knowledge, but also ideas, inspiration, feelings and emotions. The design’s content influences the possibilities and choice of representation: maps, photomontages and 3D models can each communicate different types of content in different ways. To be able to talk about content in this way requires a certain level of education, awareness of design challenges and expertise in the field. The process of designing is therefore not just about getting ideas on paper, but also about educating each other. This approach helps participants to value each other’s input better, which increases the validity of the choices made during the process.

Paradoxical content: Stakeholders are organized according to certain levels of participation. Scientific experts, for instance, contribute valuable knowledge, but rarely meet local inhabitants, Lagendijk or mayor convene with city planners, yet rarely meet ecologists or hydrologists. Integrated knowledge can only be created and shared if it is mediated between these groups. This means that stakeholders at all levels need to be included, and that the communication between them needs to flow in both directions. If this is not monitored and evaluated, specific stakeholder groups may develop their own ways of designing knowledge about the project, visual language to express that knowledge, and ways of interacting. Since these different design processes will tend to diverge, the design’s content may become incompatible, which will make it complicated to integrate them at a later stage.

The diversity of stakeholders is reflected in the diversity of interaction, readability and validity of designs. These three elements can complement each other but they can equally well overpower or even contradict each other. This diversity will influence how the design is interpreted.

For a visual representation to be effective and communicate successfully, all three elements need to be considered. In practice, the details will depend on the nature of the project, the stakeholders involved, and how their participation is organized. By acknowled-ging this complexity, and by creating (and interpreting) visual representations according to the three-step analytical framework built in this research, communication will become more conscious and empathetic, and ultimately more effective. This can lead to an increased sense of confidence and design ownership among the stakeholders, which in turn will improve the chance that the design will be implement-ed as it was intended.
Peter van Veelen

ADAPTIVE PLANNING FOR RESILIENT URBAN WATERFRONTS

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Peter graduated in 2016.


Many delta and coastal cities worldwide face increasing flood risk due to changing climatic conditions and sea level rise. The question is how to adapt existing coastal areas to these slowly changing conditions?

A major challenge of adapting existing coastal urban areas is that it requires integrating long-term trends and changes that easily exceed periods of 50 to 100 years. This brings large uncertainties in the design and planning process. Dealing with uncertainty requires improving the ability to adapt. Adaptability can be both tactical-operational (designed) and strategic (planned). On a strategic level adaptability can be achieved by developing sequences of adaptation options (pathways) that allow options open in anticipation of future conditions. Additionally, key to successful adaptation of urban environments is the ability to use moments of change in urban development and management for low-cost adaptation and to yield additional benefits. This requires a better understanding of the opportunities to spatially and timely synchronize adaptation measures with spatial development, urban management and infrastructure maintenance projects, and finally, to create multi-functional coastal landscapes.

In the Thames Estuary 2100 project, it has not yet been applied to the level of urban development and local adaptation planning. Additionally, applying the method at the local level helps to better understand if incorporating adaptation pathways into urban development processes is an effective strategy to enhance the overall resilience of urban waterfronts.

There is a wide range of adaption actions available ranging from small-scale building-to-building adaptations to large-scale flood protection infrastructures. This research concluded that, particularly under shallow, low-energy flood conditions as found in the Rotterdam unembanked areas and New York City’s waterfront, retrofitting flood resilience measures to buildings is effective in terms of flood risk reduction. However, because retrofitting flood resilience to buildings needs regular renovation and rebuilding projects to be cost-effective a building level adaptation strategy would require at least a period of 20-50 year, which would hardly surpass the expected increase in future flood risks. Additionally, due to policy regulations and economic restraint it is expected that only a small portion of the building stock will adapt incrementally. Consequently, one of the key findings of the case study research is that in high density urban conditions there is a limited potential to build resilience from household development and renovation on the short term even when new complementary policies and regulatory instruments that support building-level resilience would be developed. Distinct...
Dynamics. Method (APM) 4. Disaster management 3. preventive measures

1. Flood proofing existing buildings
   1a. dry-proofing
   1b. wet-proofing

2. Renovating one building
   2a. dry-proofing
   2b. raised buildings
   2c. dry-proofing urban infrastructure

3. Preventive measures
   3a. new mixing well
   3b. elevated quay
   3c. temporary flood defense

4. Disaster management
   4a. evacuation route
   4b. preventive evacuation and crisis management

wide flood protection is effective both in terms of flood risk and is economically beneficial, but requires large-scale transformations of the waterfront zone to seize opportunities to develop integrated protection at low costs. Additionally, a multi-purpose flood protection strategy often needs financial arrangements to capture potential values and redistribute costs and benefits fairly among the stakeholders.

Another major challenge is that a change of strategy, for example between building level and district wide flood protection, runs a risk of a financial lock-in. Every single investment in building level resilience reduces the overall flood risks and hence the benefits accruing to a district-wide protection option making a ‘transfer’ to a district-wide solution less feasible from an economic point of view. This economic path dependency is a serious constraint for moving towards more resilient waterfronts, particularly for New York City where landlords and homeowners started to invest in property protection. However, co-benefits for urban development and added values arising from flood protection investments (e.g. increase in real estate value) may have a positive effect on reducing the transfer costs, although the effect strongly depends on local conditions. This means that it is necessary to decide early in the adaptation process on the long-term adaptation strategy and to support this strategy with short-cycle, low cost interventions aiming at ‘buying time’ to increase the opportunities for creating district-wide protection that offer additional opportunities for urban development.

Based on the case study research, this research concludes that the Adaptive Pathway Method is an effective tool to evaluate and select appropriate adaptation measures. Additionally, the method helps to better grasp the timing of adaptation and develop a wide portfolio of adaptation actions, which opens up opportunities to couple adaptation measures with other planned investments or to anticipate urban design to allow for easier adaptation in the future.

However, a fundamental shortcoming of the adaptive pathway method is that it helps to identify key interventions (e.g. spatial, legal or financial) that are needed to unlock the potential of adaptation opportunities. The method helps bridging the gap between adaptation planning and urban development and management.

A more effective frame, introduced in this research, is to build pathways based on identifying adaptation intervention points, which is to capture all the actual moments of change that may be used for adaptation, adaptation transitions that are defined as changes in legal, institutional and financial structures that improve or unlock the full potential of adaptation intervention points, and, finally, adaptation transformations that are fundamental changes in urban form, policies, institutional arrangements and norms that could create new adaptation opportunities. Applying this frame to the case study locations in Rotterdam and New York (see Figures 6 and 7 below and case study pp. 74-75)

Feijenoord). (Noordereiland and

Rotterdam flood prone neighborhood.

Figure 4. Adaptive Pathways Method (APM) Dynamics

Figure 5. Adaptive Pathways Method (APM) applied in Rotterdam flood prone neighborhood Noordereiland.

Figure 6 and 7. Case study locations in New York City (Red Hook) and Rotterdam City (Noordereiland and Feijenoord).
CASE STUDIES: ROTTERDAM AND NEW YORK

DIFFERENT STRATEGIES TO COMMUNITY BASED ADAPTATION TO FLOOD RISK

Although storm at the North Sea produces moderate flood risks, the rare but severe hurricane-impacted storm surge flood levels at the river Meuse and Scheldt can show comparable flood characteristics (see Figures at top next page). The majority of the urbanized waterfront areas in New York City and Rotterdam are mostly exposed to slowly rising storm surge flooding that causes relatively short and short-lived inundations.

The New York–New Jersey estuary is particularly vulnerable to storm surge flooding because of the orientation of Long Island Sound, New Jersey Sound, and the natural funnels that drive sea water into the Newark Bay Harbor; this creates two natural funnels that drive sea water into the Western Sound and Upper East River, and up to the New York–New Jersey coast. (Boxman et al., 2005). Also, the effects of climate change are felt more intensely at the New York City-North Jersey coast. This is not only because of differences in expected storm intensity and higher expected sea level rise, but also because New York City lacks storm surge protection that reduces the impact of the storm surge and extreme water levels before it reaches the urbanized coastal areas.

This is a contrast with Rotterdam where the Maeslant barrier and Haringvlietdam strongly reduce the effect of storm surge flooding in the upstream areas. Additionally, the effect of increased river discharges is a more dominant factor in waterfront flooding, particularly for the upstream cities as Dordrecht. Both metropolitan regions share the need for adapting their urban water management to the increasing flood risks in the near future and developing sustainable flood protection strategies responding to future conditions and opportunities when they unfold.

Despite clear similarities in flood risk, the flood risk management approaches differ considerably. The US flood risk management model is based on individual building level resilience and disaster management (short-term relief programmes and evacuation strategies) and recovery after a flood less on disaster avoidance and prevention as it is the dominant approach in the Netherlands.

An essential part of the US flood manage- ment strategy is the federally operated National Flood Insurance Program (NFIP). This program enables property owners in flood prone areas to acquire insurance against damage of flood risk, as long as they meet the basic require- ments for constructions in flood prone areas. In the Netherlands, the unembanked areas are considered part of the river’s flood plain. Consequently, the property owners do not enjoy flood protection and are bearing all full economic consequences of flood risk.

Currently, it lacks a comprehensive flood risk policy for flood protection of existing buildings in the flood prone areas. There is no disaster management plan in effect and, in addition, flood risk is not available in regular home insurance. Additionally, both approaches lack a comprehensive risk approach, covering all aspects of flood risk and ignoring the flood risks arising from critical systems vulnerability.

Community based adaptation

Understanding the differences in response to increasing flood risk, we also see a com- parative adaptation approach developing both cities reach out to the community level.

To stimulate homeowners to invest in flood resilience, the New York City Department of City Planning recently updated the zoning ordinance and the City’s building codes (NYCDOCD 2013). One of the adjustments made is an extension of the opportunities to reduce flood risk and insurance rates through proofing actions, by adding an equivalent volume to the impervious area for any buildings on property. Further- more, inspired by the Rebuild by Design competition that was launched in 2013, several areas in New York City have integrated flood protection schemes under development. In these projects, close collabora- tion with the needs of the local community is sought.

In Rotterdam, alternative adaptation mea- sures are developed as well: such as dry- guided urban planning and flooding; the storm surge protection integrated in urban renewal and waterfront renovation programs. The city of Rotterdam developed together with nearby the city of Dordrecht a community information program to raise flood awareness and to stimulate homeowners to invest in flood resilience.

Both cities show that widening the portfolio of potential adaptation responses increases resilience of waterfront communities and opens opportunities for tailor-made approaches that better align with local dynamics and agendas.

The urbanized area of Rotterdam (image above, below) is located at the confluence of the rivers Meuse and Rhine into the North Sea making this area vulnerable for both coastal and Ruwals floods (Delta Program Rijnmond-Drechtsteden, 2014). A large network of dunes, primary dikes, walls and locks protects the low-lying urbanised polders of Rotterdam from flooding.

However, a considerable part of the Rhine Estuary Region has large unbanked alluvial areas that are almost entirely urbanized and not protected by the primary flood defence system. In the large metropo- litan Rijnmond-Drechtsteden region more than 2,020 ha of urban areas are located in the 100-year flood zone between the North Sea and the city of Dordrecht (RIVM, 2009), of which a large part is urbanized or in use for industrial activities. Approx. 85,000 people live in the unembanked areas of some 200 ha. (Veerbeek et al., 2007)

The former port areas and historic merchant districts of Rotterdam and the adjacent cities of Dordrecht and Vlaardingen are exposed to tidal and seasonal flooding. The majority of these unembanked areas are built on higher ground, or were elevated over time to above high tide. In the near future, the decades of flood risk is increasing due to rising sea levels and subsidence, as well because of these port areas are built on lower ground, the city and river are attractive places for urban development.

This text is an adapted version of chapter 5 of the dissertation ‘Adaptive planning for resilient coastal waterfronts’. Peter van Veelen (2010).

The most vulnerable area for flooding is the Lower Manhattan, including the financial and business district, but also parts of the Brooklyn waterfront, Long Island City in Queens and coastal zones of Staten Island, Jersey City and Hoboken. In fact, about 650,000 people and over 250,000 residential units are located in the 100-year floodplain and an additional 35,000 buildings with 145,000 residential units are located in the 500-year floodplain in New York City alone (Findlay et al., 2014). In these areas a considerable amount of vital assets, among which the La Guardia Airport, subway entrances, wastewater treatment plants and tunnels, are located in the 100-year floodplain.

New York City’s population is growing and is expected to grow in the future (NYC, 2015). The city’s housing strategy is encouraging growth of urban settlements expanding the existing city boundaries by intensifying neighbouring areas, and encouraging transit-oriented development, and transforming underuti- lized former industrial areas (NYC, 2011). Particularly former industrial sites in Brooklyn along the East River and waterfront areas, in Jersey City, can offer opportunities for large-scale, high-density development, most of them located in flood prone areas.

New York City, New Jersey Estuary: A Large Flood Prone Waterfront.

Although the major part of New York–New Jersey metropolitan region is built on higher grounds (top image), the city has a 520-mile-long low-lying waterfront area that lies less than 2.5 m above mean sea level. The largest flood-prone area is located in Jersey City and Hoboken covering over 250,000 residential units. The major flood-prone areas are located in the 100-year floodplain and an additional 35,000 buildings with 145,000 residential units are located in the 500-year floodplain in New York City alone (Findlay et al., 2014). In these areas a considerable amount of vital assets, among which the La Guardia Airport, subway entrances, wastewater treatment plants and tunnels, are located in the 100-year floodplain. The most vulnerable area for flooding is the Lower Manhattan, including the financial and business district, but also parts of the Brooklyn waterfront, Long Island City in Queens and coastal zones of Staten Island, Jersey City and Hoboken. In fact, about 650,000 people and over 250,000 residential units are located in the 100-year floodplain and an additional 35,000 buildings with 145,000 residential units are located in the 500-year floodplain in New York City alone (Findlay et al., 2014). In these areas a considerable amount of vital assets, among which the La Guardia Airport, subway entrances, wastewater treatment plants and tunnels, are located in the 100-year floodplain.

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LEGISLATION AND REGULATION IN SPATIAL PLANNING FOR MULTIFUNCTIONAL FLOOD DEFENSE DESIGN

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Can the recent rise of Dutch multifunctional flood defenses be explained by the increased integration between the water and spatial planning sectors, which compel Water Boards to collaborate with municipalities? An enquiry into the changing relations between water managers and municipalities as a result of changes in spatial and water-management regulations starting in the 1800s, and particularly since 2000s, indicates this hypothesis to be wrong.

In the Netherlands, the responsibility for spatial planning is officially assigned to the three tiers of government (Kingdom, provinces and municipalities). The responsibility for water management, on the other hand, is assigned to the single-purpose authorities. In 2003, the national policy agreement on water management in the 21st century (National Restauconrational Water Plan) led to changes in regulation. The policy agreement aimed to safeguard space for water storage, a goal of the Water Authorities that required the assistance of local governments. This ‘spatial track’ followed by water interests in pursuit of their goals may explain the construction of recent multifunctional flood defenses like the Scheveningen Boulevard/Varlijk’s parking garage or Rotterdam’s Roof Park. The water sector would not have been unique in this approach. Other sectors, such as heritage conservation, also addressed their goals calling for an integrated spatial planning approach in this period (Janssen et al., 2014).

Legislation and regulation regarding water management and spatial planning however, the historical record presents a different story of the changing relations between water managers and municipalities. In the nineteenth century, a series of acts laid down the foundations for the relations between the Water Authorities with the other governmental entities of the Kingdom, the provinces and the municipalities (Driesprong, 2014). In 1850, the Provinciewet (Province Act) formally established that the Province should supervise flood defenses managed by regional Water Authorities. ‘Waterschaps- werken’ (national water works), waters, flood defenses and road infrastructure of national concern were managed by the Kingdom, and thus exempted from Provincial supervision. The Kingdom was given many powers in the 1891 Wet Beheer Waterschapswerken (Management of National Water Works Act).

The Kingdom’s executive agency regarding these matters, Rijkswaterstaat, could make decisions independent of the Province. Moreover, the Act explicitly prohibited use of the flood defense other than for flood safety, unless the responsible Minister granted permission. At that time, the municipality had no official role in water management, through local governments were authorized to regulate land use in the 1900s. Where local and regional Water Authorities had to deal with supervision by the Province in general, Rijkswaterstaat only had to gather approval for the creation of new land, a provision arranged in the 1904 Wet Beheer Waterstaatswerken (National Water Works Act).
Relations between the different government entities and responsibilities have remained unchanged in the first sixty years of the 20th century. The 1921 Zuiderzeewet (Southern Sea Act) and the 1958 Delta Act (Delta Act) were executive laws enabling the construction of the Dutch great works: the Zuiderzee Works and the Delta Works. Both acts were replaced during the second millennium by new acts. The 1995 act concerning the Zuiderzee Works and the Delta Works had been completed. The 1995 Wet op de Ruimtelijke Ordening van de Ruimte (Spatial Planning Act) represented a change, though at the time it did not affect the planning of land use. The 1995 act encompassed the legislation of the former Flood Defense Act and the Delta Act on the large rivers. The act formalized this quick route, which permitted lengthy spatial planning procedures to be skipped. The 1995 act stated that the Water Authority could issue environmental permits in lieu of permits from other authorities. The act also added another layer of spatial planning to the land use plan. This tool was to guarantee that any new structures in flood defense zones could not jeopardize the integrity of the flood defense or hamper its intended function in the future, should the need arise (Stowa, 2001, 2016).

Thus, the 1995 act gave Water Authorities a tool that Alkmaarse had possessed since 1992, whereas they had previously had to rely (at least in theory) on the municipal land use plan. Anyone wanting to build something near the flood defense had to request at least two permits: one from the Water Authority, and one from the municipality. So, in sharp contrast to the handling of the twentieth century regulations strengthened the control of the Water Authority over the land use near and the flood defense. In the first decades of the twenty-first century, water interests have been even more intensively integrated into spatial plans. This has turned many water managers into influencer of spatial plans to accommodate not only flood defense plans, but also multifunctional flood defense in the context of this larger phenomenon of increasing interaction and plurality.

What factors have been decisive for the rise of multifunctional flood defences in the first fifteen years of the new millennium remains out of scope. It could be tied up of Dutch waterfronts has encouraged the combination of functions at sites that used to accommodate only one function, flood safety. It is clear that with the Scheveningen Boulevard, a broader phenomenon could also be at work, as it formulates spatial planning as the defining way of looking at the world and business. Modernist planning and architecture have been associated with functionality, uniformity, and modernity as the defining way of looking at the world and business. Modernist planning and architecture have been associated with functionality, uniformity, and modernity.
INTEGRATING SALT MARSH FORELAND INTO THE DIKE DESIGN

A WINDOW OF OPPORTUNITY FOR A SELF-MAINTAINING LEVEE

Integrating natural salt marsh foreland with a structural flood defense is increasingly seen as a promising approach to flood protection under changing climatic conditions and as a way to combine multiple functions and values in the coastal zone (see Van Loon-Steensma page 148 this volume). The potential of this multifunctional flood defense concept has been explored in the Dutch Wadden Sea region.

Extensive salt marshes are present along the dikes of both the Wadden Sea mainland and the barrier islands (see figure 1). These marshes form a shallow transition zone that attenuates incoming waves before they reach the dike. When water depths in this zone diminish to less than the wave base, the wave's shape is modified and it starts shoaling. Wave length and wave velocity both decrease, and wave height increases before breaking. After breaking, wave energy is further dissipated by drag induced by marsh vegetation and by bottom friction. Wave damping depends strongly on the profile of the coast, the water depth above the salt marsh, the width of the salt marsh zone, surface topography, and vegetation characteristics (Le Hir et al. 2000; see also studies cited in Anderson et al. 2011 and in Gedan et al. 2011).

Salt marshes are areas vegetated by salt-tolerant plants and subject to periodic flooding due to the fluctuating water levels of the adjoining saline water body (Adam 1990). They generally develop in the intertidal zone in sheltered conditions where wave action is limited, allowing fine sediment to settle and accumulate (Allen and Pye 1992; Allen 2000). Once the upper part of the intertidal zone is no longer submerged with each tide, salt marsh plants can become established. By trapping sediment, pioneer vegetation contributes to accretion and development of creeks, rendering the environment suitable for species (forbs, grasses and low shrubs) that need more stable sediment and are less tolerant to flooding (in duration as well as frequency) (Adam 1990; Allen 2000). This results in zones, with pioneer species seaward and more mature vegetation in the higher landward zone. Because of the positive feedback effects of salt marsh vegetation and sedimentation, vegetation plays an important role in salt marsh formation (Allen 2000).

However, like most coastal systems, salt marsh ecosystems are extremely sensitive to changing environmental conditions. Strong currents or wave attack may lead to lateral erosion. Generally, a moderate sea level rise creates conditions where marshes build up by accretion (Allen 2000) or shift landward. To keep pace with a rising sea level, however, a permanent supply of sediment needs to enter the tidal system. If sediment import is insufficient, flats and marshes will drown (Van Gror et al. 2003).

Various exploratory and field studies have been conducted in the Wadden Sea region (which is characterized by shallow water depths and moderate storm wave heights). These studies have shown that the salt marsh areas adjacent to the dike significantly affect wave impact on the dike (see e.g. Smaale, 2014; Vuik et al. 2016). Including salt marsh foreland into the dike design would affect both the height and revetment requirements needed to meet the required safety level. Analysis of the effect of realistic vegetation characteristics on modeled wave heights also showed that wave damping is strongly related to the variety of vegetation.
Extensive research on this subject can be found in the PhD thesis of Jantsje van Loon-Steensma: ‘Salt marshes for flood protection. Long-term adaptation by combining functions in flood defences’ (2014). The thesis investigates if and how the same or an even higher level of safety can be achieved in the Wadden region by means of creating a flood defence zone that favours, besides flood protection, nature and landscape values or heritage, recreational, and even economic values. While all available innovative flood defenses are considered, special attention is given to the role of salt marshes in this context.

The thesis shows that integration of salt marshes into long-term adaptation strategies is very promising for the Wadden region, especially for dike sections where salt marshes are already present or developing. Vegetation is a major factor in the wave damping capacity of salt marsh forelands, therefore it is important to take into account the zonation of different plant species and the specific zone of the salt marsh (Van Loon-Steensma et al. 2016). At the study site, a densely vegetated foreland 90 m wide would dampen the wave height more than 80% under average storm conditions (with a frequency of 5-15 times/y), whereas under extreme conditions (1/2000 y) the same foreland would dampen the wave height up to 50% (Van Loon-Steensma et al. 2016). These results emphasize the potential of a multi-functional flood defense using salt marsh forelands, which integrates safety with nature and landscape values.

However, flood protection imposes different requirements on the extent and features of salt marshes than nature conservation and development (Van Loon-Steensma & Vellinga, 2013). Wave damping is most effective with a high, stable, and densely vegetated salt marsh, while nature thrives with dynamic processes and changes in elevation (Allen, 2000). In practice, this means that the design of the flood defense must offer space for natural salt marsh processes, which require variations in height and depth developing over time in the foreshore zone. The design needs to combine hard coastal defense infrastructure with a dynamic ecological zone adjacent to it. The overall design set thus be characterized by a broad zone that includes a hard engineered solution, rather than by a merely metered cross section commonly used in engineering solutions (Figure 3). If this ecological zone is able to adapt to changing conditions, for example by keeping pace with sea level rise, then such a broad flood protection zone can be seen as a self-maintaining levee. Of course, the vegetated foreland and adjacent mudflats must be managed and maintained in such a way that they can meet as far as possible both the ambitions of flood protection and those of nature conservation.

Figure 2. Salt marshes along Galveston Island at the bay shore, Texas, USA (Image courtesy: Baukje Kothuis).

Figure 3. (above). Coastal defense system combining hard engineered infrastructure (a dike) with an adjacent dynamic ecological zone (a salt marsh) (Source: Van Loon-Steensma et al. 2014).
The application of the state of the art in ROA faces difficulties on two fronts (Neufville et al. 2008). 1. Methods of modeling trinomial lattices and stochastic dynamic programming are challenging and laborious, and the resulting full nodal connectivity does not map to the built environment; where assets are hard or impossible to sell. 2. Sourcing the probability information for constructing the aforementioned decision trees is difficult, if not impossible.

Furthermore, the exercising of an option can prohibit the application of other options. The inability to account for path dependence, makes the use of standard real options representations, inappropriate for infrastructure. To summarize, this research aims to advance the modeling of path dependence and integrating the use of a multiple of sources of uncertainty. The methodology allows for a simple yet explicit modeling of uncertainties and the path dependence of decisions. Next, it enables the activation of these decisions in a user specified time domain (cf. Figure 1).

The case study of Vietnam highlights the use of the method and analysis the results of method. The methodology is illustrated by applying it to the feasibility analysis of a multi-functional dike system in the city of Can Tho along the Mekong River. The project has a time window from 2010 until 2100 with an annual time step for the analysis (river level simulations are monthly). The outcomes of the strategy ‘do nothing’, and the strategy ‘build dikes with extra height of 120 cm.’ are visualized in Figure 2. There are six different modules (one of which is defunct) into two categories; three different foundation sizes, and their associated dike heightening (50 cm, 70 cm and 120 cm). Dike heightening can only be constructed if a base greater or equal to their pre-requisites exist. Once an artifact of a particular size has been constructed, it cannot be followed by a smaller artifact. For example the difference in risk between the strategy ‘build dikes with extra height of 120 cm.’ and their associated dike heightening (50 cm, 70 cm and 120 cm). Dike heightening can only be constructed if a base greater or equal to their pre-requisites exist. Once an artifact of a particular size has been constructed, it cannot be followed by a smaller artifact.

By increasing the safety factor, the building of the next module will be triggered, when the river level is some fraction below the maximum river value. However, as the river level is time consuming and expensive. Over time, with changing demands and threats, these artifacts need replacement, upgrades or removal. Designing these objects assuming a fixed life or for perpetuity, neglects the reality of mutability of our built environment and variations in natural systems (Milly 2008). Consequently, in locations where there is a great degree of uncertainty, it may be worthwhile to consider modular structures and systems.

Pairing flexible infrastructure with pre-planned adaptation opens the door for new forms of infrastructure systems. This is in contrast with the current ad-hoc adaptation techniques. With ad-hoc adaptation and stochastic optimization methods, it is possible to create policies that attempt to meet the multitude of values and constraints of stakeholders, with a possibility of rethinking in the long term (Hassoncni et al. 2015). To date, real options analysis (ROA) has been one of the leading methods for adaptive decision-making.

The development of the strategy ‘do nothing’, and the strategy ‘build dikes with extra height of 120 cm.’ is difficult, if not impossible. The methods of modeling trinomial lattices and stochastic dynamic programming are challenging and laborious, and the resulting full nodal connectivity does not map to the built environment; where assets are hard or impossible to sell. Sourcing the probability information for constructing the aforementioned decision trees is difficult, if not impossible.

Furthermore, the exercising of an option can prohibit the application of other options. The inability to account for path dependence, makes the use of standard real options representations, inappropriate for infrastructure. To summarize, this research aims to advance the modeling of path dependence and integrating the use of a multiple of sources of uncertainty. The methodology allows for a simple yet explicit modeling of uncertainties and the path dependence of decisions. Next, it enables the activation of these decisions in a user specified time domain (cf. Figure 1).

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By increasing the safety factor, the building of the next module will be triggered, when the river level is some fraction below the maximum river value. However, as the river levels are non-monotonic, floods can still occur if the dike height is insufficient. Furthermore, as the construction of the defense may take multiple time steps, floods can still happen during the building process.

The outcome of this application shows the consequences of different choices in construction; for example the difference in risk of the strategy ‘do nothing’, and the strategy ‘build dikes with extra height of 120 cm.’
CONCEPTUALIZING FLEXIBILITY FOR MULTIFUNCTIONAL FLOOD DEFENSES

Fatema (Flora) Anvarifar

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The very existence of the Netherlands and its prosperity is tightly linked to the provision of sufficient and reliable flood protection. Flood risk can change, as it is influenced by continually changing environmental and socio-economic factors. In such a dynamic situation, maintaining sufficient safety requires continuous investment in maintenance and reinforcement of the flood defences. Often, flood defence reinforcement requires more space, which is scarce in densely populated urban areas. While the competing needs of housing, commerce, transportation, and agriculture have to fit in a relatively small surface area in the Netherlands, the safety of the living environment and the quality of the landscape have to be maintained as well. One way that has been suggested to deal with this conflict, flood protection and urbanization is by combining activities in the available space. This can be achieved by integrating urban functions into the flood defences. These are referred to as multifunctional flood defences.

Multifunctional flood defences are long-lived, capital-intensive and generally irreversible interventions. The performance requirements for these structures can vary considerably due to socio-economic, technological, and environmental developments. Since choices made today will influence those of tomorrow, the extreme difficulty of adjusting multifunctional flood defences can lead to poor system performance with unnecessary capital and operational costs, or the need for expensive system upgrades to meet future demands. The changes that might impact the performance of multifunctional flood defences in the future are highly uncertain. One of the best ways of enhancing a system’s capability of handling uncertain future conditions is by increasing its flexibility. The question is how we can increase the flexibility of multifunctional flood defences.

Flexibility is agreed to be a capability to change or be changed rather than being static in time, but there is no consensus about what characterizes flexibility and how to achieve and evaluate it. The proposed working definition of flexibility is as follows: ‘Flexibility is a system attribute that enables responding to changing conditions, in order to reduce the negative consequences of uncertainty and change, and exploit the positive consequences, in an efficient, timely and cost-effective way.’

The use of flexibility as an approach for coping with extreme climatic events is nothing new. In spite of the popularity of the concept, there is no consensus across the literature about what characterizes flexibility and how to achieve and evaluate it. Anvarifar et al. (2016) developed a framework used to increase the flexibility of multifunctional flood defences. The framework consists of four self-consistent and step-wise questions. To help answering each of these four questions, eight characteristic features are distilled from literature: change, uncertainty, goal, capabilities, temporal, mode of response, types, and enablers. Each of these characteristic features is associated with the four questions of the framework:

Q1. Why is flexibility needed? This question identifies the motivation for consideration of flexibility. This can be done by identifying the type of change (internal or external to the system) and uncertainty (sources, levels) that is chosen to be handled.

Q2. What is it that flexibility is required for? This question seeks to describe the competences of flexibility to achieve its goal (via times, performance, cost penalties, prevented).

Q3. What are the dimensions of flexibility? This question indicates the extent to which flexibility can be achieved, from a temporal point of view (strategic, tactical, or operational) and the mode of response (proactive or reactive).

Q4. What needs to change or be adapted? This question discusses the potential ways of achieving flexibility, in this research, flexibility types (or managerial flexibility) indicate the managerial actions and decisions that should be taken to consider and use flexibility while flexibility enablers (or design flexibility) refer to the sources of flexibility (or where flexibility is) embedded in the system’s technical design.

The functionality and potential of this framework is explored in an illustrative case study in Vlissingen, where a series of buildings have been constructed on top of a sea dike (see pp. 86-87). Full explanation of the framework can be found in Anvarifar et al. (2016).
Vlissingen, situated along the Western Scheldt, in the province of Zeeland, has buildings and a promenade built onto the sea dike. For this case, the framework explained on page 87 was used to discuss flexibility of the sea dike to deal with uncertain sea level rise. Accordingly, two options for increasing the flexibility of the dike are proposed (Figure 1). In both options, some extra land is reserved for the staged reinforcement of the dike. Both options increase flexibility by enabling the postponement of dike reinforcement until more is known about the extent of sea level changes.

Next, the framework is used to discuss flexibility for the buildings. The aim is to handle uncertainty about the demand for housing. It is proposed that constructing the buildings on stronger foundations (Figure 2), will make it possible to develop more housing in the future if the demand increases.

Finally, the framework was applied to discuss flexibility for a multifunctional flood defense when the sea dike and the buildings are combined. When the two structures are combined to become a multifunctional flood defense, the embedded flexibility in each structure can reduce the flexibility of the other structures. For example, the need for a stronger building foundation will require a different dike design, one which can carry the extra load caused by the weight of the raised buildings in the future. The need for a stronger dike requires more initial investment in dike construction. Hence, increasing the flexibility of the secondary function can actually reduce the flexibility to delay the dike reinforcement interventions. In contrast, it can be seen that when the framework is used to address uncertainty of the whole multifunctional flood defense integrally, the design of one structure can actually increase the design flexibility for the other structure. For example, in the situation described above, if the buildings are built to be flood-proof, they can contribute to flood protection. In this way (Figure 3), a lower dike can be built. Therefore, the extra safety provided by the secondary function can increase the flexibility of the dike since the dike reinforcement can be postponed even longer.

From this case study, we conclude that increasing the flexibility of multifunctional flood defenses cannot be effectively achieved if the flexibility required for each function of a multifunctional flood defense is determined in isolation from the other structure.

Fatema (Flora) Anvarifar

CASE STUDY: VLISSINGEN

CONCEPTUALIZING FLEXIBILITY

Figure 1 (below left). Two possibilities for enabling the option to delay the dike reinforcement interventions.

Figure 2 (right). Two possibilities for increasing flexibility in the design of a combined structure of a sea dike and residential buildings.

Figure 3 (below). Vlissingen multifunctional boulevard. (Image by municipality of Vlissingen).

Figure 4 (below). Vlissingen multifunctional boulevard. (Image by municipality of Vlissingen)

Fatema (Flora) Anvarifar

CASE STUDY: KATWIJK AAN ZEE

PERFORMANCE ANALYSIS OF A MULTIFUNCTIONAL FLOOD DEFENSE

KATWIJK is a small coastal town located at the old mouth of the River Rhine and along the North Sea. The national flood safety inspection of the coastal area demonstrated the need for the construction of a new sea dike to protect some 40,000 people living in the city centre. The dune-covered coastline near the town is a flood zone that lacks sufficient sea car parking. To make best use of space and funds, the municipality and coastal authorities decided to combine functions and use the dune area for both flood protection and parking. As this was a first-time project, it was yet unknown how interdependencies of functions would affect the performance of this multifunctional flood defense. In this research project, we customized an existing performance analysis method to look into this issue.

Multifunctional flood defenses are a promising solution for dealing with the conflicts of flood protection and urban development as well as increasing the cost-effectiveness of interventions to reinforce the defenses. The environment in which a multifunctional flood defense system operates is dynamic, constantly evolving, and not fully predictable. Maintaining the desired performance of multifunctional flood defenses under changing circumstances, both expected and unexpected, requires a clear understanding of the interactions between the components of the system, as well as the interactions between the system and its environment. These dynamic interactions can have both positive and negative impacts; these need to be taken into account in order to increase the system’s flexibility and ability to handle future changes.

Combining flood protection with other urban functions as examples of a parking garage and/or restaurant, links the performance of each of the elements, which can create functional interdependencies. Additionally, once the functions are combined, they become part of a broader socio-ecological context. The functioning of the total system now depends not only on its technical performance, but also on the humans who operate, inspect, maintain, and use the system. To analyze the performance of multifunctional flood defenses, it is necessary to capture the complexity of the relationship between human actions and the technical functions, and the environment.

Anvarifar et al. (2017) propose a method for performance analysis of multifunctional flood defenses, which can identify how the interdependencies associated with the multifunctional flood defense, can strengthen or weaken the system when faced with environmental changes. This proposed method is a customized FRAM (Functional Resonance Analysis Method) approach and consists of five steps, which describe and visualize the performance of a multifunctional flood system and their interdependencies.

Step 1: Identifying and describing the functions.
Step 2: Generating the scenario.
Step 3: Characterizing the performance variability.
Step 4: Identifying the potential impacts.
Step 5: Synthesizing and applying the results.

We applied this method in the case study of the multifunctional flood defense in Katwijk, where we compared four alternative designs based on two initial proposals. The first plan (see Figure 1) proposed to the city council a multifunctional flood defense system's concept of installing a parking garage along a new sea dike. The parking garage and sea dike would ultimately be covered by sand, so this alternative was called 'dike in dune'. Two versions of this design were developed (A1 and A2 explained below).

Description of case A1 and A2

In both cases, a parking garage is built on the landside of the dike (Figure 3). These two alternatives are aimed at investigating how different degrees of geographical dependency between elements of a multifunctional flood defense affect the flood protection function. Both A1 and A2 represent the same types of functions, but with different levels of geographical dependency between the two structures.

Description of cases B1 and B2

In these two cases, the multifunctional flood defense comprises a parking garage, a floodwall and a restaurant. In both cases, the restaurant is on the water-side and the parking garage on the land-side of flood wall (Figure 4). The flood defense of B1 and B2 is not a dike, but a floodwall (a concrete structure). In case B1, the parking garage nor the restaurant contribute to the flood protection; B2, on the other hand, has three highly connected structures, with the restaurant and parking garage sharing a flood wall with the floodwall. The parking garage supports the floodwall and holds it in place. The restaurant is flood proof and expected to resist high water levels. The cases B1 and B2 are aimed at investigating how a secondary function may impact the flood protection function.

A later plan proposed constructing a parking garage on the landside of a flood sea wall and a restaurant on the water-side of a flood wall (see Figure 2). This combination of the three functions in close proximity provided the basis for two new versions of the design (B1 and B2, explained below). The different versions represent different levels of dependency between the functions of a multifunctional flood defense.

Figure 1 (below): The first plan for an integral flood defense in Katwijk, including a co-located sea dike (A1) and parking garage (A2). (Image courtesy OKRA Landschapsarchitecten.)

Figure 2 (below): The second plan comprising a co-located parking garage, flood wall and restaurant (CURiNET Multi-wa terswetten 2011.)
Flood protection levels

Applying the five-step method in cases A1 and A2 shows that the actual levels of safety provided in A2 may even be higher than A1. Contrary to the common belief that the close proximity between the two functions of a multifunctional flood defense can reduce the level of flood protection, we found that constructing the secondary function and the flood defense as two independent structures close to each other (as in A2) can actually result in a lower level of safety compared to constructing them as fully connected structures (as in A1).

Applying the proposed method in cases B1 and B2 shows that if the secondary functions of a multifunctional flood defense are constructed in such a way to contribute to flood protection (as in B2), it will actually be easier to reinforce the flood wall than when the positive contributions of the secondary functions are ignored (as in B1). Further elaboration on the effects of multifunctionality on flood safety in the case of Katwijk, can be found in Anvarifar et al. (2017).

Conclusions

Based on the case study, we can conclude that combining the flood protection function and one or more secondary functions increases the potential interdependencies. These dependencies increase the complexity of the design and the number of issues that need to be addressed when developing the system. It does, however, appear that these dependencies can actually improve the desired performance of the system. Using the proposed 5-step method makes it possible to track both the potential dependencies and their positive or negative impacts. When negative impacts are identified, this is a signal that something needs to be done to prevent these potential dependencies or to prevent the dependencies having these impacts. On the other hand, if the potential interdependencies have positive impacts, the possibility of improving the performance of the flood protection function should be seized.

The proposed method seems a promising way to identify the threats and opportunities associated with different design alternatives of multifunctional flood defenses. Using it during the conceptual design phase provides a qualitative tool for the developers of multifunctional flood defenses. It offers them a broader view; analysis, and visualization of possible internal and external changes to the system, as well as human, technical and environmental interactions. Thanks to a unified terminology, it is a convenient framework for developers of multifunctional flood defenses from different domains. Additionally, it can help to identify ways in which the system can be made more flexible, so that it can properly respond to unexpected events, whether caused by human interventions or environmental changes.

ENLARGED(0) FLOOD DEFENCES WITH NEW ASPECTS FOR DESIGN AND PLANNING

REFLECTION

Dick Haanen points out that the process of urban design and planning has been shaped by the evolution of urban morphology, where the focus was on the construction of buildings and infrastructure. However, the increasing awareness of the impact of climate change and the need for sustainable urban development have led to a reevaluation of traditional design and planning practices. This has resulted in a new phase of water planning, where the focus is on the integration of water and urban planning. This new phase requires a multidisciplinary approach, where experts from different fields work together to create integrated solutions that are resilient to future climate changes.

The design and planning process has been criticized for being overly technical and not taking into account the social and environmental impacts of infrastructure projects. This has led to a new approach, called adaptive management, which involves creating flexible and resilient designs that can accommodate future changes. This approach is particularly relevant in the Netherlands, where the impact of climate change has led to increased flooding risk and the need for innovative solutions.

Kevin Raaphorst highlights the complexity of the integral design and planning process, emphasizing the semantic meaning of visual representations. He explains how the participants need to transcend their own discipline, frame or expertise and think with each other instead of for their own goal. The non-linearity and flexibility manifest themselves. Designers and planners have to address this issue: Is a plan only about buildings, or does it affect flood safety discussion. They have to consider a wide range of options, and consider many forms of cooperation and associated lock-ins over the last century, since the late 19th century. Nikki Brand covers the legal aspects, different levels (designed) and the strategic (planned). APM seems an effective tool to link other tools, measures and goals. Case studies in the Rotterdam and New York showed the non-linearity and dynamics of the processes.

This section deals with the history of water planning in the Netherlands since the late 19th century. Nikkie Brand covers the legal aspects, different forms of cooperation and associated lock-ins over the last century and focuses on the changing landscape of flood planning. Brand gives an overview of the increasing integration between the water and planning sectors and institutes, and their growing interdependencies. This illustrates perfectly how the different disciplines used to struggle in different worlds. The change in thinking and understanding the way the world works has led to a more holistic approach, where the focus is on creating resilient and adaptable solutions.

Tushith Islam gives a more in-depth analysis of how adaptive decision-making with uncertainty can deal with the uncertainty, especially when design- ing infrastructure projects. He proposes a combination of simulation and robust optimization methods to help create policies that include the various values and constraints of stakeholders, thus minimizing costs in the long term. He also explored this for a MFFD case in Can Tho, Vietnam and created several models for the path dependencies of decision-making. This is important to understand the range of impact of uncertainties on the decision-making process.

In his paper, Anvarifar links the risk of flooding to socio-economic and environmental changes. To deal with the spatial aspects of flooding (especially in the densely populated urban areas), he proposes a co-locating approach (caused by the necessity for a reconsideration of the relationship between the irreversible investment interventions, based on which the systems are built) with each visual representation of the flood risk, she proposes a working definition to provide common ground for involved stakeholders to communicate. Flexibility is a planning attribute that enables responding to changing conditions, in order to reduce the negative and to exploit the positive uses of uncertainty and change, in a performance-efficient, timely and cost-effective way. Anvarifar conducted two performance analyses, one for Vlissingen and one for Katwijk. These showed the difficulty of applying the approach to the different disciplines, particularly when they work isolated from each other. However, when faced to address uncertainty, the approach can actually increase performance. He further argues that flexibility reveals areas that need more attention, using the design process more productive.

We can conclude that to deal with multi-functional flood defences we need to do more than simply enlarge dikes; we need to consider a wide range of options, and consider all the things that influence the design area. We need new tools and design and planning approaches to include the uncertainties in the process. However, in the end, we need to make the entire process more complicated, challenging, but ultimately more rewarding.
HOW INFRASTRUCTURE CAN SUPPORT AND DESTROY THE PUBLIC DOMAIN OF THE CITY

Reflection

Prof dr. Han Meyer is emeritus professor of Urban Compositions at the Faculty of Technology and Environment, Delft University of Technology. In The Multifunctional Flood Defenses research program the faculty of Architecture and the Built Environment, Delft University of Technology. In the Multifunctional Flood Defenses research program can be considered a substantial contribution to a closer collaboration among different disciplines, creating a culture in which academics and professionals with different backgrounds are looking for new ways of combining urban renewal with new types of large-scale infrastructural systems.

The strong emphasis on new infrastructures resulted in the construction of large-scale motorways, often cutting through the existing urban fabric, destroying many neighborhoods, and separating the parts which were left over. Dutch river- and seaside cities were given large-scale dikes, considered especially necessary after the disastrous flood in the southeast of the Netherlands in 1953. Those dikes created more safety against floods, but they also blocked the relation of originally water-oriented cities with the water or the sea. In Rotterdam, the construction of the “Maasboulevard” in the 1950s was a combination of a riverside motorway with a flood defense structure. The city was safer and more accessible, but in the same time more isolated from the river than ever before.

The ideas and means of this modernization had a disastrous effect on cities and on the quality of life in the cities worldwide. The 1960s and 1970s show a process of shrinking cities in Europe and North-America, losing their population, economy and amenities, and decreasing poverty. The City of New York, considered the capital of the modern world of the 20th century, experienced bankruptcy in the 1970s. Also in the Netherlands, cities like Amsterdam and Rotterdam lost more than 25% of their population between 1975 and 1985. Instead of places of triumph, cities became places of poverty, decay and crime.

A big U-turn in urban policies started in the 1980s. Urban revitalization became the number 1 priority in many political agendas worldwide. The megalomaniac ideas of the Modern Movement were rejected; designers, planners, and engineers started to collaborate in order to find new ways of combining urban renewal with new types of large-scale infrastructural systems. Instead of emphasizing the autonomy of each scientific discipline, which was the dominant model during the period of modernism, this research program is a substantial contribution to a closer collaboration among different disciplines, creating a culture in which academics and professionals with different backgrounds are looking for new solutions. This research program is a substantial contribution to a closer collaboration among different disciplines, creating a culture in which academics and professionals with different backgrounds are looking for new solutions.
How would you describe a multifunctional flood defense?

“I don’t particularly see a multifunctional flood defense as an object; from my expertise it has more to do with a process. For me, an MFFD is a project that combines spatial interventions for flood safety with other interventions in the area. You’re not just looking at the business case, asking yourself questions like ‘What are the economic opportunities in the area and how can we use them in the project?’ But you also look at what it means for various stakeholders in the area, such as the municipality, the province, Rijkswaterstaat, the water authorities and, of course, the RVB. That is what the concept ‘multifunctional flood defense’ covers for me: combining interests of stakeholders who are involved in one project.”

How were you and your organization involved in the project?

“I work on large area development projects, and the project in the Dutch southwestern delta was one of these. In this project, Grevelingenmeer and Volkerak–Zoommeer were addressed simultaneously. Although Rijkswaterstaat manages these waters, the RVB formally acts in the role of the owner. Two issues ran parallel here: Increasing flood safety in the Southwest Delta project of the Delta Program, and improving water quality in the area development process.”

What specific kind of knowledge is needed for integral design of a multifunctional flood defense?

“For us not so much hard knowledge and skills. We need more soft knowledge and tools that help stakeholders to open up questions like ‘Who are the stakeholders in this specific area?’ and ‘What do they really want?’ And in these kinds of projects, one also needs to know, or maybe to learn, how to combine the different angles of the various stakeholders in a creative way.”

“This ‘opening up for other perspectives’ is one of the aspects we recognized in Julieta’s project. Different stakeholders are often not aware that they are looking at a project from different points of view. While that is at the heart of a multifunctional flood defense design. If you really understand that, and try to match your ideas with those of other stakeholders, you will have a different conversation than when constantly working on your own interests. It will help you to seize new opportunities, and I am also convinced that it results in better projects. A lot of people are used to approaching a project from a negotiating perspective, very straightforward: ‘What do I want and how can I get it?’ That’s really a very different approach, in which you often need to battle for negotiations for a very long time.”

How did the academic research project match with your organization’s practical needs?

“The area development has changed a lot, due to the crisis in the real estate market. Previously, municipalities and commercial parties had a tendency to design large and comprehensive plans for area development and approach these from the point of the supplying. However, due to the real estate crisis, many parties opened up to a new strategy: ‘Perhaps we should look a little more into the demand.’ That’s how ‘organic area development’ caught on: you develop a small-scale project, constantly looking at and adapting to market demand. For a start, that forces you to look at the other side of the table: ‘What is that demand?’ And that reversal process was exactly where Julieta began her research. She immediately applied this to her work in productive interaction with the stakeholders. As a result, the Dilemma Cube she developed with us is very up-to-date. And because we have focused strongly on multi-actor processes, the knowledge and tools that were developed are widely applicable to other multifunctional projects. And that is very useful to RVB as a user in this STW-Program.”
GOVERNANCE & KNOWLEDGE TRANSFER

- Diversity: combining functions requires the involvement of multiple actors, from different backgrounds and different interests in a multifunctional design project. This organizational complexity adds ambiguity and dilemmas to the decision-making process.

When designing multifunctional flood defenses, the different actors often encounter these problems. Dilemmas are situations that require a choice between competing options, which may seem equally desirable. Ambiguity originates when multiple interpretations of the same point are possible. Surprisingly, when actors from such varied sectors (and administrative levels) are involved in a project, they will come up with diverse interpretations, each of them focusing on different aspects of the project.

When trying to design multifunctional projects, different actors have different perspectives, and there is no clear course of action. Stakeholders encounter dilemmas when trying to identify and select the proper combination of functions. A number of common questions arise when designing multifunctional flood defenses: Which function(s) should we combine with a flood defense? Which objectives should we prioritize in the decision-making process?

Many factors have led to the development of multifunctional flood protection projects: increasing population, sea level rise, and changes in public and private spending. These projects integrate various functions in the same area in order to achieve complementarity. Complementarity is a situation in which two or more different things emphasize each other’s qualities (Oxford dictionary).

In multifunctional projects, combining functions is a means to satisfy various objectives simultaneously and reinforce benefits. On the other hand, complementary solutions can also lead to ambiguity and raise dilemmas, which can often lead to indecision. However, precisely these dilemmas can also be used as an opportunity in the design process. The first step to overcome dilemmas and realize their potential is to create awareness that they exist, and an understanding of how they originate.

Multifunctional projects generally occur under circumstances of change, scarcity and diversity.

- Change: multifunctional projects require actors to change their practices; instead of working in mono-sectorial projects, they have to take an integrated approach, with various sectors collaborating simultaneously.
- Scarcity: functions have different benefits and integrating the functions helps to connect the benefits, thus reducing the resources required to develop the project. In this way it becomes possible to combine functions that provide a financial benefit with others that provide social benefits but which are not financially profitable. For example, various actors might consider connecting a flood defense with a shopping area. This will permit the profit from the shopping mall to compensate for the costs associated with maintaining the flood defense. As a result, multifunctional projects help to overcome a scarcity of resources by seeking complementarity among and across functions.

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It is important to remember that while dilemmas may be associated with indecision, they offer the opportunity of looking at situations from different perspectives. Rather than being a source of conflict, through these multiple frames foster diversity and the development of inclusive solutions. Creating awareness about the dilemmas that occur as a result of multiple frames can help actors to identify strategies that will contribute to the complementarity of multifunctional projects.

To realize the potential that dilemmas can offer, our research project investigated:
- How multiple interpretations can influence the way actors identify and select functional combinations,
- The three-dimensional nature of the Dilemma Cube elements of the

Figure 4. Dilemma Cube

- Participants voice their interpretations
- Positive connection
- Negative connection
- A soft collaboration tool is engaging
- Existing situation or potential actions
- Effects

Figure 3. Key features of the Dilemma Cube (Image courtesy: Jul-
ete Nato Cadarso).

- Positive connection
- Negative connection
- A three-dimensional tool helps to visualize the interrelationships that actors had not previ-

- The Dilemma Cube makes explicit these as-
- Each side of the Dilemma Cube represents functions or relevant themes in the project. For example, each side could represent a function of a multifunctional project: e.g., recreation, nature, energy and housing. The upper edges of the cube contain potential actions associated to the functions. The lower edges contain the effects associated to the actions. To show a cause-effect relationship, actions and effects are connected by means of threads of yarn as shown in the picture. Green threads represent positive cause-effect relationships, and red ones negative connections.

In a workshop setting (which can take several rounds), participants take turns adding one action, one effect, and one positive or negative connection among these actions and effects. Participants can add new actions and effects, but they can also build on previous participants’ contributions, for example to show that they perceive a negative effect of an action which a previous participant only considered as positive. When a single action has both a positive and a negative connec-

In the workshop setting, participants can discuss these dilemmas as they occur revealing dilemmas that would otherwise have remained hidden.

Using the Dilemma Cube helps make dilem-

- The three-dimensional nature of the Di-

- The Dilemma Cube helps to visualize the interrelationships that actors had not previ-

- The Dilemma Cube helps to make dilemmas explicit and encourages inclusive inter-

- Using the Dilemma Cube helps make dilem-

- The Dilemma Cube helps to identify potential conflicts. Once the dilem-

- Knowing the origin of dilemmas helps to iden-

- We had the opportunity of organizing a work-

- The Dilemma Cube acts as a canvas on which participants can paint how they perceive the situation, engaging them and providing a sense of ownership.

- The three-dimensional nature of the Di-

- The Dilemma Cube is a low-tech collabora-

- Actors were exploring different combinations of functions that would satisfy regional and local demands. During the workshop sessions, the Dilemma Cube helped to identify six di-

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- The Dilemma Cube helps to make dilemmas explicit and encourages inclusive inter-

- Participants voice their interpretations
- Existing situation or potential actions
- Effects

Positive connection
Negative connection

Key features of the Dilemma Cube (Image courtesy: Juliete Nato Cadarso).
In the Dutch Delta system, flood defense projects are part of an integrated management approach to spatial development. The Delta system consists of levees, dikes, and other structural elements designed to protect the Netherlands from high water levels. In recent years, there has been a shift towards more flexible and adaptive flood defense strategies that prioritize synchronization and anticipation in order to meet the evolving needs of the built environment.

Synchronization refers to the process of coordinating projects in time and space to ensure that different developments occur in a way that is compatible and efficient. This includes aligning flood defense projects with other developments such as housing, industry, and cultural heritage. The goal is to avoid costly conflicts and ensure that all developments are planned and executed in a coordinated manner.

Anticipation involves planning for future developments and integrating them into current projects. This approach aims to proactively prepare for future changes and risks, such as climate change, by designing flexible systems that can adapt to changing circumstances.

The research by Ellen Tromp, a researcher at Deltares, focuses on the importance of synchronization and anticipation in flood defense projects. Her work highlights the need for a multidisciplinary approach that considers the interests of various stakeholders, including residents, businesses, and cultural heritage organizations. Through her research, Tromp aims to enhance knowledge transfer and uptake and contribute to the development of more effective and sustainable flood defense strategies.

Ellen Tromp's research project, titled "LEVEES IN A CHANGING ENVIRONMENT: SYNCHRONIZING AND ANTICIPATING LOCAL CHALLENGES," is conducted in the Deltares institute in Delft. In this project, Tromp explores the integration of flood defense projects with other developments, focusing on the synchronization of levees and other flood defenses with the built environment to maximize efficiency and sustainability.

Tromp's research is part of a larger effort to improve flood risk management in the Netherlands. The Dutch government has been working on a comprehensive approach to flood defense, known as the Delta Plan 2050, which aims to integrate flood defense with other societal needs and enhance the flexibility of flood control measures. This approach involves not only constructing new levees but also integrating flood defenses with urban development, agriculture, and cultural heritage.

The research project by Tromp and her team contributes to this broader effort by identifying key findings and best practices for synchronization and anticipation in flood defense projects. These findings can help inform future policy decisions and guide the development of more integrated and responsive flood defense strategies.
GOVERNANCE & KNOWLEDGE TRANSFER

3. Funding: Regional authorities can invest in spatial development and flood risk management, provided that benefits emerge over time. This time horizon is not clear by default. Benefits can be produced by a variety of ways, including: profits from wind turbines can be used later to pay for more complete solutions, and the Public investment companies with public shareholders may also be able to provide the necessary impetus; by controlling risks and uncertainties, they enable private investors to participate in integrated planning processes and development on a berm can reduce the cost of dike upgrades in the future. In addition, water authorities can act as developers, since many dike projects involve purchase and sale of land and buildings. Public investment companies with public shareholders may also be able to provide the necessary impetus.

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4. Active building policy for space on and next to floodplains. New dike reinforcement development can be created when there is an understanding of how simple building techniques can create more flexibility for future interventions. Since the area around a dike is a special environment, it makes sense to require specific construction methods. Municipal authorities must support this policy, since they are the ones authorizing construction.

In turn, the creation of flexible spatial planning requires both water and flood authorities to work together by respecting each other’s interests, responsibilities and political agendas, and by working together to identify optimal solutions. Surplus value can be created for local residents.

Figure 4. Examples for anticipatory strategy

Table 2: Anticipation strategy

<table>
<thead>
<tr>
<th>Short term (0-12 years)</th>
<th>Medium term (12-24 years)</th>
<th>Long-term (&gt;24 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delaying the dike reinforcement by taking temporary measures. Possible solutions include temporary constructions as sand bags and flood barriers.</td>
<td>New and old buildings on and beside the strengthened dike can be built on jack-up lines to meet future challenges. Should climate change or other standards require it, they can be jack-uped to allow strengthening of the dike.</td>
<td>A building can be moved to another location in the event of a dike reinforcement.</td>
</tr>
</tbody>
</table>

Figure 5. Examples for anticipatory strategy

<table>
<thead>
<tr>
<th>Time scale for management</th>
<th>Strategy 1: Synchronization</th>
<th>Strategy 2: Anticipation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short term (0-12 years)</td>
<td>Synchronization</td>
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<td></td>
</tr>
<tr>
<td>Long-term (&gt;24 years)</td>
<td></td>
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</tbody>
</table>

Table 1: Synchronization strategy

<table>
<thead>
<tr>
<th>Interim functions</th>
<th>Are interim functions needed for integral approach?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Synchronization</td>
</tr>
<tr>
<td></td>
<td>Anticipation</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Below: The different strategies explained.
DIKE REINFORCEMENT LEKDUK

The dike reinforcement project Kinderdijk - Schoonhovenseveer (KIS) is a part of the Lekdijk, a primary flood defense that directly protects two major polders in its direction. The initial expansion of local villages (in the Middle Ages) was concentrated near the dike and around the churches, resulting in ribbon development along the dike (see Figure 2). The part of the dike, where the floodplains is a nature conservation area. The local population is aging, and village shops, businesses, and local activities are slowly disappearing. This is a shortage of housing for young people.

The Dutch regional water authorities regularly monitor dike areas in their jurisdiction, and perform periodic assessments as required by law. Water Authority Rivierenland is responsible for KIS. This specific part of the dike protects 175,000 people.

In 2005, the KIS dike section failed to meet the flood safety criteria, and as a result it was added to the Second Dutch Flood Protection Program (DFPP-2). Under DFPP-2, dike reinforcement is funded by central government, provided that three criteria are met: projects must be frugal, robust and efficient (DFPP-2, 2011). Dutch national policy formally divides a dike reinforcement project into six phases: planning, designing, tendering, implementing, operating and maintaining. During the process, Rivierenland organized many stakeholder meetings, both formal ones and ‘kitchen table’ meetings with local residents. In this way, they were able to inform residents on the progress of the dike reinforcement, as well as try to include local knowledge in the specific design. This process led to the project successfully, with consent from the local stakeholders. During the development of this dike, the contractor actively involved local stakeholders and residents to shape the process, while using social media and events.

CASE STUDY: KINDERDIJK - SCHOONHOVENSEVEER

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The success of knowledge transfer depends on four main factors:
- Relation between the two parties, due to role for the gap between them;
- Trust between the parties, and the strategy the sender chooses to transfer the knowledge.

Multi-purpose levee
One of the proposed solutions at the village of Streefkerk was to build an unbreachable dike. In order to preserve the historic and characteristic houses, a dike reinforcement would need to be reinforced in the dike. Compelling the dike over-dimensioning the crests gives the best chances to combine the dike, other ambitions and plans. The dike would offer space for new accommodations even a new citizen center oriented towards the dike and around the churches.

In the current design, both an over-dimensional outer berm and water-retaining walls are used to improve the connection of the built environment with the river, the marina and the adjacent floodplains. While developing this design, the regional government found that their joint plans that had to be decoupled, due to a tight time frame imposed by DFPP-2, which financed the dike reinforcement. For the municipality, the main challenge was to organize funding for their ambitious plans. Currently, the municipality’s main market was challenge is to organize funding for their ambitious plans. Currently, the municipality’s main challenge was to organize funding for their ambitious plans. Currently, the municipality’s main challenge was to organize funding for their ambitious plans.
In this dissertation, Ellen Tromp is a researcher at Deltares, an independent institute for applied research in Delft. In the STW-MFFD program, the core theme is the design support for multifunctional flood defenses. Ellen plans to graduate in 2018/2019.


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the uptake of knowledge (or lack thereof) in a FRM planning process. The behavior of the parties and their interventions are coherent with the identified barriers. Further research should reveal whether the framework can facilitate timely identification of barriers and failure mechanisms in ‘live’ case studies, and in this way support the design of effective process interventions.

Three different types of process interventions can be identified:

1. Knowledge management (KM) interventions;
2. Policy network (PN) interventions; and
3. Process management (PM) interventions.

We expect that each type of intervention can enhance the knowledge transfer and the uptake of knowledge. We also expect that our sender-receiver model can help us to better understand the role of ‘knowledge brokers’.

Figure 4 (left).
Dike strengthening at Kinderdijk - Schoonhovense Veer (Case study see page 110-111; Photo courtesy Ellen Tromp)

Figure 5 (right).
Knowledge transfer and uptake is as strong as the weakest link.
Dealing with collaboration challenges in integrated spatial projects

Almost everybody agrees that the environmental challenges we are currently facing need to be approached in an integrated manner, from governments to citizens and from companies to research institutes (Brown 2008; Brown & Farrelly 2009). To create multifunctional flood defenses, innovative integrated solutions are needed to be tested and used, responsibilities are shared, as well as risk-taking, are all shared. When developing integrated spatial projects, such as multifunctional flood defenses, the focus is increasingly on multidisciplinary cooperation between actors from different institutions, based on the assumption that collaboration allows knowledge to be shared and thus produces integrated spatial developments (BNA 2016; Janssen 2015; Healy 1998, 2006). But the intense collaboration involved in such projects is not as straightforward as it might appear.

Involved actors look at a project from different perspectives, based on their individual institutional frames. They often have different interests, responsibilities, and opinions about problems that might occur and which solutions might be useful to address these (Hage et al. 2009; Collins & Ison 2009; Barreteau et al. 2010). Problems can also arise because of the physical distance between involved institutions, and when participants make their contributions at different times. Actions may start taking place at different times, without always being aware of it. Emotions such as confusion, disappointment and even mutual mistrust can influence the process and the results (Heems & Kothuis 2012). In addition, collaboration can create different expectations from being informed, having a say, consulting and exchanging knowledge, to collective design, decision making, finance, execution, control and responsibilities. These differences in expectations are often difficult to manage, and cannot always be met. During the process, involved actors can forget the perspectives and interests of other partners/actors. The project team can lose its connection with their organization, and forget about the importance of organizational and societal support. This can lead to project results that the different actors do not view as equally successful in terms of credibility, salience and/or legitimacy (Cash 2002); it can even lead to outsiders rejecting the project.

Interpretative approaches from social science can clarify how multifunctional flood defenses can be successfully developed when multiple actors are involved, and considering the societal dynamics. Literature on the interaction of science and technology with society has shown that creating innovative solutions depends on complex ensembles of social and technical elements, with the technology embedded in the society (Borras and Edler 2014). Because the institutional and societal context can either support this process of embedding or, alternately, hinder it, we need to understand how this context influences the creation and realization of new projects.

Why do involved actors sometimes succeed in cooperating to create a shared project and fail other times? What leads actors to harmonize their actions, and why don’t they always do so? To answer these questions we need a deeper understanding of the different perspectives the involved actors bring to the project, and the impact of collaboration on the project’s processes and its results. Our research found that when actors are aware of the different perspectives, expectations, and emotions of other involved actors, participation, cooperation and co-creation are more effective and can contribute to credible and realistic results.
GOVERNANCE & KNOWLEDGE TRANSFER

Using learning communities to improve integrated spatial projects. Innovative solutions for integrated spatial projects, like the development of multifunctional flood defenses, are the result of multiactor sensemaking. The process of which actors give meaning to experiences. In this case, the actors need to identify and understand the problems associated with the project. After that, the actors can deal with potential difficulties, in order to develop something new together.

A useful way to approach multi-actor processes is through action research, which is a participatory process of collaboration with involved actors. Working on the boundary of research and practice, action research is able to produce scientifically and socially relevant knowledge, as well as lead to transformative action.

The approach was applied in four learning communities working on water and space, the so-called ‘Leergemeenschappen Water & Ruimte’ of Platform 31. Initiated by the Dutch Ministry of Infrastructure and the Environment and the Rijkswaterstaat, the Dutch Union of Water Authorities, and the Dutch Delta Program (a national project managed by the Ministry of Infrastructure and the Environment), these voluntary communities include employees of Water Authorities, municipalities, and provincial government, as well as municipalities or provinces). Members of the learning communities need strength and perseverance. Incentives for change are often missing, and innovative solutions often lack support within the institution.

To improve the results of integrated spatial projects in practice, members of the learning communities created a tool during a national workshop in 2014, called ‘Zoden aan de dijk’². The kit presents inspirational events of the four learning communities for water and space.

Footnotes:
1. The results were posted to the Platform 31 website (http://www.platform31.nl). Platform 31 organized and facilitated regional and national events of the four learning communities for water and space.
2. A Dutch idiom that can’t be translated literally; it means putting sod on the dike and means “doing something really useful.”
3. For more information on the toolkit please contact Jan Dirk van Duijvenbode at Rijkswaterstaat (jandirk.van.duijvenbode@rws.nl) or Trudes Heems (trudesheems@hotmail.com).
As the name implies, multifunctional flood defenses (MFFDs) are flood defenses that also incorporate different functions and purposes. MFFDs are objects designed to offer systemic, valued effects for given stakeholders or a community. MFFDs have integrated parts, and while the degree these different functional parts are integrated can differ, this combination makes them complex objects. Whatever things are made complex, novel systemic effects are created, effects that are not reducible to the parts. In this chapter, I want to look at one such emergent effect: the increased complexity that any given group participating in the MFFD experiences. This alters the behaviors and dynamics of the groups involved in the MFFD.

The MFFD is not just an object that changes the physical mix of an environment, and thus has different effects on its surroundings. It also is expected to change the ties between groups that share their knowledge and interests to design, exploit and maintain the MFFD. As their mutual dependencies change, we can expect significant changes in behavior. Though the strategic behaviors that may result have been studied from the governance perspective (e.g., De Bruijn & Ten Heuvelhof 2010), little is known about how groups manage the difficulties faced during knowledge formation and transfer. This is particularly a problem when dealing with MFFDs.

In this chapter, I wish to make some general caveats about MFFDs. These are based on case studies, but this makes them no less expected. The cases in this book included the Roof Park in Rotterdam (page 166, this volume), the Jubilee River in Great Britain (page 124, this volume), and various efforts to figure out multifunctional designs in Texas, USA (see page 142, this volume). Though these cases differ widely in their governance context, they all encountered difficulties between different stakeholders. Of course, the specific difficulties highlighted below will not necessarily occur in every MFFD project, but they are possible challenges which planners should be prepared for. Allowing sufficient resources to deal with, by shaping intergroup learning. Through the question of how groups deal with intergroup difficulties and the lessons they learn, we can come to a complex issue.

This chapter will only present an overview.

Combining functions is challenging. Each function in the MFFD serves multiple functions, and while addressing its primary function, it must not compromise the other functions. This also means that each group, while working on its own tasks, needs to consider the other functions and benefit from other stakeholders. New normative knowledge must be developed to create confidence that the combination of functions will work. Clear arrangements must be made to help coordinate groups. As the groups interact, assuming all goes well, this creates novel knowledge and arrangements, and the MFFD is expected to increase benefits for the surroundings thanks to the stakeholder learning process.

While we initially assumed that such learning is not only possible, but to be expected, there are two reasons to doubt this. First, combining functions increases uncertainty and means that there will be more areas in which individual stakeholders have no expertise. And second, it means that different groups have to spread their resources more widely. Shared knowledge development is demanding, as tasks interfere and different stakeholders have different expectations of the effort involved. As a result, each group will have to determine the amount of effort they can invest in the project, of which...
financial costs are just a part. As the number of initiatives increases, the difficulties that need to be resolved increase, and the intergroup conduct can be foreseen, but the difficulties which users will face are not precisely calculated. It is possible that the difficulties encountered will cause the-MFFD to fail to fit the MFFD into the context of the other stakeholders. This is important that no group has to explain why the change in the intended functions of the MFFD is not possible. The process means that the intergroup relationship can obscure the fact that we have not learned, and we may make decisions based on false confidence. The clarity can, however, erode when new stakeholders have to interact with the different groups, parts of different networks, which developed after construction, in the ongoing lifecycle, since the surroundings evolve over time. This clarity is fraught with difficulty, because intentions are less able to be shared and understood by different stakeholders. To continue cooperating, it can obscure the fact that we have not learned, and we may make decisions based on false confidence. To cooperate and coordinate well in conditions of deep uncertainty, intentions must be clear within the group, and easy for other groups to understand. Is the intention still available for the MFFD, both groups designed? The MFFD, the two functions strengthen each other. The assumption behind the MFFD concept is that stakeholders, including different stakeholders working together, are able to create collaborative, mutually beneficial, and sustainable consequences. When stakeholders have to interact with other groups, in some situations, they may have to explain why the other group cannot assist in the flood risk, harming less well-off groups. \[\text{(748x54)}\] 

Unfortunately, forming shared meaning, which includes knowledge transfer, incurs much reluctance, encouraging groups to look after their own interests. Individuals or groups are willing to make decisions that benefit themselves, while ignoring the collective benefit resulting. This is also the case with MFFDs. Of course, when stakeholders work cooperatively, they would be less likely to realize that their choice amplifies this amorphous. Similarly, if engineers, responsible for design, do not restrict the single-mindedness of the group's core aims over time, making a strong argument for knowledge transfer and interdependence.

Conclusion

The assumption behind the MFFD concept is that stakeholders, including different stakeholders working together, are able to create collaborative, mutually beneficial, and sustainable consequences. When stakeholders have to interact with other groups, in some situations, they may have to explain why the other group cannot assist in the flood risk, harming less well-off groups. \[\text{(748x54)}\] 

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When different groups are clear about their intentions and the process, they can work cooperative and practically. When this occurs, this is the ideal situation, as the stakeholders understand each other. This clarity can, however, erode when different groups, other members of the organization, and the other groups that are also accustomed to working with the MFFDs, are interdependent over a long period. The more interdependence excluding the possibility of knowledge transfer, the more difficult it is for the stakeholders to understand the other's intentions and difficulties establishing a shared meaning to result—this can be a shared meaning to result. When different groups are clear about their intentions and the process, they can work cooperative and practically. When this occurs, this is the ideal situation, as the stakeholders understand each other. This clarity can, however, erode when different groups, other members of the organization, and the other groups that are also accustomed to working with the MFFDs, are interdependent over a long period. The more interdependence excluding the possibility of knowledge transfer, the more difficult it is for the stakeholders to understand the other's intentions and difficulties establishing a shared meaning to result. When different groups are clear about their intentions and the process, they can work cooperative and practically. When this occurs, this is the ideal situation, as the stakeholders understand each other. This clarity can, however, erode when different groups, other members of the organization, and the other groups that are also accustomed to working with the MFFDs, are interdependent over a long period. The more interdependence excluding the possibility of knowledge transfer, the more difficult it is for the stakeholders to understand the other's intentions and difficulties establishing a shared meaning to result—this can be a shared meaning to result. When different groups are clear about their intentions and the process, they can work cooperative and practically. When this occurs, this is the ideal situation, as the stakeholders understand each other. This clarity can, however, erode when different groups, other members of the organization, and the other groups that are also accustomed to working with the MFFDs, are interdependent over a long period. The more interdependence excluding the possibility of knowledge transfer, the more difficult it is for the stakeholders to understand the other's intentions and difficulties establishing a shared meaning to result.
England floods frequently. While the damage is mostly economic, the number of floods and their geographic dispersion is startling: Eight percent of a rich country, with a strong central government. This government has set up a special agency to prevent flooding: the Environment Agency (EA). And while the coastline is rugged and the types of flooding varied, the situation is not so complicated that this degree of flooding would be expected. The common explanation is that the EA lacks resources because its budget has been cut numerous times since the financial crisis. While a lack of resources compromises flood management, my research shows that the EA suffers from deeper design flaws. As a so-called ‘quango’ (quasi-autonomous non-governmental organization) that bears responsibility but has no power, it is neither fish nor fowl. Effective decentralization, with taxation and rule-making connected to the dispersed local uncertainties, could lead to better tailored policies in this landscape of dispersed flood-problems. I here want to suggest that small and locally maintained multifunctional flood defenses could benefit the EA (and England), in a modest way, making possible small moves towards effective decentralization.

The current system with the EA in charge of the flood-management task arose from a governing philosophy envisioned the EA as flexible, but constrained in its choices by centrally located technical expertise in the environment, in addition, the EA is itself constrained by centrally located organizations for finance, organizations that have difficulty entering decision-making, even with a strong central government. This complicated long-term planning and prevented a systems-view. While the budget-cycle has now changed, it shows the fragilities in governing stem from actively visiting flooded environments (e.g., they are forbidden to take a boat to inspect flood damage).

The role of a MFMD: A multifunctional flood defense based for local conditions is the use of GIS to develop more accurate flood maps. However, giving more freedom to civil servants and investing more in the development of ties on the local level, should lead to a quicker, if less precise, assessment of relevant local uncertainties. Yet, the development of such methods is selected against:

- First, the EA relocates personnel throughout England, limiting their exposure to local variations over time, and thus reducing their knowledge of local behaviors of people and floods.
- Second, government rules and the EA’s own regulations prohibit EA employees from actively visiting flooded environments (e.g., they are forbidden to take a boat to inspect flood damage).
- Third, the EA limits contact with citizen-activists, even those who volunteer their time to identify, and map problems in the flood-management system.

Obviously, activists can have criticisms of varying merit, and often an interest that provides bias. Moreover, citizens will present their views in different ways than the EA is accustomed to, although this too is an effect of organizational design. The net result is that local views of the flood management system have difficulty entering decision-making, even if they spot relevant problems arising quickly.

The noted fragilities in governing stem from: those who volunteer their time to identify, and map problems in the flood-management system. Obviously, activists can have criticisms of varying merit, and often an interest that provides bias. Moreover, citizens will present their views in different ways than the EA is accustomed to, although this too is an effect of organizational design. The net result is that local views of the flood management system have difficulty entering decision-making, even if they spot relevant problems arising quickly.
from ineffective decentralization, and multifunctional flood defenses could be used to help shift materially towards a better polycentric regime. By having varied functions maintained by different groups, a multifunctional flood defence could:

- increase funding streams from the local levels,
- align anticipations according to shared responsibilities, and
- increase the exchange of views by necessarily as that different, organized groups learn to communicate relevant information better with each other, even if it is in their own typical ways (although there are exceptions).

Of strong importance is the small scale of the artefacts here, as bigger scales will involve more unintended consequences, and draw in more scales of governance, complicating choice processes. The localized aspect of an artefact, such as a flood defense (structural and non-structural), could provide an anchor for the development of local capacity, information-sharing and responsibility. Small multifunctional flood defenses that push more responsibility downward could be a good local policy in both urban and rural areas, with a more active monitoring role for the EA.

Various functions would be tied to various local stakeholders, and if projects are limited in size, this added complexity should be easier to overcome (or, by contrast, abandon early). The multifunctional flood defenses could then be designed to counter the fragilities the Environment Agency experienced at the central level. First, multifunctional flood defenses can be locally financed, ensuring local authorities and private actors situated in the flood prone region have a stake in the outcome, and would gain independence from centrally financing groups that shift priorities. Since different parties have to manage their stakes together, they must develop a language that allows them to share relevant insights. And since these parties are locally based, it will be hard for them to miss relevant aspects in flood management. Such an approach requires that the flood interest (minimizing flood risk) remains dominant compared to other interests (such as profits), unless the flood risk is low and other functions have stronger priorities. Since different parties have to manage their stakes together, they must develop a language that allows them to share relevant insights. And since these parties are locally based, it will be hard for them to miss local relevant aspects in flood management. Such an approach requires that the flood interest (minimizing flood risk) remains dominant compared to other interests (such as profits), unless the flood risk is low and other functions have stronger priorities. The advantage is that this can be designed on a case-by-case basis, and ensured by legal contracts among stakeholders and settled agreements on how the involved parties will manage differences of interest. For example, instead of heading to court when there would be occasion, the involved parties could codify that they move from facilitated dialogue to mediation, and then to arbitration first. Good contracts are crucial, since cooperation is fragile and a source of uncertainty, and must allow good exit-conditions for the involved parties. Moreover, the involved parties must understand that they become part of a more complex entity than when they would operate separately. This will increase the length of the design process and deliberations during maintenance. Yet, the end result will have higher odds to be tailored to the local setting, and more robust in a governance-sense (cf. Ostrom 2005).

In this proposal, the EA would focus on the design of MFFDs, and safeguard minimal safety-standards in the designs, on broadening the horizons of local settings by advocating alternative successful options than those initially favored (e.g. through scenario-building methods), and to keep an eye on the systems-level, to ensure that local choices are not just local optima, and don’t transfer risks elsewhere. For example, in Greater London, increasing decentralization and public opinion by considering the views of directly affected citizens led to favoring conventional structural designs, but disregarded more adaptive ones (Harries & Penning-Rossell 2011). Local governments would, from this view, be best legally required to monitor and enforce flood risk and safety-standards, though this would mean a cultural shift that may be unlikely to occur. The current design of the EA, as inferred from its manifested activities in the past, is ill-suited to govern floods effectively, having few of the benefits of effective decentralization or centralization. Local multifunctional flood defenses could function as a tool to build up effective decentralized capacity.
Dr. Baukje Kothuis was a Postdoc in the STW- program at the Faculty of Technology, Policy & Management, TU Delft in the project ‘Integrated design’. Currently she works at the Faculty of Civil Engineering & Geosciences as a researcher in the MFFD (Multifunctional flood defense) program. This was easier said than done. In the very first team meeting, the researchers discussed ‘the definition of a MFFD’, and it became clear that many concepts featuring in the design of a MFFD meant different things to different participants. The challenge became clear: how could we integrate these different perspectives towards an integral design? This chapter explains the analytical framework I developed as a practical route towards integrating academic knowledge. Additionally, I provide examples of several practices we developed to reach the goal and finish with the lessons learned in this challenging, but fun, trajectory.

Working towards Academic Knowledge Integration (WAKI)

Differences in conceptual approaches, assumptions, and terminology are sometimes explicitly acknowledged by the disciplines, but more often they are implicitly present. To deliver an integrated design, multidisciplinary teams need to find common and complementary ground, and use this space to realize their specific disciplinary knowledge. To make this possible, researchers not only need to share their knowledge, but also have to go through a knowledge integration process. To provide insight into this process, I expanded a basic model of Van Beers (2005) called ‘Working towards Academic Knowledge Integration’ (WAKI, Figure 1) to reflect the steps we found to be productive and valuable for integrating activities in the MFFD program. This was easier said than done. In the very first team meeting, the researchers discussed ‘the definition of a MFFD’ and it became clear that many concepts featuring in the design of a MFFD meant different things to different participants. The challenge became clear: how could we integrate these different perspectives towards an integral design? This chapter explains the analytical framework I developed as a practical route towards integrating academic knowledge. Additionally, I provide examples of several practices we developed to reach the goal and finish with the lessons learned in this challenging, but fun, trajectory.

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Figure 1. Working towards Academic Knowledge Integration (WAKI) for integral MFDD-design

Figure 2 (left below). WAKI Step 2: Knowledge internalization

Figure 3 (right below). WAKI Step 2: Knowledge internalization

Figure 4. Negotiation

Figure 5. Integration

Figure 6. Translation

Step 1. Externalization

Step 2. Internalization

Step 3. Translation

Step 4. Negotiation

Step 5. Integration

Step 1: Externalization

Every researcher has specific disciplinary knowledge that is unfamiliar to other researchers. This ‘unshared or internal knowledge becomes external knowledge’ when the researcher communicates it. We made this step by means of mini-lectures and case presentations. However, communicating knowledge is a one-way action: it does not mean that other researchers actually absorb the information given. To achieve this, they have to become active as well.

Step 2. Internalization

Only when other researchers internalize ‘external knowledge’, does it become ‘shared ground’. The researchers have to actively acquire the content being communicated. However, sharing is a two-way street; once acquiring the content does not imply processing or understanding. The words and concepts describing the knowledge content might still entail different meanings and assumptions in different disciplines.

Step 3. Translation

Recognizing and acknowledging multi-interdependency and disciplinary differences permits the ‘Shared ground’ to be translated into ‘Recognized knowledge’. In this step, researchers work to understand each other’s assumptions and points of view, which gives them a collective pool of knowledge. As words can have different meanings in different disciplines, or different words can have the same meaning, it is necessary to co-create tangible objects in this step (e.g., maps, architecture models, drawings) and discuss the underlying ideas during the process. We discovered that different interpretations became clear when tangible objects had to be designed together. ‘Ah, so this is what you mean by design variables.’ Nevertheless, after this step, researchers may - and often will - still have different insights, goals, or values for the final design. However, at this stage, they now recognize each other’s insights, goals, and values.

Step 4. Negotiation

When the differences and commonalities between researchers in the team are recognized and understood, the floor is open to negotiate common and complementary ground and find the design-space for co-creating an integrated design.

Step 5. Integration

Once this common and complementary ground has been established, different disciplinary knowledge blocks can be combined into an integrated design. In the collaborative design process, these five steps are often iterated and do not always occur in this precise order. Designing, like many other creative activities, is a messy process.
and financial input.

Environmental, social, and technical aspects are all significant. The goal is to develop several ways to support knowledge integration within the MFFD program. This includes knowledge exchange and regularly recurring activities:

- Three-monthly Program Reflection Days (PRDs) with all researchers in the program (IPDs and postdocs), often with the Program Leader (the MFFD Project Officer) from STW, and - when relevant - various project leaders and supervisors. The PRDs generally lasted a full day and included multiple activities contributing to the steps in the WAKI process (see also page 132).

- Monthly Postdoc Meetings (PDMs) to develop integration on a theoretical level and to discuss activities to practically facilitate the knowledge integration process within the full research team. For the last goal, the PDMs worked fairly well. Although the PDMs were based in different (sometimes competing) faculties and universities, these regular personal contacts created mutual trust. The PDMs also led to collective activities and Program Case studies (see page 138). However, integration on a theoretical academic level turned out to be very difficult, if not impossible, and only few multidisciplinary publications resulted (see also page 140-141).

- Yearly User Days (UDs) to disseminate knowledge gathered by the researchers, to exchange their experiences and needs, and to collectively learn from other projects and users. UD5 were also partly successful, as many practitioners are unable to devote a full day to an academic research program. This meant that only a handful showed up. Despite the low turnout, the UD5 were successful in persuading researchers to summarize and communicate their work at various stages and for different audiences (including the MFFD colleagues). Users who did participate were generally positive about what they learned and could communicate during UD5.

AKI practices in MFFD program and AKI practitioners in MFFD program need professional support; it does not happen by itself. A program that aims for multidisciplinary knowledge integration requires resources in time and money to support the WAKI group process. Additionally, experienced and knowledgeable researchers must be appointed to guide and study this process. This involvement provides the key to a successful WAKI process: personal engagement with all researchers, and time to create and facilitate activities that help develop mutual recognition and trust, and assist in the group process.

3. To stimulate knowledge integration, the aim must not be perfection! When building, communicating, and ‘playing’ with the tangible objects, being imperfect, not pretending that everything is correct and under control, is precisely what tempts other participants to bring in their knowledge, to make changes, to collectively create tangible objects that different disciplinary knowledge was effectively integrated, what was taking place at that very moment? Many respondents mentioned making something tangible.

- By drawing, cutting and pasting, screwing, hammering, and tin-ting, the perfect demonstrates professionalism, but it also has adverse effects on knowledge integration. For participants, the perfection suggests that everyone has already been taught of and is ‘correct’, which constrains new contributions. This means that a topographic map with rough, detailed controls provides a better basis for co-design than a printed digital version. And asking a group of researchers to co-build a potential design by hand, using wood, ropes, plastic, Lego© or ‘play-Slime©’, is more likely to prompt them to contribute and share than asking them to follow instructions virtually in a professional pre-designed environment or lab-based activities. ‘Imperfection’ can also be reached by using the ‘pressure-cooker’ method. Having limited time prevents participants from working too analytically and trying to make things perfect – something which academic researchers, in particular, seem inclined to do, but instead makes them interact intuitively, opening space for creativity and new input.

4. Integration in an academic research program needs professional support; it does not happen by itself. A program that aims for multidisciplinary knowledge integration requires resources in time and money to support the WAKI group process. Additionally, experienced and knowledgeable researchers must be appointed to guide and study this process. This involvement provides the key to a successful WAKI process: personal engagement with all researchers, and time to create and facilitate activities that help develop mutual recognition and trust, and assist in the group process.

- Lessons learned
  - 1. Trust and interaction are necessary to make knowledge integration happen, especially at the stage of going from Shared ground to Common & Complementary ground, which is a necessary condition for integration. This does require a certain level of continuity, which seems to be best created by regular meetings in person, which not only entail ‘work’ (exchanging content), but also ‘play’ (building trust and mutual understanding).
  - 2. Researchers need to collectively ‘build’ tangible objects to effectively integrate multidisciplinary knowledge; discussing and presenting information is not sufficient. We acknowledged that researchers from different disciplines often speak different ‘languages’, with their specific knowledge and jargon and discovered that just talking does not make them bridge their specific boundaries or recognize multi-interdependencies. However, collectively creating tangible objects often led to an ‘aha experience’, making researchers aware of their disciplinary boundaries and better able to transcend them.

- In the MFFD project, this pattern was clear with the maquette-game of wind turbines on or near a dike (see page 133), and the development of the Lego game (see page 132). It was also reflected in many of the interviews. When we asked the question ‘When you experienced that different disciplinary knowledge was effectively integrated, what was taking place at that very moment?’, many respondents mentioned making something tangible.

- By drawing, cutting and pasting, screwing, hammering, sketching or coloring, while at the same time discussing and negotiating, effectively integrated, what was taking place at that very moment? Many respondents mentioned making something tangible.

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During the five years of the MFFD program, Reflection Days were planned (on average) once a month to reflect on the whole design. The activities included: 1. A visit to a local MFFD. This permitted everyone to become personally acquainted with the subject of the program, in this case the multifunctional flood defense (MFFD). The intention was to be convinced and learn something new, create shared experiences (building collective memories and trust), and connect to the ‘real world’ where their academic designs are supposed to land. 2. Activities to communicate specific knowledge about the discipline. This permitted researchers to share knowledge content from different disciplines, who served as guides and explained the MFFD. The intention was to create an environment where all WAKI-steps (see previous chapter) can be covered in a ‘pressure-cooker’ setting, dealing with a single, relevant question. The World Café turned out to be a strong catalyst in the MFFD knowledge integration process (promoting a group process); it gives each participant a new perspective on his or her own research. This awareness of different ways that other disciplines view things, which in turn stimulates others to consider using some of them in future. For example: 1. The ‘MFFD-Decisions Lego’ game. This game aims to make MFFD design decision-making tangible and visible. How do you quantify which function brings which safety risk and how much can that function cost? What alternative will make the most happy people? The developers wanted non-engineers to understand the concept MFFD. They developed a game played with up to four teams, each trying to design the most optimal MFFD model, within a certain budget. The different functions like flood risk reduction, envi- ronmental impact, and storm protection, all involve different costs, but don’t have the same priority for everyone. The game components consist of Lego blocks, and budget calculations took up too much time and slowed down the game, a simple software-program was developed. The teams have to survive three rounds of flooding problems. Not only did the game teach the researchers to combine their governance and civil engineering knowledge, it also gave them a better understanding of the other disciplines involved. 2. ‘Wind turbines on a dike’ game. The ‘Wind turbines on dikes’ game in 25 potential locations (‘holes’) to put three wind turbines. The aim is to find the optimal combination of locations which location presents various challenges and every combination means new challenges. Each of these challenges lights up with a green or red light as the player puts the turbine in one of the 25 holes. Knowledge integration was realized in two ways: Internal. Amongst researchers while developing the model, by discussing technology, governance and planning for the design, and then rating of scores. External. Relationships with stakeholders explaining what the game does and how it could be used in their field. (Project by Patrick Hölscher and Bauke Kothis) 3. Informal activities: The goal of these activities was to develop personal and mutual trust and to integrate the whole design. The activities could be of any kind, as long as they require different skills, negotiating, and active collaboration, and as long as they have a tangible collective outcome. A simple but effective way to do this is ‘World Café’ (see previous chapter). After the World Café, participants had five minutes to write at least three things they had learned from their colleague, after which they found a new partner. They then spoke with every other participant, or until we run short of time. Then, the facilitator announces a plenary session and writes the initial question on a whiteboard. With the help of the group, the various evolution- ary paths that the question took are traced. The white board fills with comments. After 15 minutes, the facilitator asks the participants at each table to reflect a minute on what they are discussing at that moment, to think of a new question, something intriguing, a puzzle of sorts that flows from their discussion. For instance, participants may find them- selves asking questions like ‘Where did the idea come from?’, ‘What is this idea, or may they conclude they don’t find the issue that important. The participants are thus required to come up with a new question that captures this new point. The secretary writes down the question. The facilitator, who keeps track of time, interrupts again after five min- utes (max), and asks the group to form new groups, or to continue with the new tables, re-shuffling the groups. Each participant is now sitting with new people (try to avoid sitting with others with whom you have nothing in common). The secretary, however, stays at the original table and informs the new participants of the question left by the previous group. This cycle is repeated for three or four rounds, until each participant has spoken with every other participant, or until we run short of time. Then, the facilitator announces a plenary session and writes the initial ques- tion on a whiteboard. With the help of the group, the various evolution- ary paths that the question took are traced. The white board fills with different questions revolving around the project. The facilitator asks the members of the group how they arrived at a particular question, or the question may be discussed in the plenary session. The purpose of the World Café is to diffuse ideas, and make people aware of different ways that other disciplines view things, which in turn gives each participant a new perspective on his or her own research. This creates an environment where all W40-steps (see previous chapter) can be covered in a ‘pressure-cooker’ setting dealing with a single, relevant subject. The World Café turned out to be a strong catalyst in the MFFD research program, initiating the knowledge integration process, and pro- voking recurring discussion about contexts and definitions. In our case the starting question was: ‘What is a Multifunctional Flood Defense?’ (Project by Jaap de Boer; 2005). The World Café, shaping our future (through conversations that matter: San Francisco, Bennett-Kothis)
HOW MUCH TIME DO WE ACTUALLY HAVE TO DEVELOP MULTIFUNCTIONALITY?

PROFIL

Timo Hartmann is a professor of Systems Engineering at the TU Berlin. In his research and practical work he develops state of the art system visualization and simulation technologies and integrates these technologies with the working processes of construction, engineering, and architectural professionals. In the Multifunctional Flood Defenses research program he was a supervisor at Twente University in the project “Governance and finance of MFFD”.

Reflection

According to the latest report of the Intergovernmental Panel on Climate Change (IPCC), the average sea level rose by 0.17 to 0.21 m between 1901 and 2010. There is a high confidence that with ongoing global warming, sea levels will continue to rise. Some scientists predict levels as high as during the last interglacial period: a staggering minimum of 5 m above present levels. The rising sea level poses a severe threat to urban areas that are located close to the sea, areas in which 80% of the global population lives. It is now clear that the coming years will bring an increase of inland and coastal flooding. This increase already seems to be evidenced by the frequency and severity of recent large and catastrophic flood events.

Global warming and with it sea level rise will not be reversible. Hence, as engineers we will be responsible for mitigating its negative effects. For populated urban areas, this means for a large part mitigation by building complex systems of engineering structures, such as dikes, dams, and other hydraulic structures, which together can protect densely populated areas from extreme flood events. Such connected flood defenses are not only complex technical engineering systems, but also of social and economic functionality is a driver of complexity, both in terms of system-related technical aspects and in terms of the social and environmental contexts that these projects need to be realized in.

The projects in this third work package of the MFFD program show that in addition to passing technical complexity, it is important to understand the complex social and economic aspects of a project. Dealing with this second type of complexity is the key to one of the most urgent problems that we are facing in upgrading our urban flood defenses to mitigate the threats posed by climate change: Time. If we consider the traditional engineering projects that are being realized in our cities at this moment, progress seems to be painstakingly slow. From the initial steps of a new project idea to its final realization often takes decades of planning and engineering and trying to integrate these new plans into existing systems is often context-dependent. It is obvious in the case studies we conducted within the MFFD program. The planning, design, and engineering work on cases such as the Roefpark in Rotterdam, the Grevelingen-Volkerak-Zoommeer, or the Kinderdijk-Schoonhovenweer started long before the four years of the MFFD program began and, with the exception of the Roefpark, none of them were even close to finished when the program ended in 2017. Considering that we can expect even fewer cases in the coming years, the question is whether we can still afford the luxury of project planning cycles of ten to twenty years.

Our work on the MFFD program showed that speeding up the planning cycles is not something that technology alone can accomplish. The projects we studied have shown that innovative technical solutions are often hindered by long planning cycles. Can we even speak of innovative technical solutions or innovations are only implemented decades later? Our case studies show that the true complexity of flood events does not only come from the scarcity of innovative new technical solutions, but rather from governance and social issues. The theme of time in relation to innovation; or rather delays in implementing innovative solutions, is prominent in each of the projects. This has already been illustrated in this book: Julieta Matos-Castaño found that dilemmas caused by the different perspectives taken by different project stakeholders are an intrinsic part of any multi-functional project and that these dilemmas can often lead to paralysis and indecision. Ellen Tromp discussed the fact that putting aside innovations is common practice in our cities at this moment, progress seems to be painstakingly slow. On the contrary, implementing new and innovative planning and engineering cycles. These range from suggestions for governing complex multi-functional flood defense project environments, such as multi-district teams helping project practitioners to grasp and speed up projects, to suggestions for governance to the dilemma cube, which can help project participants to quickly find and negotiate the existing dilemmas at very specific project situations and stages. Considering the scale of the problem and the urgency of the situation, our suggested solutions are a small stepping-stone for a much wider research agenda for the years to come. I hope that our part on the MFFD project provides motivation as well as inspiration for the next generation of researchers that will provide more innovative and engineering cycles. Stepping-stones that will allow us to react to the pressing challenge of sea level rise, and quickly.
MULTIFUNCTIONAL FLOOD DEFENSES: CHALLENGES FOR GOVERNANCE

Over the past centuries, numerous examples of what we now call multifunctional flood defenses (MFFDs) have emerged in the Netherlands, ranging from houses or even entire villages built on polder dikes, to large scale developments in urban areas like Rotterdam, Dordrecht, and Schwerin. These developments were not planned as such, but emerged as a consequence of other unforeseen events.

We are now considering more deliberate functional combinations, but working towards planned MFFDs is no small task. One reason is that, over time responsibilities in different sectors have become more specialized and complex, leading to different institutions and traditions in fields like flood protection, land use planning, and economic/urban development. The importance of flood protection, for example, has led to the assignment of other responsibilities and strict rules designed to guarantee the reliability of flood protection; as a result, there is often strong resistance to combining secondary functions with primary flood protection infrastructures. Yet, there are good reasons to explore combinations of functions, combinations that do not necessarily lead to threats to the flood protection function.

The various contributions in this book provide a cross section of perspectives on the challenges for planning and design of MFFDs, and on possible ways forward. Most of the contributions in the governance part of this book focus on the challenges of connecting and intertwining knowledge from different sectoral traditions and from different disciplines. As experience in Policy Analysis shows, there is no single approach to do this. Typically, a combination of approaches is needed: for example, a process design that stimulates frame-reflection (such as a dilemma cube, a map, a touch table, or a joint ‘model’), and blocks for further steps. While the academic setting of the program and the requirements for PhD research do not provide the incentives (or the blocks) for full knowledge integration, creating a community of young researchers who have been exposed to the knowledge and perspectives of other disciplines related to MFFD is an important contribution.

Moving towards a situation in which effective cooperation and integration across disciplines, sectors and stakeholders is the rule instead of the exception takes significant time. It is essential to establish learning communities that build on experience in practice, and innovative educational programs that prepare future generations for cross-disciplinary cooperation.

While this remains challenging, a recent visit to Bangladesh and Indonesia made me realize once more that the Netherlands can build on 50 years of experience in development and innovation in flood protection. As exemplified, for example, by the success of a program like Room for the River, and parts of the Delta Program. The STW-sponsored research program underlying the contributions to this book provides building blocks for further steps. While the academic setting of the program and the requirements for PhD research do not provide the incentives (or the setting) for full knowledge integration, creating a community of young researchers who have been exposed to the knowledge and perspectives of other disciplines related to MFFD is an important contribution.
LEGO to collaborate. Different ways of collaboration were tried, explored, isolated, stuck, successful, and not less as useful as others that helped develop into useful products (see for example the ‘MFFD-education’ LEGO-game and the ‘Wind-turbines-on-dike’ Electronic-game, p. 13).

One of the ways we stimulated multidisciplinary collaboration in the MFFD program was using what we call a Program Case. This was a case study from which researchers in different disciplines worked together on one specific case location, aiming to deliver input for an integral design. This kind of collaboration worked well in the MFFD program, although it was by no means sufficient for all the input that the postdocs nevertheless needed to work on one of their individual case studies. As a rule, they may or often can not give this task priority. Luckily, some provisions were made for this in the MFFD program, with respect for existing and future relationships. Researchers from different faculties and universities need to be managed carefully, with respect for existing and future relationships. They often already start on the use of certain concepts, definitions, and imagery, which can be quite different between disciplines. We discuss these and require supervising authors from the different disciplines. Co-publishing with a researcher from another discipline requires a knowledge of the research topic. Postdocs are often assigned such management tasks; however, they are not selected on these aspects, or ‘Interesting, but this is far too planning-oriented for our discipline-specific journals, their readership is smaller, and their Journal Impact Factor (JIF)-scores are lower. Last but not least, working together on a publication requires far more time than alone and requires supervising authors from the different disciplines. Co-authors always have to balance and bargain on the content of the paper, but with a co-author from another discipline, the discussions often start already on the use of certain concepts, definitions, and imagery, which can be quite different between disciplines. We discuss these and require supervising authors from the different disciplines. Co-publishing with a researcher from another discipline requires a knowledge of the research topic. Postdocs are often assigned such management tasks; however, they are not selected on these aspects, or ‘Interesting, but this is far too planning-oriented for our
PROGRAM CASE: HOUSTON GALVESTON BAY REGION, TEXAS, USA
HOUSTON, WE’VE GOT A PROBLEM

INTRODUCTION PROGRAM CASE HOUSTON GALVESTON BAY REGION, TEXAS (USA)

Dr. Nikki Brand was a Postdoc in the STW-MFFD program at the Faculty of Architecture & the Built Environment, TU Delft in the project ‘Integration of architecture strategies for flood-prone cities’. UoH’s master’s students from Houston, Buenos Aires and New Orleans recognized the Three Continents Exchange, an educational project where based groups in the region studied and promoted flood risk reduction strategies. The invited reached the MFFD program and sparked off a quest to compare architecture strategies for flood-prone cities. UoH’s professor Tom Colbert invited TU Delft’s Architecture Faculty to participate.

In 2012, the University of Houston’s (UoH) Architecture Faculty organized the Three Continents Exchange, an educational project where master’s students from Houston, Buenos Aires and New Orleans compared architecture strategies for flood-prone cities. UoH’s professor Tom Colbert invited TU Delft’s Architecture Faculty to participate. The invitation reached the MFFD program and sparked off a quest to include as much academic capacity as possible to address the region’s urgent flood risk issues.

The Houston Galveston Bay Region in Texas is the fourth largest metropolitan area in the US, housing the largest petrochemical harbor in North America. Houston is located inland on Galveston Bay, and as a city, it is notorious for not having land use controls. The city has expanded rapidly by incremental building activities, exacerbating run off, destroying natural habitats of bayous and wetlands, and reducing water buffer capacity. Houston is especially prone to flooding by severe rainfall events at least three times in 2016 and early 2017. By contrast, the historical city of Galveston, located on a barrier island that shields Galveston Bay from the Gulf of Mexico, is prone to flooding by devastating storm surges. In 2008, Hurricane Ike produced a storm surge of 22 feet (6.8 meters), wiping the Bolivar Peninsula clean of houses. While flood safety efforts in the past also meant that a variety of complex and multidimensional nature of the flood risk challenge of the Houston Galveston Bay Region provided a unique opportunity for the MFFD researchers to study flood risk reduction in all its facets, employing multiple disciplines.

The complex and multidimensional nature of the flood risk challenge of the Houston Galveston Bay Region provided a unique opportunity for the MFFD researchers to study flood risk reduction in all its facets, employing multiple disciplines. The lack of flood safety efforts in the past also meant that a variety of comprehensive flood risk reduction strategies might still be feasible.

However, the region’s flood risk challenges turned out to be so large, and the demand for knowledge and support so great, that it could not be served by the MFFD program alone. MFFD researchers became part of a larger research consortium.
that combined Texas A&M, SSPEED, TU Delft, WUR and a variety of consultancy and engineering firms. In order to assess the true contribution of the MFFD program, the results of this program case have to be read together with other publications like Delft Delta Design: The Houston Galveston Bay Region (Kothuis et al., 2015) and the Land Barrier preliminary design (Van Berchum et al., 2016). Milestones in the Dutch-Texas collaboration were winning the multi-million dollar NSF PIRE research grant for the Coastal Flood Risk Reduction program and the introduction of the ‘multiple lines of defense’ approach in 2015. This concept, based on the consideration of residual surge in Galveston Bay even after the completion of the Ike Dike, combined and balanced proposals that had been presented earlier. It also introduced new flood defense strategies and structures like the Coastal Spine and the Midbay Barrier.

Meanwhile, local initiatives pushing for comprehensive flood risk reduction in the region have grown, with new groups like the Bay Area Coastal Protection Alliance (BACPA) influencing policy-making of for-mal decision makers like the Gulf Coast Community Protection and Recovery District (GCCPRD) and the Texas General Land Office (TGLO). New approaches, incorporating concepts like Building/Engineering with Nature and Natural-and-Nature-Based Solutions to address flood risk in the Houston Galveston Bay Area, are seriously being considered and explored by governmental agencies as well as academics.

The research collaboration that the MFFD program inspired, continues to thrive and yield new results, even though changes have occurred in the group. In 2015 professor Tom Colbert passed away. But his legacy of including spatial co-benefits in the design of a flood risk reduction strategy lives on (just as in the MFFD program’s philosophy). This is demonstrated by the role of landscape integration (Van Berchum et al., 2016) and Noordwijk-style suggestions for artificial dunes (see for example “Ike Dike could be hidden by dunes” in the Houston Chronicle, October 25, 2016). The NSF PIRE, a US Federal research grant, has made it possible for the existing consortium to expand their research and educational portfolio, and every year dozens of new students join place-based case studies. These efforts continue and stimulate ongoing multidisciplinary and transatlantic knowledge transfer in flood risk reduction.
PROTECTING GALVESTON BAY SHORES AND THE BARRIER ISLANDS

The Houston-Galveston Bay area consists of a large bay with barrier islands millions of people live here, and the area represents large economic value. Though the region does not have yet an integral flood defense system, the feasibility is being investigated as the area is hurricane prone. In the simplified optimization problem, a number of defenses have been set to a fixed level: F1, F2, and F3 (Figure 1). Only one single system configuration is considered in this case study, but this assumption will not have a large impact on the conclusions as in these locations of the flood defenses are already built, and it would require a huge amount of resources to relocate them. Consequently, as we see in Figure 1, this leaves us with only three defenses which will be part of the economic optimization: a single front defense in the form of a storm surge barrier (B1), and two rear defenses (A1 and A2). Tables 1 and 2 show the outcomes of the simplified case study: Table 1 with the front defense and Table 2 without the front defense. It can be concluded that the front defense reduces the hydraulic load dramatically, and that it is cost effective in this case to have multiple lines of defense.

Many alternatives can reduce the flood risk around Galveston Bay (for an overview, see page 146). But which combination of alternatives suits the society most? This is no doubt, a political decision, with various interests each playing a role. Nevertheless, we can always ask which combination is most attractive from an economic point of view. In my research, this question is answered by minimizing the total costs of ‘multiple lines of defense’. In such an approach, for example the ‘front defense’ reduces the hydraulic load on the flood defenses that ultimately protect the vulnerable areas. The outline of the optimization approach is given in Figure 3, where the different variables are presented. The application is based on work from a real, ongoing case study in the Galveston Bay area near Houston. However, the actual decision-making problem is simplified in order to investigate the principles behind optimization of multiple lines of defense. Therefore, the results are primarily useful for a comparison between an application with and an application without multiple lines of defense.

Guy Dupuits is a PhD candidate in the STW- HFGZ program at department of Hydraulics, Engineering, faculty of Civil Engineering & Geosciences, Delft University of Technology. He is part of the project ‘Safety and reliability assessment of multi-level local flood defenses’. Guy is expected to graduate in 2017.

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Table 1 and 2. Optimal investment scheme for the Galveston Bay example using the numerical framework for the simplified optimization problem, with (left) and without (right) the influence of a front defense. The corresponding system risk values for a coastal flood defense system with multiple lines of defense.

<table>
<thead>
<tr>
<th>Year</th>
<th>Defense</th>
<th>Height Increase</th>
<th>Year</th>
<th>Defense</th>
<th>Height Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A1</td>
<td>From 0 to 5 meter</td>
<td>0</td>
<td>A1</td>
<td>From 0 to 6 meter</td>
</tr>
<tr>
<td>100</td>
<td>A1</td>
<td>From 5 to 7 meter</td>
<td>100</td>
<td>A1</td>
<td>From 6 to 8 meter</td>
</tr>
<tr>
<td>150</td>
<td>A2</td>
<td>From 0 to 7 meter</td>
<td>150</td>
<td>A2</td>
<td>From 7 to 10 meter</td>
</tr>
<tr>
<td>180</td>
<td>B1</td>
<td>From 0 to 7 meter</td>
<td>180</td>
<td>B1</td>
<td>From 7 to 10 meter</td>
</tr>
<tr>
<td>170</td>
<td>B1</td>
<td>From 7 to 11 meter</td>
<td>170</td>
<td>B1</td>
<td>From 11 to 15 meter</td>
</tr>
</tbody>
</table>

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Figure 1. Galveston Bay area with contours indicating the defense types for the hypothetical application from OpenStreetMap (©OpenStreetMap contributors, http://www.openstreetmap.org/copyright).
ENHANCING VALUES AND FUNCTIONS OF THE RURAL ENVIRONMENT BY MULTIFUNCTIONAL FLOOD DEFENSES

INSPIRATION FROM THE DUTCH WADDEN SEA REGION AND THE TEXAS COAST

Dr. Jantsje van Loon-Steensma is a researcher and lecturer of Climate Change and Flood Protection in the department of Environmental Sciences at Wageningen University & Research. In the MFFD Program she works as a Postdoc in the project ‘Contribution of Multifunctional Flood Defenses to landscape values and coastal quality’. Her research focuses on climate adaptation by integrating functions in flood defences, she combines hydraulic, ecological, geographical and economical aspects in the search for climate proof robust flood defences that in addition to flood protection, also favor nature, landscape, heritage, recreation or economic values.

Multifunctional flood defences are often considered promising options to both spatial scarcity and integrate different stakeholders in densely populated and intensively used urban areas. In rural areas, as well, interests, values and stakes may collide with the interaction of land and water, and they may also compete for space. For example, many defaun coastal areas have important natural value, but they are also used for agriculture, recreation, industry and urban expansion. Not only does human use of the coastal zone affect the coastal habitat and biodiversity, it also requires protection from storm surges. In these rural areas, the concept of multifunctional flood defences might also offer an interesting opportunity to combine distinctly different values and functions with flood protection.

To gain insight into the potential of multifunctional flood defences in rural coastal areas, current practices and ideas for future flood protection were studied along the Dutch Wadden Sea coast and the Texas coast. Of course, there are significant differences between both coasts. They represent different climate zones (temperature and precipitation), have different storm patterns (the Texas coast is hurricane prone), and different tidal ranges (the range along the Texas coast is very modest). However, they also have several similarities. Both coasts are deltaic, comprise a barrier island coast, are bordered by large flat areas that are used for agriculture, and host petrochemical industries. Furthermore, both coasts also serve as important recreation and touristic function. Comparison of these two cases shows that including wetland habitats in the flood protection could be beneficial for each area, but requires in-depth understanding of the different local conditions and flood risk management strategies.

Flood protection in the Dutch Wadden Sea: The Wadden Sea is a large tidal area, renowned for its sandflats, mudflats and salt marshes (CWSS, 1991; Reise et al., 2010). It has been designated as a Ramsar site and has been on the UNESCO World Heritage List since 2009 in recognition of its unique mudflat ecosystem (CWSS, 2008, UNESCO, 2009). Fauna common to tidal flats flourishes in this system, making the Wadden Sea an important foraging, wintering and resting site for millions of birds on the East Atlantic Flyway.

The Wadden Sea region has a very long history of human habitation and flood protection. The first inhabitants settled on the natural high grounds in this tidal landscape. The marshes were used for grazing (by cattle and sheep) and for harvesting hay. About 2,000 years ago, with increasing population, the inhabitants of the coastal area started to raise artificial earth mounds for protection against flooding (Cools, 1948). Starting in the Middle Ages, these mounds were progressively connected by dikes, leading to the formation of rings of dikes protecting the hinterland. As settlement on the seaward side of these dikes proceeded, new salt marshes, new dikes were built to reclaim these areas for agriculture (for both grazing and arable land). Centuries of land reclamations caused the boundary between land and the Wadden Sea to gradually shift seawards. The interaction of nature and human activity created a unique flat and open landscape of broad horizons, with extensive dikes along the coast and semi-natural salt marshes adjacent to them. Throughout the landscape, the remnants of historical dikes can be found.

Currently, the low-lying coastal zone (mainland and barrier islands) is inhabited by some 1,25 Million people. Some 227 km of dikes
dike slope and height) and the need for dike design? What are the implications of the decreased wave height and reduced wave energy on flood defense practices and the need for dike slope and height design? How could these changes influence the design of new dikes along the Wadden Sea coast? These questions highlight the need for an adaptive approach to dike design, considering the dynamic nature of coastal environments.

In the Netherlands, the Afsluitdijk (completed in 1932) and the Oosterschelde barrier (1957) are examples of high dikes designed to protect against extreme coastal events. However, as sea levels rise and storms become more frequent, the current dike heights and slopes may no longer be sufficient to protect coastal areas. This highlights the need for ongoing research and adaptation in dike design practices.

In the Wadden Sea region, dike height and slope are determined based on a cost-benefit analysis, historical flood disasters, and integrating natural habitats in flood defense schemes. The height and slope are crucial, but with some homes intermingled, some wetlands have been replaced by hard revetments and rocks. Nevertheless, the presence of salt marshes could have a favorable effect on the biodiversity and habitat value of the dike systems. In addition, salt marshes provide characteristic and valuable habitats (e.g., Adam, 1990) and have a potential to modulate wave energy (e.g., Costanza, 1992).

In the Netherlands, the Ministry of Infrastructure and Environment has not allowed the raising of dikes above a certain elevation (4.5 m above mean sea level). However, in the Texas coastal region, the idea of integrating salt-marsh foreland into the dike design has been explored. This approach aims to enhance the ecological function of the dike system and provide additional benefits, such as improved water quality and coastal erosion control. The goal is to develop a balanced solution that addresses both flood protection and ecological conservation.

In Texas, on the other hand, the idea to include wetland habitats in the flood protection strategy for coastal areas faces a spatial and historical risk strategy. Assigning coastal wetlands, prairies, and bottomland for nature conservation could prevent their becoming built up. With no protective dikes, beach houses are severely damaged each time there is a flood, while expensive beach houses have been constructed on stilts to protect them against coastal flooding caused by hurricanes. Sometimes, homeowners have tried to stimulate dune formation in order to protect their houses. This approach is currently designed for a 1/100 year and flooding occurs with each major hurricane passing the region; several ideas have been proposed to include dune restoration into the dike design. However, due to the historical flood disasters, these include different criteria for the dike design on Galveston Island, and dams and barriers along the mainland side of the bays and estuaries.
The CIGAS-approach was first introduced in 2011 in South-Africa in the Great-Basin-region by J.J. Singer, Scott Cunningham and Leon Hermans (see Singer at et al. 2014). The method was further elaborated for the workshop in Texas in 2014, as introduced here (for a full report see Kothuis et al., 2014). We would like to express our gratitude to Jim Blackburn, who was indispensable to us in executing this CIGAS workshop.

Figure 1. Systems modeling techniques in a two-day workshop. Since participants are understood to have different interests and values, the goal is neither to reach consensus nor to solve conflicts, but discussing these issues with academic partners at Rice University and Texas A&M Galveston, the MFFD researchers saw similarities to other multifunctional flood defense development projects. For a project in South Africa, a stakeholder consultation approach was developed to address local values and interests and deal with contested issues of flood management (Singer at et al. 2014). Accordingly, the team proposed conducting a workshop along these same lines in the HGB region.

The CIGAS approach strives to co-create insights regarding the contested environment, using action research, game structuring, and system modeling techniques in a two-day workshop. Since participants are understood to have different interests and values, the goal is neither to reach consensus nor to solve conflicts, but discussing these issues with academic partners at Rice University and Texas A&M Galveston, the MFFD researchers saw similarities to other multifunctional flood defense development projects. For a project in South Africa, a stakeholder consultation approach was developed to address local values and interests and deal with contested issues of flood management (Singer et al. 2014). Accordingly, the team proposed conducting a workshop along these same lines in the HGB region.

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Three major coalitions of stakeholders - CIGAS Workshop October 2014

In the CIGAS workshop, participants engaged in a series of exercises designed to help identify and prioritize the interests of different stakeholders. Four outcomes are outlined in Table 2.

<table>
<thead>
<tr>
<th>National interests</th>
<th>Infrastructural interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Flood protection</td>
<td>- Infrastructure provision</td>
</tr>
<tr>
<td>- Flood insurers</td>
<td>- Emergency response</td>
</tr>
<tr>
<td>- American people</td>
<td>- Land use protection</td>
</tr>
</tbody>
</table>

Four outcomes on the Pareto Optimum - CIGAS Workshop October 2014

Outcome Description

- Flood protection in engineered structures, which is designed with hard infrastructure and includes soft infrastructure measures.

The primary goal of the CIGAS method is to facilitate joint action among stakeholders. The workshop is not to take sides, but rather to explore the contested issues and help participants to develop a more inclusive listing of key players and their perceived interests. The workshop is conducted in a stepwise manner, with each step building on the previous one.

Workshop Outcome and Follow Up

The workshop provided insight into the contested situation by exploring the following three central issues:

1. What do the stakeholders care about? The participants discussed and described the systems and values important to them, which are evident in Table 2.

2. Potential conflicts among the identified stakeholders. The workshop revealed irreconcilable differences among the various coalitions, but also an appreciation of the issues on which they agreed.

3. Positive outcomes. Of course, these differences would represent their worst nightmares. The workshop could discuss the contested issues and come to an agreement to cooperate in the future.

For the researchers, applying CIGAS in the Houston Galveston Bay situation provided further information on the usefulness of the approach. It yielded insights on how it can be adapted for eventual further use. Nevertheless, the workshop could not be a ‘low-tech’ workshop focusing more on functional requirements to further explore potential flood risk design based on the results from the stakeholders in the CIGAS-Texas workshop.

The workshop participants recognized the importance of developing joint action; in this section, they agreed that the workshop provided an inclusive form of a platform where key players could discuss the contested issues and come to an agreement to cooperate in the future.

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Galveston is a barrier island with a population of approximately 60,000, located between Galveston Bay and the Gulf of Mexico on the Texas coast. Due to its location, Galveston is not only on the front line of hurricane-induced storm surges coming from the Gulf, it is also a key site for any flood defense aiming to protect the entire Houston-Galveston Bay region. The island and its namesake city’s history have been marked by devastating storms, most notably the 1900 Great Galveston Hurricane, and Hurricane Ike in 2008. The back and west end of the island are particularly vulnerable to flooding during Hurricane Ike in 2008. Given its vulnerability and key importance to preventing storm surge for the region, Galveston is also the cradle of one ambitious flood risk reduction proposal: the Ike Dike, sometimes known as the Coastal Spine. Despite its high vulnerability to flooding, the bay region’s current tradition regarding flood risk reduction remains patchy: a patch of different organizations, primarily reacting to flood damage after the fact, and, from a Dutch perspective, an impressive and sophisticated form of emergency management (Brand & Hogendoorn, 2015). The Bay region’s flood risk challenge is currently being analyzed by the US Army Corps of Engineers in the Coastal Texas Protection and Restoration Study. Existing large-scale flood defenses that aim to prevent flooding, like the Galveston Sea Wall on the Gulf-side (Bellis Bixel & Hayes Turner, 2000; Wright-Gidley & Marines, 2008), were only built under exceptional circumstances: financial support from federal agencies. To start with, no local agency has been designated responsible for flood risk reduction, and there is no preferred leading agency. It is thus not surprising that the Ike Dike started as an initiative of the Texas A&M University of Galves ton. Galveston’s governance arrangement for flood risk reduction is composed of a variety of different local agencies, ranging from multipurpose authorities (the City of Galveston and Jamaica Beach) to single-purpose authorities (the Galveston Park Board of Trustees) and interest-based associations (the West End Homeowners Association). All the agencies involved in flood risk management do so secondary to their primary aim. The Park Board, for example, safeguards the economic interests of tourism, for which the continued existence of the beach is key. To this end, the Park Board successfully completed two beach nourishment projects in 2015-2016. In order to do so, the Park Board collaborated with the US Army Corps of Engineers, paying the so-called ‘incremental costs’ to relocate dredge spoils from the Houston Ship Channel to Galveston’s beach.

GOVERNANCE AND PLANNING AS BOUNDARY CONDITIONS FOR FLOOD RISK REDUCTION IN TEXAS

Galveston Island’s Flood Risk Challenge

Dr. Nikki Brand is a Postdoc at the Spatial Planning & Strategy Department of the Faculty of Architecture & the Built Environment, TU Delft University of Technology, where she is involved in the JPI-NWO funded PICH-program and the ESPON-funded COMPASS-program. Additionally, she works as an independent research associate at Urban Integrity, studying the contribution of networks of plans to vulnerability for flooding in the US and the Netherlands, within the Texas A&M-based resilience scorecard-project. In the STiP-MFFD program she was a postdoc in the project ‘Urban design challenges and opportunities of multifunctional flood defenses’. In the project ‘Urban design challenges and opportunities of multifunctional flood defenses’ (Brand, 2015). Considering Galveston’s governance arrangement for flood risk reduction, several obstacles exist for a flood defense on or near the beach front, adjacent to the existing sea wall. However, Galveston’s planning system also does not seem to offer many options for an alternative flood risk reduction strategy. Agencies and their jurisdiction

Nikki Brand
The only agency that explicitly mentions safety from flooding in its directives is the Texas General Land Office, a state author- ity (TGLO, 2014). TGLO allocates funding for projects depending on requests by local partners. But neither TGLO nor the Park Board earmark funding specifically for flood risk reduction projects, which means that new negotiations are required for each project, competing against other funding priorities. The most complicating issue is that jurisdic- tion on the island is a complex matter. With the exception of Jamaica Beach, which has its own local government, the City of Galves- ton has jurisdiction over most of the island; for designated sites on ‘the dry beach’, the responsibility has been outsourced to the Park Board. However, local property owners seem to overcome the so-called rolling easement in 2011, a legal tool that allows mandatory public access to the beach follow- ing the vegetation line.

Spatial planning

Although greater Houston is internationally known for its absence of zoning (Land, 2017), Galveston City does have some of the basics, US planning tools (Berke et al., 2006): a com- prehensive plan, land use regulations (LDR), and building codes. For an outsider, it’s hard to get a proper understanding of how Galves- ton’s planning system functions - but the preliminary evidence is not reassuring. While spatial planning on Galveston Island does not seem to put constraints on the construction of a flood defense, but it does not promote development that reduces vulnerability either. The LDR and building codes within the city’s jurisdiction do not appear to be very effec- tive or up to date. For example, the disturbing fin- dings from the 2004 Galveston Island Geo- hazard Map (which put much of Galveston’s beachy areas at risk) are not currently being enforced by the city - Galveston’s planning system functions - but the preliminary evidence is not reassuring. While spatial planning on Galveston Island does not seem to put constraints on the construction of a flood defense, but it does not promote development that reduces vulnerability either. The LDR and building codes within the city’s jurisdiction do not appear to be very effec- tive or up to date. For example, the disturbing fin- dings from the 2004 Galveston Island Geo- hazard Map (which put much of Galveston’s beachy areas at risk) are not currently being enforced by the city.

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Concluding remarks

Galveston’s governance arrangement for flood risk reduction does not favor prevention, nor does it favor spatial planning. Measures to reduce vulnerability in the built environment face obstacles. As in February 2015, a national coastal flood defense. However, during the time the NPIF program was involved in Texas, the Ike Dike gained increasing support (Houston Press, 2016). While the Gulf Coast Commun- ity Protection and Recovery District - a six-
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When most people think about flood control, they associate it with technical knowledge. Of course, without technical expertise, the various ways of anticipating floods would be impossible. To implement these, we need policies, and these policies rely on a proper understanding of the relations in nature. They also depend on technical and precise design, where consequences are inferred with the help of simulations and the occasional scale-model. And since determining the potential height of water levels or the peak load of concrete is a highly specialized task, people leave the actual design of flood risk reduction measures to the applied disciplines, such as civil engineering.

In the design process, there will be technical discussions and disagreements, but eventually a design or approach is found that satisfies the technical requirements and reduces harm from flooding. However, in many cases, the technologically 'best' design does not get implemented. To understand this outcome, we took a broader perspective in this study, and found that when implementing a project to reduce flood risk, different government modes and how people view the government are as important as the technical details. This is a realm that is not usually associated with flood control.

We examined how people’s expectations of government and their political values affect flood risk planning: do they have an enabling effect, an obstructing one, or a moderating effect? Do these factors influence whether flood risk planning will be incorporated into the decision making? To answer these questions, we used the IMPACT model. We took a broad perspective in this study, and found that stakeholders’ political values affect even the most technocratic decisions, and that technical requirements and other limitations are not enough to decide the final design.

We expected, for example, that if people value government as central and powerful, water management projects would roll out one after the other, as if it were an assembly line. This can be seen in the Chinese system. On the other hand, if government is valued as a service, it will encourage deliberation and negotiation between a variety of decentralized groups. In such a case, flood control measures of every kind may be proposed, but the lengthy decision-making process means that the final design is frequently very different from what people started with. This is the result of satisfying the many and disparate demands of the different groups that are involved. We can see such a pattern in the North-East Asian deltas, where the development of Multi-functional Flood Defenses illustrates the technical possibilities. And finally, at the other extreme, if people accept little or no government, we may expect that government-intensive flood control policies will have difficulty finding support. Such political values are reflected in the Greater Houston area, where the state constitution, tax-policies, urban planning, and general cultural mindset exemplify so-called ‘Red State’ values. As this relates to government, it can be summarized as ‘low taxes, low services’.

To test whether attitudes towards government (and associated institutions) actually affect even the most technocratic decisions, we examined the case of Greater Houston (Hogendoorn 2016; Brand and Hogendoorn, forthcoming). This case has a kind of signal value on the one hand, few regions in the world are as adamant in their aversion to government. On the other hand, the Greater Houston area frequently experiences various types of flooding often very costly disasters like the tidal surge caused by Hurricane Ike in 2008. Moreover, the emphasis on small government has been remarkably consistent, dating back to the 19th century, when Texas was still primarily an agricultural economy.

Daniel Hogendoorn, MSc, is a Postdoctoral researcher at University College London, Department of Science, Technology, Engineering and Public Policy, where he researches knowledge transfer to South East Asian deltas. He was a PhD candidate in the STW-KIVI program at department of Policy, Organization and Public Affairs, University of Technology. He took part in the project ‘Governance and finance of MFFD’ and is expecting to graduate in 2017.

When most people think about flood control, they associate it with technical knowledge. Of course, without technical expertise, the various ways of anticipating floods would be impossible. To implement these, we need policies, and these policies rely on a proper understanding of the relations in nature. They also depend on technical and precise design, where consequences are inferred with the help of simulations and the occasional scale-model. And since determining the potential height of water levels or the peak load of concrete is a highly specialized task, people leave the actual design of flood risk reduction measures to the applied disciplines, such as civil engineering.

In the design process, there will be technical discussions and disagreements, but eventually a design or approach is found that satisfies the technical requirements and reduces harm from flooding. However, in many cases, the technologically ‘best’ design does not get implemented. To understand this outcome, we took a broader perspective in this study, and found that when implementing a project to reduce flood risk, different government modes and how people view the government are as important as the technical details. This is a realm that is not usually associated with flood control.

We examined how people’s expectations of government and their political values affect flood risk planning: do they have an enabling effect, an obstructing one, or a moderating effect? Do these factors influence whether flood risk planning will be incorporated into the decision making? To answer these questions, we used the IMPACT model. We took a broad perspective in this study, and found that stakeholders’ political values affect even the most technocratic decisions, and that technical requirements and other limitations are not enough to decide the final design.

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However, the social pattern in Greater Houston has become very complex: it is not only the energy hub of the US, the fourth largest metropolitan region in the country, and an important ecological zone. Yet, instead of increasing centralization, Greater Houston’s government has coped with such complexity by finding many low-level forms of distributed government, including the possibility for landowners to administer their own affairs.

For this case study, we first identified all flood-related policies executed by the numerous governments within the region’s Houston-Galveston Metropolitan region, which includes Houston, the Ship Channel, and Galveston Island. We then classified those policies into more abstract strategies. We assigned each of these strategies a verb, dividing them in terms of actions and how those actions anticipated flooding events.

- The strategy Inform involves disseminating content to assist and encourage distributed decision-making, for example when government informs people of an approaching storm or develops an app to identify safe zones.
- The strategy Limit is used to nudge people away from some options or remove certain options when people decide where to seek safety from flooding. For example, when the city is evacuated under the policy of contra-flow, all highways move one-way leading out of the city.
- The strategy Modify occurs when policies request people to adjust the characteristics of vulnerable assets and environments to make them less vulnerable. This can be seen, for example, when new development requires the homeowner to build on stilts, or the developer to dig earth elsewhere, to avoid lowering the floodplain.
- The strategy Recover accepts the flood event and vulnerability, but anticipates dealing with the aftermath. A typical Texan example is shadow-contracting private companies to clear debris or provide space for refugee camps in the event of a disaster.
- And finally, the strategy Control intervenes directly to address the flood event itself. The greater the risk, the more collective means are expected to be necessary to deal with it. Large-scale flood defenses are the most clear example of this strategy.

We started from the hypothesis that policy-intensive flood control will seldom be found in a system where people accept little or no government. We could check this assumption based on the classification into strategies, since each strategy represents an increased level of government intervention (i.e., the strategy Inform would be most aligned with Tea-Style values and the strategy Control the least). Based on our hypothesis, we should not find policies in the control category except for small-scale and local efforts, projects justified by very special circumstances, or projects shoehorned to explicitly fit the political values during implementation. Similarly, if large-scale flood defense planning or other control policies had been attempted, but had failed, this would also support the hypothesis. Indeed, when we listed all water management efforts in the region, we found that this was the case.

Nevertheless, it is unclear whether this situation can continue in Greater Houston. First, the region’s complexity and the value of its economic activities mean that potential storm surges will become increasingly costly. Moreover, the important economic role of the region has attracted increasingly diverse populations, who often have different expectations of government. And finally, since Hurricane Ike in 2008, signs have become more promising for large-scale flood control measures.

Growing networks of experts are actively working on large-scale plans that work counter to traditional Texas political values. The Greater Houston area offers many opportunities for multifunctional flood defenses. Since government may need local support to develop large-scale measures, other groups may be approached for collaborative design, such as landowners or petrochemical companies, or NGOs active in the management of ecosystems. Some previous efforts suggest that such ad hoc coalitions that disassemble once the project is completed have higher odds of success (Colbert, personal communication, 2015). Despite all this, large-scale flood control requires dedicated public resources for maintenance throughout the life cycle, and this is likely to compromise private property rights. In the unlikely event of another major hurricane surge flood, this could cause unintended consequences, requiring even more government intervention. Our research shows that prevailing political values of the region determine a large extent what government investments governments are willing to make, and thereby limit the space civil engineers and the other specialists have to implement their plans. Engineers and professionals need to take this into account in their designs for flood risk reduction measures.
EVERYTHING IS BIGGER IN TEXAS

The saying goes that ‘Everything is bigger in Texas.’ This holds true for both the flood risk in the Houston-Galveston Bay Area, and for the complexity of issues that need to be dealt with in order to reduce it, assuming there is an agreement that the current risk is unacceptable. There is currently no direct solution, and hence no preferred direction for designing a strategy for flood risk reduction.

The region has a very different political setting compared to the Netherlands, which means that most studies in this MFFD program case explored the boundary conditions for a future strategy. Researchers had to be aware of political sensitivities while working with American ‘users’, and had to recognize another view on the role of government. Collaboration with the communities in Texas was therefore challenging, and resulted in a type of study that can be characterized as action research. Findings made during the study had a real impact on the collaborative network in the region. Additionally, the Texas case study considerably broadened the predominantly Dutch perspective of the MFFD program.

For almost a decade, Dutch flood risk policy has broadened its scope to a three-layered strategy, with the first layer considering protection, the second layer reduction of vulnerability by spatial planning tools and building codes, and the third layer and final layer crisis management. The first layer of protection has traditionally been dominant with the construction of flood defenses. In sharp contrast, the US is known for giving priority to recovery and emergency management. This makes it interesting to explore what the potential of the first and second layers of the multi-layered safety approach could be in Texas. As efforts to reduce flood risk on the regional scale in Texas have been limited to date, many future strategies can still be envisioned. With formal leadership in regional flood risk reduction virtually non-existent, engaging more bottom-up support for a broader strategy becomes feasible. This ‘void of support’ provides fruitful conditions for the design of multifunctional flood defenses, as co-benefits can be decisive for engaging bottom-up support.

The MFFD-studies within the larger Dutch-Texas research collaboration focused on identifying building blocks for designing a flood protection strategy, ideally a multifunctional one. Van Loon concludes that given the large amount of pristine wetlands along the coast of Texas, and the large amount of other lands that will be very valuable for flood protection. Dupuits analyzed how wetlands could contribute to a future flood safety strategy, ideally a multifunctional one. He shows that multiple lines of defense can be very cost-effective compared to a single line. However, the Galveston seawall is a very prominent example of engineering in this area.

Despite these and other results (Kothuis et al., 2015, Van Berchum, 2016), both a comprehensive analysis of the boundary conditions and of the collectively preferred flood risk strategy are still lacking in 2017. The hypothesis that local actors need to assume an important role to compensate for lack of governmental involvement still needs to be confirmed, though a multifunctional flood barrier (usually framed with concepts such as ‘co-benefits’ or ‘landscape integration’) has been well received in this region. This can also be observed in practice, as the existing Galveston seawall is a road on top. For now, we can conclude that both the first and second stage of multifunctional safety - flood defenses that prevent events, and spatial planning and adaptation that reduce vulnerability - face considerable obstacles, ranging from lack of institutions and tools to lack of political support. This does not mean that the Houston Galveston Bay Region’s position is hopeless. First, Texas history provides several examples of flood events forcing federal, national and local decision-makers to take action exploiting short windows of opportunity to build flood defenses. The Galveston seawall is a prime example. Moreover, between 2012 and 2017, the formal and informal network of actors pushing for flood risk reduction has expanded to include formal decision-makers at all administrative levels. In fact, the Texas General Land Office currently offers a ‘You Tube video supporting the construction of set off barriers along the Texas Coast. The ongoing research collaboration between the Netherlands and Texas also increases the chance of action before the next big storm event. And if the Houston Galveston Bay Region could overcome the many obstacles on its road to reduce flood risk without a disaster, it could not only be a huge step for the Houston Galveston Bay region, but for mankind as well.
PROGRAM CASE: ROTTERDAM ROOF PARK | DAKPARK
A CITY PARK ON TOP OF SHOPS AND A DIKE

INTRODUCTION

Dr. ir. Peter van Veelen is Delta Coordinator for the Delta, Infrastructures and Mobility Initiative at TU Delft University of Technology. In the STW-MFFD program he worked as a PhD candidate in the project ‘Urban design challenges and opportunities of multifunctional flood defenses’. Dr. ir. Mark Voorendt is lecturer of Hydraulic Engineering at the Faculty of Civil Engineering & Geosciences, TU Delft University of Technology. In the STW-MFFD program he worked as a PhD candidate in the project ‘Structural assessment of multifunctional flood defenses’. Ir. Chris van der Zwet is tendermanager at Van Hattum en Blankevoort. In the STW-MFFD program he worked as a PhD candidate in the project ‘Contribution of multifunctional flood defenses to landscape values and spatial quality’.

The idea for a large city park is part of an old agreement with residents to add more green space that stems from the urban renewal process of the surrounding district ‘Bospolder - Tussendijken’. The parties involved in its inception include the Municipality of Rotterdam, the Water Authority of Delfland, and DURA Vermeer (Stichting Dakpark Rotterdam, 2012). Initially, the Water Authority of Delfland strongly opposed this project, but under strong pressure from the Rotterdam Municipality, the project was finally realized. The Water Authority was only involved as a licensing authority and the municipality has promised to pay the extra costs involved in strengthening the flood defenses in the future (Van der Leeuwen, 2008).

This is an adapted version of part of the chapter ‘Design challenges of multifunctional flood defenses. A comparative approach to assess spatial and structural integration’ published in Flowscapes (2015). All authors contributed equally to this chapter.
In the context of urban planning, concepts of multiple land-use refer to situations where the existing space is more intensively used (justifications cited in Hooimeijer et al., 2001). This can be achieved by morphological integration of functions (stacking of multiple functions in one building or construction), by mixed space use (multiple functions in a certain defined area) and by temporal shared-use of the same space.

The degree of spatial integration we use is based upon a classification by Ellen (2011) and adapted by Van Veelen (2013), who distinguishes four spatial dimensions of multifunctionality: These dimensions are used for evaluating the degree of spatial and functional integration, with slightly adapted terminology (see also Figure 5):

1. Shared use
   A flood defence structure is (temporarily) used by another function, without any adjustments to its basic structure. It is, generally, well possible to use the flood defence for infrastructure, recreation and agricultural uses, as long as the functioning of the flood defence is not impeded.

2. Spatial optimisation
   The basic shape of the flood defence is adapted to create space for other structures. These structures are technically spoken not part of flood defence structure. Spatial optimisation is found in many places in the highly urbanised areas of the Dutch delta. The most compact and spatially optimal shape is obtained if a vertical retaining wall is applied which replaces a dike slope or berm, leaving space for, e.g., housing.

3. Structural integration
   An object is built on, or under the flood defence structure, but does not directly retain water. The concept of structural integration is used in situations where the current dike is over dimensioned (super dike) or many times stronger than necessary (concept ‘unbreachable dike’).

4. Functional integration
   The water-retaining element of the flood defence also functions as a part of the structure with another function (the ‘object’). Although this concept is technically feasible, it is hard to find realised examples of full integration. There are some historically evolved situations in which the dike is part of a medieval city wall (e.g., in Kampen) or a row of old buildings (e.g., in Dordrecht).

The determination of the degree of integration starts with identifying the composing elements of a flood defence structure.

- As a first step it should be determined whether an element has a water-retaining function or influences the strength and stability of the flood defence structure as a whole.

- If this is not the case, the integration is categorised as ‘shared use’ as long as the basic shape of the flood defence is not altered.

- If the flood defence shape is adapted to allow more spatial compactness, the situation is categorised as ‘spatial optimisation’.

- If an object or part of it fulfills a structural function but is not part of the flood defence in the flood defence structure, it is evaluated as ‘structural integration’.

- If this structural role is retaining water, the category is called ‘functional integration’.

The flood Park complex itself does not contain structural elements that are part of the flood defence. The additional soil layer on top of the dike is not considered to contribute to the retaining height because the Water board regards the existing profile as the flood defence. This profile has not been adapted to make space for other functions. The Roof Park therefore is classified as ‘shared use’.

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Peter van Veelen, Mark Voorendt, Chris van der Zwart

ROTTERDAM ROOF PARK: A MULTIFUNCTIONAL STRUCTURE OF SHARED USE

DEFINING FOUR SPATIAL DIMENSIONS OF MULTIFUNCTIONALITY

PROGRAM CASE STUDIES
‘DECONSTRUCTING’ THE ROTTERDAM ROOF PARK

Kevin Raaphorst

PROTOCOL CASE STUDIES

Kevin Raaphorst MSc is a PhD candidate in the StW PhD program at the Claw Group Landscape Architecture, Department of Environmental Design, Delft University of Technology. He is pursuing a more iconic design: they presented the Roof Park as part of the Parklane’, a park interwoven with the commercial real estate beneath the park, the infrastructure of the park lane, as well as the realistic 3D artist impressions at ground level presented their vision of the ‘Bigshops Parkboulevard’. The perspective of all cartographic material, as well as the bird’s eye view, was now oriented towards the park lane (southwest - northeast), emphasizing the connectivity with the local community and the neighborhood role of the Roof Park. The ‘Parklane’ is clearly present in the perspective drawings, but not emphasized in the cartographic material. The combination of spatial functions is visualized using a layering of small iconic drawings (Figures 3, 4, 5 page 176). In a later stage, the project developer pressed for additional commercial exploitation: a combination of 3D bird’s eye visualizations and realistic 3D artist impressions at ground level presented their vision of the ‘Bigshops Parkboulevard’. The perspective of all cartographic material, as well as the bird’s eye view, was now oriented towards the park lane and the neighborhood (southwest - northeast). This perspective put the emphasis on the infrastructure of the park lane, as well as the commercial real estate beneath the park lane, as well as the commercial real estate beneath the park lane and the neighborhood. This perspective was influenced by visual language by building a scale model (Figure 2). They were looking at the project from a larger perspective, focused on connectivity, embedding the project in a structure of iconic city projects.
There was a logical succession from analogue towards digital techniques as the project developed: as the design ideas became more concrete, they were also represented more precisely. But these images also reflect the interests of the people behind them: the project developer presented an attractive shopping boulevard, and the municipality used a 3D aerial perspective to emphasize the ‘Parklane’ (Figure 6). The focal point of the images was no longer just the park and its connection to the neighborhood; it had become the development of the shopping boulevard and its connection to the ‘Parklane’ concept.

Conclusion

Every aspect of a design representation, whether it be scale, perspective, technique, lighting, or color scheme, is an implicit or explicit choice. Design representations are thus political instruments, and should be treated and studied as such. The case of the Rotterdam Roof Park shows the increasing interest in design-based participatory and interdisciplinary workshops, in which the design process is used as a means to achieve a common future vision; it also shows the convincing power of sophisticated visual representations and how stakeholders use this to emphasize their interests.

Different stakeholders have different interests and communicate these interests in different ways. This analysis shows that a project like the Rotterdam Roof Park is not reducible to a single image: a 3D bird’s eye view does not show all the design ideas that make up the project, and neither does a handmade scale model. The emphasis on the Bishops Boulevard in some visualizations does not exclude the social functions of the park for the community, and vice versa. By looking at all of these images, and identifying the ideas and interests that are embedded within them, we can get the most complete representation of a design project. The pictures that end up on a website or billboard only represent a small part of a design, even though these are often the images that become the focus of public discussion.
Multifunctional projects offer advantages because they enable synergetic effects among functions. However, realizing these plans is more challenging for multifunctional projects because of the difficult adjustment of several functions in an area and the involvement of a larger diversity of actors with often conflicting interpretations about decision contexts. In this project, we looked into the time line of project events and the decision-making process of the Rotterdam Roof Park (Figure 1), and analyzed how predominant interpretations mobilize actors and influence their choices.

The three main decisions in the multifunctional land use project Rotterdam Roof Park are related to: 1. Adapting the design of the project to flood protection requirements; 2. Selecting the function under the park; and 3. Making a decision about whether or not to remove the existing rail tracks in the area.

Table 1 (next page) provides an overview of the decision events here described, the involved actors, the emerging predominant frames, and the mobilization of actors with different interpretations.

In our analysis of the decision-making process we observed how frames influenced the interpretations of actors about a decision context and the decisions actors made. In particular, we observed the influence of frames on how these decisions evolved, and how actors reached a resolution. We evaluated frames as schemata that actors use to simplify the world and search for diagnoses and forecasting the future. This produces a predominant frame, used for purposes of collective actions. In the decision-making process we observed how frames influenced the mobilization of actors involved, their own frame predominant, and, as a result, their own frame predominant. We did not find instances of actors purposefully making their own frame predominant and, as a result, gaining influence in the process. Nevertheless, we do not reject this situation in multi-actor contexts.

Interestingly, our results also showed how actors are likely to mobilize around a predominant frame that satisfies their interests although that mobilization might entail a tradeoff. In the case of the selection of shops instead of office space, we acknowledged that the predominant frame of the private developer allowed mobilizing actors around a strategy that could satisfy the interests of the district authority and the municipality. Although the province had the authority to approve the land use plan and delayed the approval of the land use plan and refused to give the provincial authority to approve the land use plan and delayed the approval of the land use plan. However, the province used their power or authority to make their own frame predominant. We did not find instances of actors purposefully making their own frame predominant and, as a result, gaining influence in the process. Nevertheless, we do not reject this situation in multi-actor contexts.

In our study, the episodes of the integration of the site in the project, and the selection of the function under the park showed how actors used their power or authority to make their own frame predominant. We did not find instances of actors purposefully making their own frame predominant and, as a result, gaining influence in the process. Nevertheless, we do not reject this situation in multi-actor contexts.

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rail tracks

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Selection of

3.

requests

Flood

2.

protection

Existence of

rail tracks in

Federal region

a dike in the

Decision

- Private
depveloper

Municipality

Removal

rail company

Political

Transport

service

Removal of the

rail company

Private
depveloper

Removal

Financial

Table 1. 

Decision event

Decision situation

Main involved actors

Diagnostic frame

Prognostic frame

Emergence predominant frame of:

Mobilization of actors

Decision

1. Flood decision requirements

Existence of rail tracks in the project area

Municipally

Financial

Design integration

Water board using authority

Water board uses its authority to satisfy their interests

Multifunc-
tional frame respecting the existence of the dike

Mobilization of actors

also be argued that actors had a preference for different decision-making-oriented frames to develop retail instead of office space, allowing the longer-term regionally oriented decision to develop office space and fill the market. The consequences of mobilizing around the private developer frame instead of the dike frame of the province’s one are still disputed.

Moreover, the case of the integration of the dike and the multifunctional frame showed how the water board used their legal authority to make their own frame predominant. Although this predominant frame did not fulfill the interests of the private developer and the municipality, actors mobilized around it and accepted the conditions that the water board proposed. This way there was a trade-off between the permits of the water board and the dike (which was not possible to develop the project hence actors decided to mobilize around this frame) and tools for strategies that avoided an impasse in the decision-making process. Municipalities take the risk of demolishing the building in case the dike is reinforced.

Our research results show that the emergence of a predominant frame proved to be important only for institutional actions but also for individual ones. Indeed, in our case we observed how actors mobilized around multiple, and sometimes contradicting frames, not only among different organizations, but even within the same organization. The most prevailing example of multiple simultaneous frames is the decision of whether or not to remove the rail tracks influenced by the rail company’s multiple frames. The rail company struggled with two potential strategies (1) to satisfy political interests or (2) to facilitate the process of implementing the new project by removing the rail tracks. However, the decision for the rail tracks was a compromise that the rail company had to make in order to avoid the consequences of mobilizing around that frame. The pressure to remove the rail tracks was also supported by the mobilization of the municipality that encouraged the railroad company to remove the railroad. This case shows the influence of a predominant frame across different decision-making-oriented frames, helping to resolve the indiscernibility resulting from the existence of multiple divergent frames within the same organization.

In summary, our results show that frame divergences are often related to the emergence of a predominant frame to make an actor gain influence in different decision arenas and contexts. When actors use their power to establish their own frame as predominant, other actors might mobilize because the prevalent frame helps them to achieve their own interests, or because they are forced to follow a predominant frame of action. Mobilizing around a predominant frame involves decision tradeoffs. Although tradeoffs are unavoidable in decision contexts, we consider it important to bring to the surface stakeholders’ interests or (2) to facilitate the process of implementing the new project by removing the rail tracks. However, the decision for the rail tracks was a compromise that the rail company had to make in order to avoid the consequences of mobilizing around that frame. The pressure to remove the rail tracks was also supported by the mobilization of the municipality that encouraged the railroad company to remove the railroad. This case shows the influence of a predominant frame across different decision-making-oriented frames, helping to resolve the indiscernibility resulting from the existence of multiple divergent frames within the same organization.

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We have seen that actors use power and authority to make their own predominant to mobilize others in the direction of achieving their own interests. In light of our results, we believe that deliberative processes to explore the potential predominant frames that help to achieve mutual benefits. Finding these strategies seems highly relevant for multifunctional projects, where different interdependent organizations, or resources might help to create awareness about the consequences of stakeholders’ choices. In light of our results, we consider it important to bring to the surface stakeholders’ interests or (2) to facilitate the process of implementing the new project by removing the rail tracks. However, the decision for the rail tracks was a compromise that the rail company had to make in order to avoid the consequences of mobilizing around that frame. The pressure to remove the rail tracks was also supported by the mobilization of the municipality that encouraged the railroad company to remove the railroad. This case shows the influence of a predominant frame across different decision-making-oriented frames, helping to resolve the indiscernibility resulting from the existence of multiple divergent frames within the same organization.

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Several alternative concepts could be developed that would integrate the structure of the Roof Park shopping complex with the flood defense. It is common practice in engineering to develop various concepts, keeping the project goal in mind. This is a creative process that should not be hampered by overly precise descriptions of the desired performance. The provisional concepts need to be verified in a later design step, to guarantee that the final solution meets the project requirements (see pages 62-65 for an explanation of the design method).

This results in a limited number of realistic alternatives, one of which has to be selected for further development. This selection is usually done on the basis of a set of criteria that could be considered ‘soft’ requirements. Different concepts for the Roof Park can be obtained by varying the degree to which functions are integrated or by varying the role of different structural elements for flood protection. The water-retaining element is an essential structural element, whose minimum height needs to be related to the current water level, and prepared for expected rises in sea level. The water-retaining element can be located at the water-side in an intermediate position (somewhere in the multifunctional complex), or at the rear. The choice of location has consequences for the connectivity between the different parts of the complex, the location of entrances, as well as where the complex (or parts of it) is located; whether they are in or outside the flood-protected area. In contrast with the present situation, a design alternative could be developed where the entire shopping complex is located behind the flood defense. This could be considered an advantage since the entire complex is located inside the protected area, local societal disruption in the case of extreme high water would be considerably reduced. An alternative would be to locate only the shops behind the flood defense and accept a higher flood probability for the parking garage.

Figure 1 shows an example of a concept where the flood defense is located at the waterfront. The entrance to the parking is from the landside, at both ends of the complex. Displacing the flood defence to the harbor side would make it possible to reduce the height of the entire complex. Now, the top of structure is 13.2 m above average sea level, but the required height of the flood defense is only a bit less than 6 m above average sea level. Lowering the top of the complex, by making the building one story instead of two, would make the project less of a barrier between the residential area and the harbor. It would also improve the accessibility of the shops from the garage, since elevators and stairs would no longer be necessary. If the present district heating pipes could be relocated, which is said to be very expensive, that would create even more design freedom.

Furthermore, there are ample possibilities for creating and varying green and leisure areas. As an extra option, several mutistory housing blocks could be planned on top of the garage on the harbor side of the complex. This would lessen the strict separation of housing and harbor, while at the same time improving the urban quality of the residential area.

So, from a structural point of view, it is very attractive to combine the flood defense with the shopping complex. For reasons of governance, however, it might be more desirable to separate the structures. However, this would lead to a less efficient structure in terms of costs (e.g., double walls) or space. The consequences of changing the shopping front from the harbor side to the residential area should be studied in more detail in cooperation with the stakeholders, because of effects on urban quality.
Many functions are combined in the Rotterdam Roof Park project: It is a shopping mall, a parking garage, a park on the roof, and last but not least, a flood defense. The research in our program was done after the buildings and structures had been built. So the research projects were not hampered by the conflicting interests of stakeholders during the design and implementation process, as might sometimes be the case in so-called action research. Still, the case study of the Roof Park clearly shows the pros and cons of Multifunctional Flood Defenses.

The flood defense is located in an urban area, where existing space is generally assumed to be used more intensively. Despite this, Van Veenen, Voorendt and Van der Zwaard clearly showed that the Roof Park complex does not actually contain structural elements that are part of the flood defense. The building (shopping mall and garage) has a LAT (Living Apart Together) relation with the flood defense: the actual flood defense is not part of the Roof Park complex. From a technical point of view this could have been easily achieved, and Voorendt shows various options for an integral design. He concludes that combining the functions would result in a more efficient design, but one in which the governance would be more complicated. In that case, a joint effort by the relevant stakeholders would be needed to manage and maintain multi-functional structure.

Raaphorst clearly shows how the visual rhetoric of the Roof Park is part of a bigger story: “...the increasing interest in design-based workshops in which the design process is used as a means to achieve a common future vision.” A challenge to such visualisation is that there are many possible images of the same alternative, and then the question arises how to visualise the alternatives, and which perspectives to choose. Raaphorst answers that “... every aspect of a design representation, whether it be scale, perspective, technique, lighting, or colour scheme, is an implicit or explicit choice. Design representations are thus political instruments, and should be treated and studied as such.” This is an important observation, because if design representations are political instruments, politicians need to be involved in making these choices. However, that is not the complete story, since the designer has also the responsibility to visualize the alternatives as well and fairly as possible.

Matos Castillo shows how frames influence the selection of functional combinations. Different stakeholders use different frames, and the intriguing question arises how a choice can then be made. Matos Castillo shows that the “emergence of a predominant frame proved to be important not only for collective action, but also for individual ones.” This may seem obvious, but this insight can help to stimulate the emergence of predominant frames that help to achieve mutual benefits.

The Roof Park Rotterdam turned out to be an interesting case study in the MFFD program. It was not the most efficient solution: However as Simon (1957) showed more than 50 years ago: in decision-making processes people are not only interested in the most efficient solution (if a single solution existed), but also satisfying their minimal demands. To achieve this requires open communication between all concerned stakeholders. However, the stakeholders decide how they participate. As Matos Castillo says, “Actors might use their power of authority to make their frame resonate or vice versa to achieve their own self-interest without taking the consequences for the project as a whole into consideration.” Though this is less a scientific challenge than a sociological and political one, incentives might be developed to increase the trust between parties and their willingness to cooperate.
When the MFFD program took off in 2012, its general goal was to gain a deeper understanding of multifunctional flood defenses. To provide a solid foundation for their design, assessment and management. As a point of departure, it is assumed that a new generation of aesthetically multifunctional flood defenses will be a product of the need to accommodate competing spatial claims, and, perhaps, contributory savings by combining functional. Morphs projects like the Schelwingeren Boulevard and Katwijk’s ‘hybrid’ parking garage complement an older generation of multifunctional flood defenses, the traditional example being dikes with sheep grazing or a road on top. The contemporary multifunctional flood defense was viewed as a complex but desirable phenomenon. The answer to multiple needs, and therefore best studied from a multidisciplinary perspective. What are the lessons learned regarding the design, assessment and management of multifunctional flood defenses in 2017, based on this multidisciplinary research? And to what extent does the MFFD program’s experience confirm the known pros and cons associated with such multidisciplinary research efforts? Interdisciplinary research in all forms (ranging from non-committal knowledge-sharing to mandatory integration of parallel research trajectories) is known for its challenges; in particular, paradigmatic confusion between the natural and the social sciences, and the lack of possibilities for academic publication and prestige (De Boer et al., 2006). On the other hand, benefits are found in terms of innovation, greater applicability and societal acclaim. With its ambitious point of departure - a multidisciplinary approach to a complex subject with a broad scope - the MFFD program started as an academic experiment. It was designed in such away, that disciplinary insights could be integrated into shared case studies that addressed the practical needs of users (this model is known as ‘goal integrative’). The program’s findings were grouped in three sections for this book, each relating to one of the program’s original goals: risk assessment (risk, risk assessment and safety knowledge), design and planning, and governance & knowledge transfer.

In the first section, steps were taken towards risk assessment of multifunctional flood defenses, compared to their monofunctional counterparts. Chen studied the influence of waves on the safety of buildings and their inhabitants, to reduce the probability of possible future lock-ins. However, the true bottleneck is that an integral design also requires integration of parallel research trajectories. It has been realized in an infinite number of combinations, and is therefore hard to model. This should, however, not be considered an impediment to the implementation of multifunctional flood defenses. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon made a plea to include salt marshes among the coastal in the design of flood-risk reduction alternatives. Contributions dealing with planning also reflected different conceptualizations of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach. Van Loon and Islam, on the other hand, addressed temporal aspects of the same term. Brand considered spatial planning as a driver for multifunctional flood defenses, using the adaptive planning approach.
management and spatial planning, and the opportunities this offers for streamlining spatial developments or interventions for flood risk reduction. Studying knowledge transfer, Tromp, Kothuis and Heems emphasize the importance of trust between actors. Institutions have a direct effect on building and sharing of knowledge (Hogendoorn, Tromp).

In addition to a variety of single case studies, the program included two program cases: Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park had the advantage of being a local, completed project, whereas the design and decision-making process could be reconstructed and analyzed. The Texas case dealt with international knowledge transfer and was at the regional level which is still the subject of continuing research. The advantage of this was that the decision-making and design process for the multifunctional flood defenses could be studied as exposed. The Roof Park is a construction where flood safety, recreation (park) and shopping (mall) are combined in the same site; this was studied using visual, urban design, architectural and frames analysis. This confirmed the role of several interdependent actors, which resulted in a conclusion where the shopping mall and the flood defense were ultimately structurally separate; this led to social management for the design of multifunctional flood defenses and –strategies from the Dutch Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense strategy for the Houston Galveston Bay Region in Texas. Rotterdam Roof Park (Dakpark) and a future flood defense
Reflection Days: there’s always more to discuss! Clockwise from top left:
- Exploring Vlissingen Boulevard multifunctional flood defense with adaptable infrastructure and buildings.
- In Utrecht, discussing the definition of a multifunctional flood defense.
- At Fort aan de Klop, one of the historical inland defense lines in the Netherlands.
- Exploring the Sand Engine, where multiple functions are combined by means of Building with Nature.

REFERENCES


Army Engineer Research and Development Center, http://ehland.usace.army.mil/.
Discussion Days: there’s always more to discuss! Clockwise from top left:

- Visiting a German-multifunctional flood defense along the Rhine river in Emmerich.
- Field visit to stress-testing historical flood levels and multifunctional flood defense at Delfzijl waterfront.
- NYFD-team cooking fun in a dike-mounted wall with a shallow foreshore. Coastal Engineering (image by Torba Muller courtesy Rhijswaterstaat).
- Schavendijk Dawn-Boulevard discussing multi-functional flood defense with local experts.


INTEGRAL DESIGN OF MULTIFUNCTIONAL FLOOD DEFENSES
Multidisciplinary approaches and examples

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